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RESEARCH ARTICLE

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# Sustainable management of electronic waste: Empirical evidences from a stakeholders' perspective

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## Abstract

With rapid advancements in technology, the evolution and demand for electronic/electric devices have drastically increased. The exponential increase in the use of technology to fulfill the needs of the fast-paced information era has led to electronic and electrical devices being discarded or disposed of at a faster rate than in the past. This phenomenon has resulted in e-waste becoming the fastest-growing form of solid waste. E-waste is classified as hazardous waste and can be harmful to the environment and health if not disposed of responsibly. Therefore, alternatives, such as exporting, landfilling, and recycling (from different economic, social, technical, and environmental criteria), are of interest to minimize the disposal of this toxic waste form into landfill sites. The analytic hierarchy process approach was deployed to evaluate and prioritize alternatives for e-waste processing systems in the United Arab Emirates context. The obtained results indicate that recycling has the highest priority among the studied alternatives in the e-waste processing system. The low economic and environmental awareness of stakeholders with regard to e-waste shows that e-waste management system initiatives must be expedited to adhere to e-waste best practices implemented nationally and internationally.

KEYWORDS
analytic hierarchy process (AHP), e-waste, e-waste management (EWM), integrated sustainable solid waste management (ISSWM), sustainablity, United Arab Emirates (UAE)

## 1 | INTRODUCTION

Currently, global warming and changes in atmospheric conditions are restructuring many economic sectors, especially those that significantly impact the environment, such as the electronics industry (Di Vaio et al., 2019). All electrical and electronic equipment (EEE) and their components that have been rejected or are not being used anymore are regarded as electronic and electric waste (or e-waste). E-waste management (EWM) is a significant problem in several emerging countries, such as the United Arab Emirates (UAE), primarily because of the increasing e-waste generation rate. The high growth in the e-waste generation rate generally occurred because of rapid advances in EEE industries, population growth, urbanization, and lifestyle consumption patterns (Aboelmaged, 2020). This type of waste is from several sources, such as the government, companies, and households. IT industries contribute the most significant share to the e-waste stream, and consumer electronics also contribute substantially. Most businesses, public and private sector establishments, hospitals, researchers, academic institutes, and individuals at the household level rely profoundly on EEE and thus add end-of-life electronic gadgets to the existing waste stream in the form of e-waste (Islam et al., 2020).

The United Nations (UN) reported that e-waste generation increased to more than 44 million metric tons annually (equivalent to nearly 4500 Eiffel towers) by the end of 2020 (Bocken & Short, 2021). Onac et al. (2020) found that e-waste quantities are increasing more rapidly than any other form of municipal waste and will increase to 74.7 Mt 2030. The estimated global cumulative e-waste volume could reach 78 million Mt by 2050 (Asefi, Shahparvari, & Chhetri, 2019). The topic of e-waste attracts scientists, policymakers, and practitioners because it is hazardous waste that significantly threatens human health and the environment. E-waste contains over 1000 substances, many of which are toxic (Dhir et al., 2021). Emitted toxic substances may alter microbial structure and function and exhibit high toxicity to aquatic and soil-dwelling organisms (X. Liu et al., 2019). EEE production requires many raw materials, including metals, plastics, rubber, glass, semiconductor, oil, gas, and wood. Many materials can be recycled and reused (Minoja & Romano, 2021). Therefore, increasing consumption and demand for resources has led to the growing importance of e-waste because of its environmental and health impacts. It is a secondary source of metals (Gunarathne et al., 2020).

The increased academic attention to the topic also illustrates its importance and relevance. Despite its problems, e-waste growth also offers significant potential economic value because of valuable metals. The existence of precious metals such as gold (Au), silver (Ag), palladium (Pd), platinum (Pt), and other rare earth elements makes e-waste recycling economically attractive (Islam et al., 2020). Therefore, implementing sustainable EWM practices in the UAE remains a critical challenge for the e-waste industry. Stakeholder involvement is essential for acquiring an environmentally sustainable EWM approach. However, each country must independently agree on the level of its cooperation; the unwillingness of either the population or local authorities to cooperate presents a critical problem (Ahmad et al., 2019). This endeavor requires evaluating and integrating the views and perceptions of all inner stakeholders, including manufacturers, take-back operators (i.e., suppliers, distributors, retailers, service centers), consumers, and government consumers (Veronica et al., 2020). Wang, Qu, et al. (2020) identified that parties can have conflicting points of view. Therefore, increased awareness regarding the EWM needs of various stakeholders is necessary.

There are several options for processing and disposing e-waste, as well as EWM. E-waste processing mainly includes exporting, landfilling, and recycling. Meanwhile, e-waste is primarily disposed via sanitary landfilling. Each of the mentioned options for EWM has different environmental, economic, social, and technical aspects. For selecting the most appropriate alternative for EWM, different aspects of each alternative and associated disadvantages and advantages in terms of social, environmental, economic, and technical issues should be precisely evaluated.

It should be noted that the most appropriate alternative for EWM should be an economically affordable, environmentally practical, socially acceptable, and technically feasible option (Malek & Desai, 2019). As the options for EWM grow in complexity and number, there is a need for an effective strategy to evaluate these options. Emerging countries have limited research capabilities with regard to EWM. This study thus aims to fill the research gaps by identifying and integrating various criteria for evaluating and comparing several e-waste processing alternatives, prioritizing and ranking both criteria and sub-criteria for strategic and systematic implementation, and recommending the study's implications to facilitate EWM options in the UAE. This study aims to address these gaps to help stakeholders and policymakers identify the causing factors that influence the e-waste ecosystem adversely. This study attempts to answer two questions: (RQ1) what key factors influence e-waste processing options, and (RQ2) which alternatives are most or least preferred by the stakeholders in the UAE context?

Based on the perspective of the UAE, this study aims to identify and analyze the critical factors affecting EWM processing options. According to stakeholder theory (Freeman, 2010), factors affecting the recycling of e-waste can be comprehensively identified from the perspective of multiple participants. Stakeholder theory (Freeman, 2010), and the multicriteria decision-making (MCDM) method can be applied to quantify the relations between factors affecting the recycling of UAE e-waste, allowing critical factors to be revealed more scientifically than they have been in the literature. Several strategies, including MCDM, extended producer responsibility (EPR), material flow analysis, and life cycle assessment, have been established to manage the assortment of the most suitable options for EWM (Kannan et al., 2020). The objectives of those studies were achieved through a methodology involving a hybrid MCDM technique. This technique has been applied in many studies in various fields (Liu et al., 2021; Xiao, 2018). The analytic hierarchy process (AHP) technique was employed in this study because of its advantages over other MCDM methodologies. Only a few studies have applied AHP analysis to the EWM field. In addition, AHP is employed to evaluate and rank the functional pathways concerning the sub-criteria. It provides an unbiased, transparent construction process that decision-makers can easily comprehend (Kheybari et al., 2019).

Building on the literature, this study makes theoretical contributions and offers practical value. First, this is one of few studies conducted in the UAE to determine the hierarchal and causal relationship structure among the key factors that influence stakeholders' decisions in determining the most appropriate e-waste processing option, which satisfies their economic and environmental considerations in both the long and short terms while using the AHP method (Gupta & Barua, 2017). Additionally, this study provides insights into applying models and procedures in an integrated approach, particularly the integrated sustainable waste management model (ISWMM) for the EWM system, to fill the gap in the literature by introducing a sustainability framework (Asefi, Shahparvari, & Chhetri, 2019). Furthermore, this study suggests policymakers and practitioners to implement EWM practices in which the chosen aspects are interconnected; therefore, this result requires absolute commitment from all major stakeholders, including managers, consumers, and recyclers, to make e-waste recycling convenient.

The remainder of this paper contains four sections. The first section presents the literature review and identifies the research gaps related to e-waste criteria. This information will help government decision-makers focus on processing EWM implementation. Additionally, the methodological concerns of stakeholder theory are explored. The third section provides the research methodology and data collection methods used in this study. The results and findings of this study are presented in the fourth section. The discussion of the results is provided in the fifth section, which focuses on sensitivity analysis and the theoretical contributions and implications. The conclusions, limitations, and opportunities for further research are presented in the final section.

## 2 | RELEVANT LITERATURE REVIEW

### 2.1 | Stakeholder theory

Through a circular economy of "resources," the recycling of e-waste in the UAE develops a closed-loop supply chain. Multiple stakeholders must be involved in the closed-loop supply chain to improve the low recovery rate of e-waste recycling in the UAE (Tsai et al., 2021). Other actors perform the waste management process based on elements of trust by using reports that are not completely formalized and other players with high risks of conflict of interests, conflicting roles, or opportunistic behaviors (Di Vaio et al., 2019). The study by Söderberg and Kain (2006) also underlines the importance of including perceptual and effective parameters when explaining outcomes of multi-stakeholder assessments. Here, neither local working group participants nor any other policymakers, experts, or researchers were acting in a void and free from external influence; they always worked within formal and informal structures and were influenced by multifarious personal considerations. Major economic theories such as the stakeholder theory (Freeman, 2010), demonstrate that adopting sustainable practices embedded in corporate strategy can improve performance (Del Giudice et al., 2021). Previous studies have analyzed the implementation of reverse logistics in developing and emerging countries from the perspective of stakeholder theory (Freeman, 2010) to analyze if the rules, beliefs, and concerns from the external environment (in which the organizations and government are inserted) motivate the adoption of measures to overcome these barriers (Xu, Yeh, et al., 2020). Stakeholder theory (Freeman, 2010) mainly refers to corporate stakeholders because this economic theory was formulated by researchers in the United States and the United Kingdom who were studying corporate cognition and governance. Stakeholder theory (Freeman, 2010) begins with the assumption that values are necessarily and explicitly a part of doing business (Fuldauer et al., 2019). It asks managers to articulate the shared sense of the value they create and bring their core stakeholders together. It also pushes managers to be clear about how they want to do business; that is, what types of relationships they want and need to create with their stakeholders to deliver on their purpose. The management and decision-making of ecosystems can be more effectively conducted by integrating the knowledge of stakeholders (De Gooyert et al., 2017).

Stakeholders are individuals or groups that affect or are influenced by the achievement of organizational goals. Stakeholder engagement explains the connection between the actions and the consequences (Hughes et al., 2021). Indeed, stakeholder engagement influences the economic and social values of the organization in the medium and long term (Cillo et al., 2019; Singh et al., 2020). A major issue of the stakeholder theory is the management of the relationships between an organization and its stakeholders for value creation (Veronica et al., 2020). The foundation of shared purpose has focused on creating a shared vision to align the energy, investment, and interests of both the manufacturer and retailer, thereby participating in the ecosystem and creating sustainability value (Chaurasia et al., 2020). Several researchers have used the stakeholder theory as a theoretical lens (rather than integrating it) to examine corporate sustainability-related issues (Singh et al., 2021). Stakeholders in the recycling of e-waste are identified according to the connotation of stakeholder theory (Gunarathne et al., 2020.) Freeman's (2010) theory laid the groundwork of stakeholder identification, and the latter added new groups or amended impetus based on Freeman's identification. Some simple questions can be used to help to list the stakeholders. For example, who supervises the e-waste recycling industry, from where do collectors obtain the e-waste, and what is done to the collected scarps. When listing the stakeholder groups in the empirical part, not all stakeholders should participate; those with marginal and powerless stakes for the e-waste recycling joint venture should not be considered. After stakeholder identification, several organizations have been identified to positively or negatively affect the e-waste business (Bătae et al., 2021).

Stakeholder theory can enable the analysis of conflicting points of view and interests of different stakeholders involved in this context of decision-making; for example, governments, private companies (e.g., manufacturing and retailers), recycling companies, third-party logistics providers, consumers, community, research centers, final consumers, and waste pickers (Bhaskar & Turaga, 2018). According to the stakeholder theory, the objectives of a system should be derived by balancing the conflicting demands of the members of the system. Thus, organizations positively affect the proactive orientation of stakeholders (Pinto, 2019). In solid waste management systems, the main challenge is to develop models to support decision-making by considering cooperative interactions between stakeholders. Electronic waste management requires the participation of many experts and stakeholders, resulting in a decrease in this type of waste and thus decreasing the environmental impacts associated with its final disposal (Kumar & Dixit, 2018). Therefore, in this work, establishing a link between stakeholders (government, society, and academia) in waste management has been a critical factor in providing a holistic approach, which has also been described in the literature (Salem et al., 2018; Zhang et al., 2019).

## 2.2 | Overview of E-waste in the UAE

Owing to the UAE's fast-growing development and the increasing demands for natural resources, such as energy and water, which surpass their availability, this nation is considered the world's highest energy consumer. It is ranked alongside India and Brazil as one of the countries most in need of environmental protection (Aboelmaged, 2021). The UAE has one of the most significant oil and natural gas reserves globally, making it responsible for adopting sustainable development initiatives (Sahin et al., 2019). However, the UAE's higher GDP per capita (USD 4200.000 in 2017) is nearly 326% of the world's average. Rapid growth, low initial cost, global technological evolution, consumption habits, and planned obsolescence have turned the UAE into a hub for EEE consumption. The change in lifestyles now depends on EEE. Products are becoming obsolete rapidly. As a result, the country has one of the world's lowest life expectancies for electronics, with an average amount of e-waste exceeding 13.5 kg per resident, which is more than double the global average of e-waste per inhabitant (6.1 kg). This mass consumption contributes to a rapidly mounting surplus of e-waste in the UAE.

This should be a massive cause of concern for environmentalists and local citizens. With the revival of the consumer electronic durables market in the UAE (valued at USD 0.85 billion), the situation of e-waste looks grimmer than ever (Aboelmaged, 2021). UAE has around 4.8 million residents, and almost double the number of mobile phone subsricptions. UAE residents' increasing per capita income has alarmingly contributed to the mindless disposal of electronic waste in this great Emirate nation. Even though the recycling industry is in its nascent stage in the UAE, it is slowly gaining momentum (Al Bloushi et al., 2020). According to the research by Aboelmaged (2021), the amount of generated e-waste in UAE for eight selected electronic items (including laptops or notebooks, photocopiers, radio and tape recorders, televisions, mobile telephones, personal computers, printers, and video projectors) was the highest among all of Asia. E-waste disposal has neither been conscious nor channelized, which has resulted in the improper disposal of e-waste. There is an unclear procedure for EWM in the UAE; generally, e-wastes are collected, processed, and disposed of under deplorable management conditions. Meanwhile, academic research on e-waste in the UAE context is very scarce when compared to other types of waste, as demonstrated through a careful examination of previous research. Accordingly, the UAE government has shown increasing interest in adopting solutions to the EWM problem (Zabala, 2019).

## 2.3 | E-waste disposal in the UAE

In the UAE, there are no official statistics about e-waste collection or how the waste is getting disposed of in landfills; thus, there is a cause for concern. Currently, e-waste is treated as general municipal solid waste, and no unique consideration is being given to the activities associated to its collection and treatment. There is no known environmentally friendly method to dispose of e-waste (Wang, Qu, et al., 2020). The current e-waste accumulation rate is not sustainable, and limited dumpsites are filling fast. Legislation related to e-waste is not performing well. The reason for this could be that e-waste is a newly emergent waste type in the country; hence, no action has been taken since the impact of the waste is unknown yet. The non-conformance by industries to international legislation regarding environmental management was a clear indication of a critical challenge in terms of EWM, as most industries might not follow the laid down procedures for e-waste handling. However, 100% of the companies hinted that they look forward to introducing EWM policies at an individual level (Aboelmaged, 2021).

Most of the actions related to e-waste handling are executed by informal players who do not have the practical and infrastructural skills or awareness regarding the grave consequences of e-waste mishandling on the environment and human health. The characterization, quantification, and movement of e-waste are still hazy within this industrial community. The chief stakeholder involved in waste handling is the local municipality (Ouda et al., 2021). It carries out the collection, transportation, and disposal of industrial waste; however, such traditional methods of waste management cannot be deemed compatible with e-waste requirements. The deficiency of a proper disposal strategy pushes most industries to use the traditional solid waste management methods, which involve dumping the e-waste scrap with no segregation from regular solid waste.

Additionally, there is no specific legislation on e-waste; thus, its regulation can be incorporated into hazardous waste management. Unfortunately, there is no large-scale organized sector for recycling operations, and it is performed only by the unorganized sector. Legislative policies would aid in clarifying the roles and responsibilities of affected stakeholders for developing a successful management system, such as extended producer responsibility (ERP). Thus, it is necessary to investigate the available opportunities for collecting and recycling used electronic equipment to minimize the amount of solid e-waste that would go to the landfill (Abdallah et al., 2021).

With the possibility of recovering valuable materials from this waste, methods have been recommended for collecting, handling, and disposing of e-waste and evaluating the feasibility of recovering valuable materials from e-waste. The several options for collecting, processing, and disposing of e-waste generally represent EWM. E-waste processing mainly includes exporting, reusing, refurbishing, and recycling. E-waste disposal options are mostly sanitary landfills and incineration. However, reliable data on the potential revenue gained from e-waste recycling in the UAE are not available, which may discourage governments and businesses from investing in EWM. Insufficient data have become a significant problem in managing e-waste (Hasan et al., 2020).

## 2.4 | Sustainable e-waste management in the UAE

The debate around sustainability has a long history. Preliminary contributions in this field have been provided by studies interested in the relationships between human and nature (Caputo et al., 2021).

Sustainability fulfills current needs and acknowledges the needs of future generations. Furthermore, sustainability is defined as "adopting business strategies and activities that meet the needs of the enterprise and its stakeholders today, while protecting, sustaining, and enhancing the human and natural resources needed in the future." Although the management of e-waste is considered a challenge for many countries globally, the present study covers sustainability in the e-waste industry in the UAE, which varies in scope and objective. Even though sustainability has been studied in different service sectors, there is a lack of research in the e-waste sector.

In the UAE, the volume of e-waste generated is increasing because of unsustainable management practices fueled by the increasing perplexity among diverse stakeholders (Klemeš et al., 2020). Therefore, the e-waste situation is worsening. The most effective solution to the growing e-waste problem is to recycle raw materials from used electronics. Recycling e-waste will benefit the community and reduce the volume of solid waste placed in designated dumpsites. The resale and reuse of computers continue to be high, depending on the assembled machines. No reliable figures quantify e-waste generation, while computers become more affordable with increased access to technology. In addition to consumers, the extensive software industry is a source of obsolete computers (Patwa et al., 2021). Cutting-edge technology increases computing speed, and efficiency necessarily increases the obsolescence rate. Similarly, as the standard of living increases, dealers are providing monthly payment/installment facilities/banks that provide loans, increasing the ability to buy televisions, mobile phones, and other household appliances. As the consumption pattern increases, e-waste generation also increases (Ouda et al., 2021).

E-waste is a problem, especially in emerging countries, where efficient EWM systems are not fully adopted; thus, a significant transboundary e-waste movement was reported (El Bilali & Ben Hassen, 2020). Sustainable development has undergone numerous transformations since the UN adopted the first principles at a conference in Stockholm in the document "Transforming our world: the 2030 Agenda for Sustainable Development" (Mawed, 2020). The UAE has also inaugurated a sustainable economic development initiative as a top priority within the "Green Economic Agenda (2015-2030)" in the transition to sustainable development. E-waste handling should be undertaken sustainably to reduce the unnecessary deposition of e-waste in the available landfill site. For instance, a facility was constructed to function as the region's primary center for managing e-waste in the Middle East, with an initial phase that could handle 39 kt (kilotons) of e-waste every year.

Meanwhile, the UAE is developing policies and regulations for managing electronic waste. However, further efforts are required to ensure the implementation of these regulations (Zabala, 2019). The business community and local authorities such as Dubai Internet City and Dubai Science Park were the drivers of other initiatives in the UAE, including the e-waste collection campaign in 2017. The campaign collected nearly two tons of discarded electronics (e.g., laptops, printers, cameras, and mobile phones). Additionally, economical methods of undertaking this endeavor will be interrogated, while sustainable and cheap methods to handle e-waste will be developed. Adopting various sustainable developments without understanding e-waste impacts often leads to an additional waste of resources and not achieving the intended outcomes.

## 2.5 | Integrated sustainable solid waste management

Challenges experienced by EWM systems in emerging countries such as the UAE are multidimensional. Improper waste management has several implications on the environmental, social, political, and economic levels. Therefore, the integrated municipal solid waste management (IMSWM) has gained importance in handling e-waste. They require examining both the "physical components" (e.g., collection, disposal, recycling, and infrastructure) and the "governance aspects" (e.g., users and service providers and the macro environment) (Al Bloushi et al., 2020). A failure to understand and address the problems of the entire waste system would lead to fragmentary solutions that are neither effective nor sustainable (Gunarathne et al., 2020). Hence, a well-structured methodology is necessary for a comprehensive understanding of the prevailing situation.

Therefore, this study uses the ISWMM to provide a broad understanding of the challenges experienced by EWM systems in the UAE (Ouda et al., 2021). The ISWMM was developed to overcome conventional waste management systems. This model was developed in the mid-1990s by a group of practitioners to address waste management problems in developing and emerging countries. It recognizes a combination of two crucial dimensions of waste management: (1) aspects of the local context and (2) stakeholders involved in and affected by waste management (Pujara et al., 2019). The integrated model highlights the linkages and interdependencies between the various stages of waste management, stakeholders, and "points of view" (sustainability aspects). Although the ISWMM model was developed for waste management, stakeholders can overlap in the context of e-waste. These overlaps are outlined in sustainability reports (involving stakeholders and governments and attracting investors) released annually by many organizations to identify their sustainable environmental objectives, strategies, and accomplishments (Minton et al., 2018). Hence, it is necessary to build business models that consider the specificity of a context characterized by specific regulations and the presence of numerous stakeholders (Di Vaio et al., 2020). This study uses a modified version of the ISWMM to suit EWM in emerging countries such as the UAE (Figure 1). The revised model specifically links e-waste system elements to the stakeholders involved.

The first dimension of this model (waste system aspects [or lenses]) considers the factors that affect the sustainability of a waste management system. This study covers four elements: social, technological, environmental, and financial/economic aspects (Scheinberg et al., 2004). Environmental sustainability aims to eliminate waste, pollution, energy consumption, emissions, and consumption of hazardous materials (Chandrashekhar et al., 2020). Economic sustainability involves the production and operations stages,

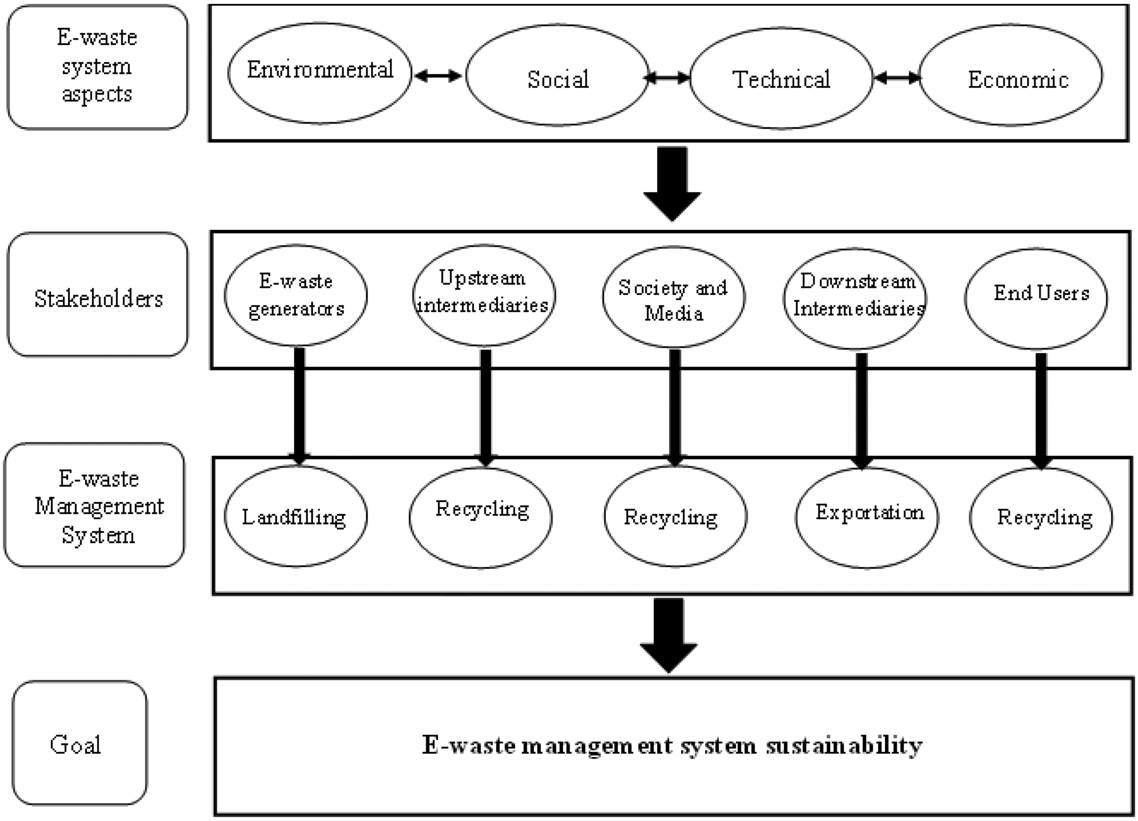



FIGURE 1 Modified integrated sustainable waste management model (ISWMM) for e-waste management system. *Source*: Based on Freudenreich et al. (2020) and Scheinberg et al. (2004)

economic conditions, market share, and income (Goworek et al., 2020). Furthermore, economic and sustainable improvements in developing economies rely on financial refinement. Fulfilling the public's needs and protecting the environment is necessary in sustainable waste management, and both internal and external parties are involved in social sustainability projects; this encourages autonomy in supply chains and increases quality of life, including well-being and security, educational opportunities, and employment rates (Asefi, Shahparvari, Chhetri, & Lim, 2019).

These aspects can also assess existing waste management systems or design new systems. Depending on the recycled e-waste, the importance of a waste system differs. For instance, in e-waste, the recycling of precious materials is essential, and recycling is driven by economic factors. However, standard practices incentivize the development of refrigerators vulnerable to carelessness or irresponsible recycling practices (Zanghelini et al., 2018). Further, many waste system aspects can influence the "public's" (and business organizations') disposal behavior and awareness/perception, which is central in any successful EWM initiative (Borthakur & Govind, 2019, p. 1065). Thus, considering the influence of waste system aspects in totality is imperative.

The second dimension of the model, stakeholders involved in the waste management system, comprises individuals or organizations interested in waste management (Scheinberg et al., 2004). The UN Emissions Gap Report (2017) stated that e-waste had become a global challenge because its management requires diverse stakeholders (Danso et al., 2020). In the EWM system of an emerging UAE, these stakeholders comprise e-waste generators, upstream intermediaries, society and media, the marketplace, downstream intermediaries, and end-users (Zeng et al., 2017) (Table 1). These stakeholders play different roles and have diverse interests in an EWM system. The ISWMM emphasizes the challenge of reaching a consensus for the common purpose of improving the EWM system. Moreover, these stakeholders play an essential role, and their activities threaten the environment and society (Freudenreich et al., 2020).

As evidenced in the aforementioned literature, the significance of a systems approach is enumerated by the equal significance of environmental, social, and economic positions to motivate sustainability, while being consistent with advances in digital technology and leading to the sustainable and efficient management of solid waste disposal (Ouda et al., 2021). Therefore, evaluating the primary factors that impact e-waste processing options and alternatives in the UAE context by assessing institutional and policy effectiveness is necessary.

## 3 | RESEARCH METHODOLOGY

In EWM, various criteria are wholly or partially conflicted. Models based on MCDM techniques are considered beneficial criteria (Kheybari et al., 2019). According to Xiao (2018), MCDA is typically

**TABLE 1** E-waste management stakeholders

| Stakeholders | Description |
|---|---|
| E-waste generators | Households, business organizations, focal company workforce. (shareholders are included), and Government institutions. |
| Society | Society, community, and non-governmental organizations. |
| Marketplace | Market and competitors. |
| Upstream intermediaries | Upstream Party in the Supply Chain, local governments, Informal waste collectors & sorters, and formal waste collectors & sorters. |
| Downstream intermediaries | Waste buyers and exporters. |
| End users | Local industrial buyers and foreign industrial buyers. |
| Media | Information dissemination means (traditional and social). |

*Source*: Zeng et al. (2017).

used to evaluate the sustainability of a waste supervision model. Nevertheless, the ecological, financial, mechanical, and informally workable development indicators are moderately or wholly incompatible. The benefit of MCDA analysis in assessing a sustainable waste treatment scenario is that it allows qualitative and quantitative criteria for sustainable development indicators; equally, it allows the contribution of different decision-makers, even with contrasting goals, in essential domains and policymaking.

## 3.1 | An overview of the analytic hierarchy process

Multicriteria decision analysis (MCDA) is commonly used to assess a waste management model's sustainability when the environmental, economic, technical, and socially sustainable development indicators are partially or wholly conflicting (Liu et al., 2021). This study is based on the quantification of several mutually conflicting assessment criteria using the AHP. The AHP has been used to assess experts' perceptions of the EWM stakeholders in the UAE. Although AHP is one of the oldest MCDA methods, developed by Saaty (1980), it is still widely used today. AHP allows the problem to be broken down into its constitutive elements that are related to the primary goal. AHP is a multicriteria decision-making technique, which can concurrently consider qualitative and quantitative comparison criteria and where a lot of baseline research literature is available. Therefore, AHP is ideally suited to a similar project that needs comparative research involving many stakeholders with different interests. AHP is applicable in a wide range of fields, including management, business, and policy, and is also often used to solve complex problems in environmental management.

The AHP provides a means of prioritizing the various elements in the hierarchy, helping governments and industry practitioners focus on the most critical matters (Saaty, 1990). The AHP proposed by (Wind & Saaty, 1980) aids managerial decision-making in a six-step process to generate priorities:

i. Structure a problem as a hierarchy or as a system with dependent loops;
ii. Conduct measurement and data collection;
iii. Elicit judgments that reflect ideas, feelings, and emotions;
iv. Represent those judgments and compute normalized weights;
v. Determine a synthesized-finding solution to the problem; and
vi. Analyze sensitivity to changes in judgments.

The flow chart is shown in Figure 2 (Vargas, 1990); it was developed to explain the AHP's phases. The AHP is a theory of measurement initially devised by Saaty (1980), employing paired comparisons and relying on practitioners' or stakeholders' judgments to derive priority scales for an issue or system. As a quantitative tool and multi-criteria technique, the AHP provides a practical and precise means of choosing options by measuring tangibles and intangibles. Qualitative and quantitative factors are evident in many disciplines, such as waste management (Saaty, 1990). (Figure 3)

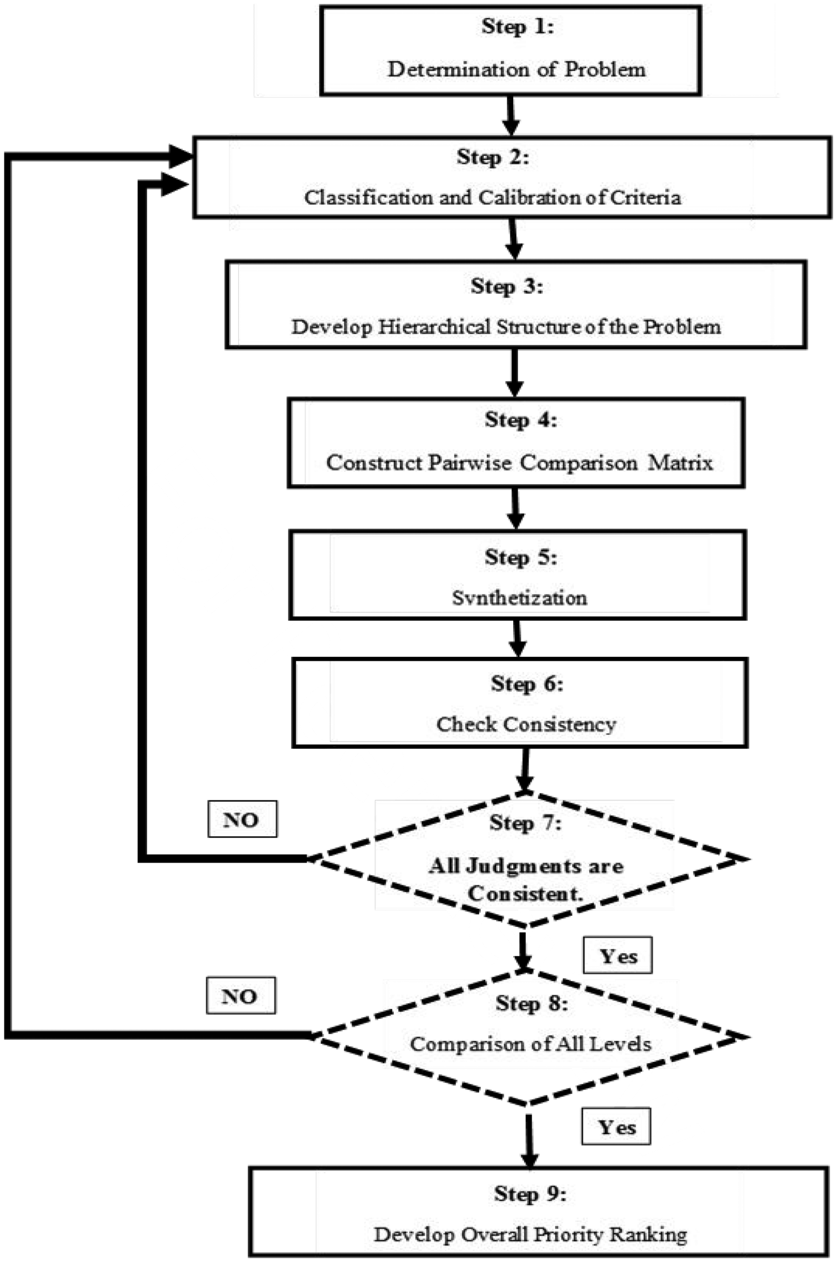
## 3.2 | Identification and selection of criteria and alternatives

The main criteria or variables were identified in the decision problem related to EWM and the variations (which are encountered by some authors as part of its activities, e.g., recycling, exporting, and landfilling). Additionally, the main criteria or variables were considered in the decision-making of EWM processing aspects. Qualitative analysis of the complete articles was conducted through content analysis, as proposed by Bardin and Shumeiko (1977). The results are shown in Table 2. Shumon et al. (2016) developed the criteria and alternatives used in this study.

Criteria for article inclusion in the content analysis were classified as follows:

i. Economic Aspects (i.e., Investment Cost [IC], Operation Cost [OC] for managing the waste daily, Collection Cost [CC], and Profit from reused products [PP]).
ii. Technical Aspects (including Functionalism [FM], Experience [EX], Adaptability [AD], and Flexibility [FX]).
iii. Social Aspects (including Public Acceptance [PA], Health & Safety [CF], Education and Training [ET], and Job creation [JC]).

FIGURE 2 AHP phases




iv. Environmental Aspects (including Air Quality [AQ], Noise Pollution [NP], Water Quality [WQ], and Resource Conservation [RC]) categories.
v. Alternatives were also divided into types of E-waste processing (e.g., recycling, exporting, and landfilling).

## 3.3 | Developing the hierarchical structure

The purpose of this research was to pursue e-waste processing options by identifying and prioritizing the UAE's e-waste stakeholders' aspects. This study used the ISSWM model by defining *hierarchy* as a system that interacts with the alternatives and the main goal through a loop in which priorities of other options and primary purposes were determined (van Dyck & Ismael, 2015). Figure 2 presents the hierarchy structure and illustrates the vital elements and their relationships for EWM processing options. The main goal is to divide the first cluster on the top into criteria and sub-criteria in a hierarchical structure with different alternatives at the bottom. Studies have identified and generated a list of 16 factors influencing EWM processing options of the UAE e-waste stakeholders. The four aspects followed the criteria of level 2, and each aspect was further divided into level 3 (sub-criteria) to illustrate the typical manifestations of the proposed model. Level 3 includes the sub-criteria selection based on the literature review performed to identify the most influential sub-criteria feeding into each main criterion. This research used the extent analysis proposed by Chang (1996), which is a practical AHP solution. Moreover, criteria or sub-criteria are compared for the primary goal (AlJaberi, 2018).

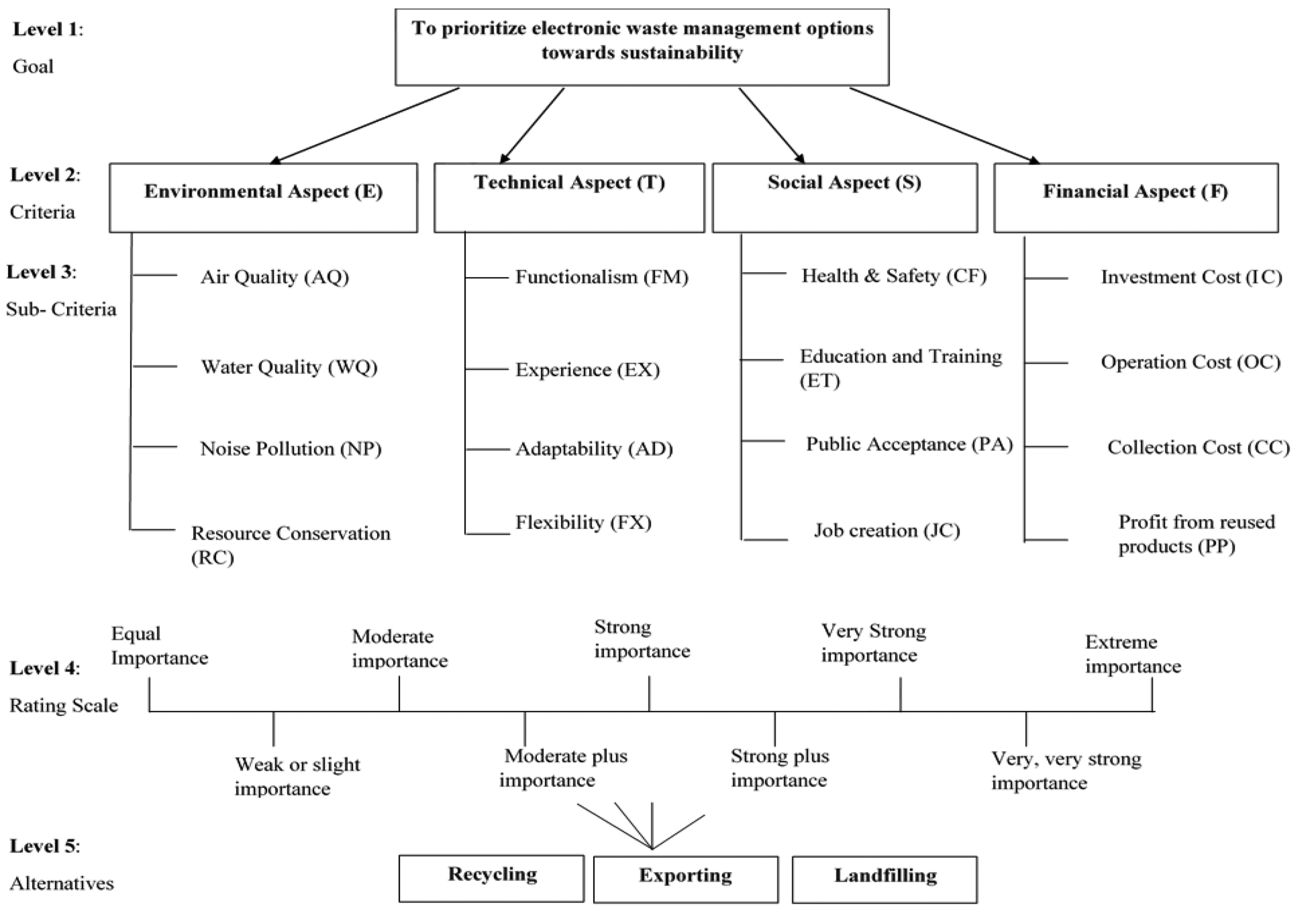



**FIGURE 3** Analytic hierarchy process (AHP) hierarchical model

## 3.4 | Sampling design, administration, and questionnaire development

The primary data in this study were collected using a survey questionnaire. In general, a survey questionnaire was issued to develop concession judgments on substitutes and criteria. Numerous studies have used surveys and focus groups on building decisions and deriving agreement weightings (Chowdhury & Paul, 2020). This study's targeted data were collected from five major government organizations in Abu Dhabi, with a population of approximately 1500 employees (Adnoc, Daman, Mubadala, Tadweer, and Abu Dhabi Municipality). In the current study, respondents were chosen in different categories ranging from academic to executive experts with experiences in the waste management area to cover different interests and points of view. A sample of 52 employees in senior managerial positions was issued a survey questionnaire. Saaty (1990) asserted that a small sample size was acceptable when using the AHP methodology. Each respondent participated in the questionnaire survey based on personal experience and knowledge in EWM and their understanding of conditions of the current practice of EWM (including all economic, technical, social, and environmental concerns) in the study area. The AHP involves participants theoretically classified as experts (e.g., director of operations, director in strategic planning, and senior project manager) in their field. Consideration of EX in expert selection is a priority because the focus is on a specific aspect of the problem, and judgments were deduced. The respondents had at least 10 years of managerial EX in the sustainable industry; they understood waste management and sustainability practices and were involved in setting and implementing strategic decision-making processes.

A survey questionnaire was suitable because it helped derive some compromise judgments on alternatives and criteria (Partovi, 1994). Several studies have revealed that using a questionnaire survey while holding group meetings helps determine and consequently derive consensus weighting (Bozbura et al., 2007). Alternatives and criteria and their related advantages and disadvantages were described in detail in meetings to improve respondents' understanding of the different options and criteria and increase their awareness of the decision problem as much as possible (Saaty, 1990).

The pairwise comparison in the AHP assumes that the decision-maker can associate any two elements at the same hierarchy level and provide the numerical value of the ratio of their importance (Demirbag & Tatoglu, 2008). The nominal scale used in the AHP enables decision makers to incorporate EX and knowledge simplistically and naturally (Partovi, 1994). The nominal-scale representation used in the AHP is detailed in Table 3. The preference or priority scale is designed at values of 1, 3, 5, 7, and 9 to represent preference, with

**TABLE 2** Criteria to be included in the model

| Aspect | Criteria |
|---|---|
| Economic | Costs of transportation, service cost, cost of refurbishing and operating the disassembly workstations; system feasibility; system efficiency, innovation, and generation of new economic activities, competitiveness of formal products in regard to informal products; sales quantity; costs of maintenance of equipment; costs of workforce; costs of infrastructure; strategic cost/benefit; Total cost of the network; Total profit; Total revenue; Total cost; Total emission cost; Total collection cost; Total fixed facility cost; Total disposal cost; Total processing cost; Total investment; sales quantity of new devices realized by the retailer during one period; recovery rate; selling price of refurbished devices; refurbishing/remanufacturing cost; inspection/sorting cost; disposal cost for devices not selected for refurbishment; recycling fee to distributor; creation of policies for materials re-utilization; savings through the use of recycled materials; revenues from the sales of e-waste; costs of advertising campaigns; costs of installation of collection points for e-waste; incentives for customers to return e-waste; |
| Technical and managerial | Specification of a new product; marketing implementation feasibility, production capacity; technical information; quality control; level of expertise; facility capacity; information system; credibility; confirmability; control; transferability; sorting/segregation requirements; storage requirements; processing/cleaning; storage needs; collection container type; physical effort, physical access; staff interactions and assistance; drop-off procedure; integration and coordination; volume and quality of waste; installing capacity; collection network; quantity of discarded products; handling system capacity; human resources (number of staff involved); |
| Environmental | Compliance with environmental legislation; environmental concern from consumers; population awareness and adhesion to reverse logistics; promotion of environmental education; natural resources savings; policies for correct disposal of e-waste by customers; mass balance; energy use on the process level; energy use on the facility level; product volume and capacity use; ton-kilometers and fuel consumption trucks; degree of substitution per recovery options; conversion factors $CO_2$; carbon footprint; water footprint; |
| Social | Social inclusion, formal employment/jobs; generation of income; opportunity for professional development; Health & Safety; labor conditions; access to healthcare; access to education; digital inclusion; gender issues; inclusion of vulnerable workers; diversity issues; socio-demographic variables; socioeconomic variables; Stakeholders' participation/willingness to cooperate; engagement in community; qualification/training programs. |

**TABLE 3** Nine-point scale for AHP preferences

| Intensity of importance | Definition | Explanation |
|---|---|---|
| 1 | Equal importance | Two criteria equally contribute to the objective |
| 3 | Moderate importance | Judgment slightly favors one over another |
| 5 | Strong importance | Judgment strongly favors one over another |
| 7 | Extreme importance | A criterion is strongly favored, and its dominance was demonstrated in practice |
| 9 | Absolute importance | Importance of one over another affirmed on the highest possible order |
| 2, 4, 6, 8 | Intermediate values | Used to present a compromise between the aforementioned priorities |

*Source*: Piprani et al. (2020).

the advantage of being insensitive to minor changes in preferences. Scores of 2, 4, 6, and 8 represent intermediate preference levels to cater to areas with unclear preference judgments. The third phase obtains the relative priority weights once the preference ratings are collected and fed into the pairwise comparison matrices. Local priority weights were calculated, and the ranking of the desired alternatives (global weights) was determined to satisfy this problem (Wang et al., 2008). The consistency of the obtained weight needs was assured through the consistency index (CI) defined by Saaty (1990) as follows:

$$\mathrm{CI} = (£_{\max} - n)/(n - 1)$$

where $£_{\max}$ is the maximum eigenvalue of the matrix of the priority ratios, and $n$ is the factor in the primary criteria level. Next, the consistency ratio (CR) is used to assess whether a matrix is sufficiently consistent. Calculated by the ratio of the CI to the random index (RI), which is the CI of a matrix of comparisons generated randomly:

$$\mathrm{CR} = \mathrm{CI}/\mathrm{RI}$$

Random pairwise comparisons were simulated to produce average random indices for matrices of different sizes. The RI values are listed in Table 4. The inconsistency is acceptable if the CR is smaller than or equal to 0.10 (Saaty, 1990). The final phase of the AHP methodology was concretization. In this phase, the global priority weights were calculated by multiplying the normalized priority weights at a high level (Bureš et al., 2020).

For performing the comparisons, factual data on the elements were used to build their relative meaning and significance. Based on the opinions of the 52 expert participants, a pairwise comparison matrix of the four main criteria (AHP criteria) was established; this was followed by synthesizing multiple judgments using their geometric mean. The geometric means of the pairwise comparisons for the

TABLE 4 Random index

| n | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| RI | 0.00 | 0.00 | 0.58 | 0.90 | 1.12 | 1.24 | 1.32 | 1.41 | 1.45 | 1.48 |

*Note*: *n* is the number of factors.

TABLE 5 Geometric means of pairwise comparison of Main criteria (EWM processing options)

| Criteria | Environmental aspect | Technical aspect | Social aspect | Economic aspect | Priority vector |
|---|---|---|---|---|---|
| Environmental aspect | 0.69 | 0.84 | 0.46 | 0.31 | 0.58 |
| Technical aspect | 0.10 | 0.12 | 0.46 | 0.30 | 0.24 |
| Social aspect | 0.10 | 0.02 | 0.07 | 0.34 | 0.13 |
| Economic aspect | 0.12 | 0.02 | 0.01 | 0.05 | 0.05 |
| CR value: 0.07 < 0.10 (consistent) | | | | | |

TABLE 6 Evaluation of EWM processing options alternatives in the environmental aspect

| Criteria | Priority weight | Sub-criteria | Priority weight | Alternatives | Priority weight |
|---|---|---|---|---|---|
| Environmental aspect | 0.58 | Air quality (AQ) | 0.55 | Recycling | 0.41 |
| | | | | Exporting | 0.59 |
| | | | | Landfilling | 0 |
| | | Water quality (WQ) | 0.27 | Recycling | 0.39 |
| | | | | Exporting | 0.55 |
| | | | | Landfilling | 0 |
| | | Noise pollution (NP) | 0.13 | Recycling | 0.29 |
| | | | | Exporting | 0.09 |
| | | | | Landfilling | 0 |
| | | Resource Conservation (RC) | 0.06 | Recycling | 0.19 |
| | | | | Exporting | 0 |
| | | | | Landfilling | 0 |
| CR value: 0.07 < 0.10 (consistent) | | | | | |

four main criteria are presented in Table 5, and the rightmost column shows their relative priorities. The eigenvalue method was used to estimate the relative weights of the elements and their degrees of importance. Relative weights are then integrated and synthesized to finalize the given decision alternatives and priorities.

## 4 | RESULTS

Applying the AHP methodology resulted in obtaining priority weights for the factors assigned to the sustainability of EWM. Conflict of interests was also observed (e.g., some experts considered economic criteria more important than environmental conservation issues, and vice versa). Similarly, the literature does not ubiquitously agree on the preference of specific alternatives concerning the environmental, economic, technical, and social aspects (e.g., although many studies suggest that E-waste recycling is the most suitable alternative, some of them do not consider this alternative as the best possible solution mainly because of the adverse environmental impact of a recycling plant; Gupta & Barua, 2017).

The local and overall weights of the studied criteria and sub-criteria, which have been derived by applying the proposed technique, are presented in Tables 5–9. Each criterion with a higher weight is more effective in decision-making. The CR value of 0.07 (<0.1) for Table 5 indicates consistent results. The calculated CR is 0.08 (less than 0.1), indicating that the judgment is acceptable. As highlighted in Figure 4, Environmental Aspect (0.58) has the highest weight, followed by Technical Aspect (0.24). These two factors account for 82% of the total importance assigned to all four factors in this study. The third highest factor is the Social Aspect (0.13). The least important factor was the Economic Aspect (0.05); these results answer RQ1. This implies that the primary concern of respondents, with regard to selecting the most beneficial alternative for processing E-waste, is environmental issues.

The alternatives are compared according to each criterion or sub-criterion. Moreover, in the case of criteria or sub-criteria, they are

**TABLE 7** Evaluation of EWM processing options alternatives in the technical aspect

| Criteria | Priority weight | Sub-criteria | Priority weight | Alternatives | Priority weight |
|---|---|---|---|---|---|
| Technical aspect | 0.24 | Functionalism (FM) | 0.54 | Recycling | 0 |
| | | | | Exporting | 0.95 |
| | | | | Landfilling | 0.25 |
| | | Experience (EX) | 0.27 | Recycling | 0 |
| | | | | Exporting | 0.44 |
| | | | | Landfilling | 0.56 |
| | | Adaptability (AD) | 0.14 | Recycling | 0.68 |
| | | | | Exporting | 0.32 |
| | | | | Landfilling | 0 |
| | | Flexibility (FX) | 0.06 | Recycling | 0.53 |
| | | | | Exporting | 0 |
| | | | | Landfilling | 0 |
| CR value: 0.07 < 0.10 (consistent) | | | | | |

**TABLE 8** Evaluation of EWM processing options alternatives in the social aspect

| Criteria | Priority weight | Sub-criteria | Priority weight | Alternatives | Priority weight |
|---|---|---|---|---|---|
| Social aspect | 0.13 | Health & Safety (CF) | 0.59 | Recycling | 0.89 |
| | | | | Exporting | 0.29 |
| | | | | Landfilling | 0 |
| | | Education & Training (ET) | 0.24 | Recycling | 1 |
| | | | | Exporting | 0 |
| | | | | Landfilling | 0 |
| | | Public acceptance (PA) | 0.12 | Recycling | 1 |
| | | | | Exporting | 0 |
| | | | | Landfilling | 0 |
| | | Job creation (JC) | 0.05 | Recycling | 1 |
| | | | | Exporting | 0 |
| | | | | Landfilling | 0 |
| CR value: 0.07 < 0.10 (consistent) | | | | | |

compared together with regard to the primary goal. The sub-criteria following the environmental aspect criterion resulted in the priorities summarized in Table 6. AQ was the highest among the sub-criteria, with a weight of 0.55. The WQ priority was 0.27. The next priority for NP was 0.13, and the RC balance was at least 0.05. The CR value for the second sub-criteria was 0.07 (<0.1), thereby indicating consistent results. Sub-criteria related to the technical aspect showed the highest priority to an FM frequency, with a weight of 0.54. EX was the second priority with a weight of 0.27. AD showed a weight of 0.14, and FX was the fourth priority at 0.05. The CR value of this sub-criteria was 0.08 (<0.1), indicating consistent results. Sub-criteria for social aspects resulting in health and safety exhibit the highest priority of 0.59; ET, PA, and JC exhibited the second, third, and least priority, respectively. The CR value of the sub-criteria is 0.08 (<0.1), indicating consistent results. The economic aspect sub-criteria offer the highest priority for IC, with a weight of 0.57. For the other three sub-criteria, OC, CC, and PP, the weights were 0.6, 0.12, and 0.05, respectively. The CR value of 0.07 (<0.1) indicates a consistent result. The priority weights for the alternatives concerning each specific criterion for EWM processing options are presented in Table 6. In the EWM processing options, recycling has the highest economic, social, and technical (AD and FX) criteria, with priority weights of 0.82, 1.00, and 0.68, respectively; these results answer RQ2.

Additionally, exporting as a processing alternative has the highest priority in environmental and technical (FM) criteria with priority weights of 0.59 and 0.95, respectively. Landfilling had the lowest priority for all criteria and sub-criteria, except for the technical dimension (EX), with a priority weight of 0.56; this result also answers RQ2. The sub-criteria local weight was multiplied by the criterion's value to obtain the global weights of all sub-criteria within the study (Figure 5). The higher the criterion's weight, the more effective it is in the decision-making process. Each alternative's priority weights for all

TABLE 9 Evaluation of EWM processing options alternatives in the economic aspect

| Criteria | Priority weight | Sub-criteria | Priority weight | Alternatives | Priority weight |
|---|---|---|---|---|---|
| Economic aspect | 0.05 | Investment cost (IC) | 0.57 | Recycling | 0.82 |
| | | | | Exporting | 0.18 |
| | | | | Landfilling | 0 |
| | | Operation cost (OC) | 0.26 | Recycling | 0.79 |
| | | | | Exporting | 0.08 |
| | | | | Landfilling | 0 |
| | | Collection cost (CC) | 0.12 | Recycling | 0.65 |
| | | | | Exporting | 0.09 |
| | | | | Landfilling | 0 |
| | | Profit from reused products (PP) | 0.05 | Recycling | 1 |
| | | | | Exporting | 0 |
| | | | | Landfilling | 0 |
| CR value: 0.07 < 0.10 (consistent) | | | | | |

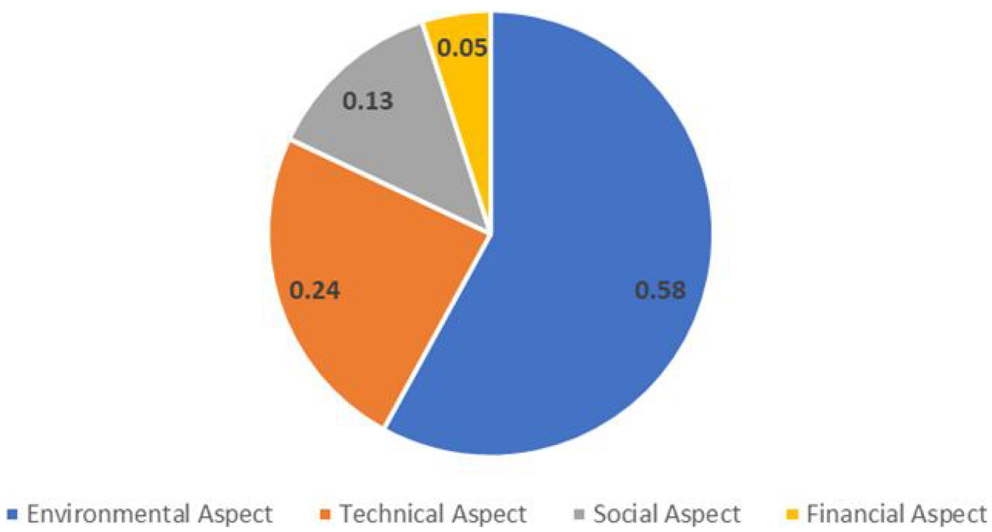



FIGURE 4 Relative weights among four main criteria (CR value: 0.07 < 0.10 [consistent])

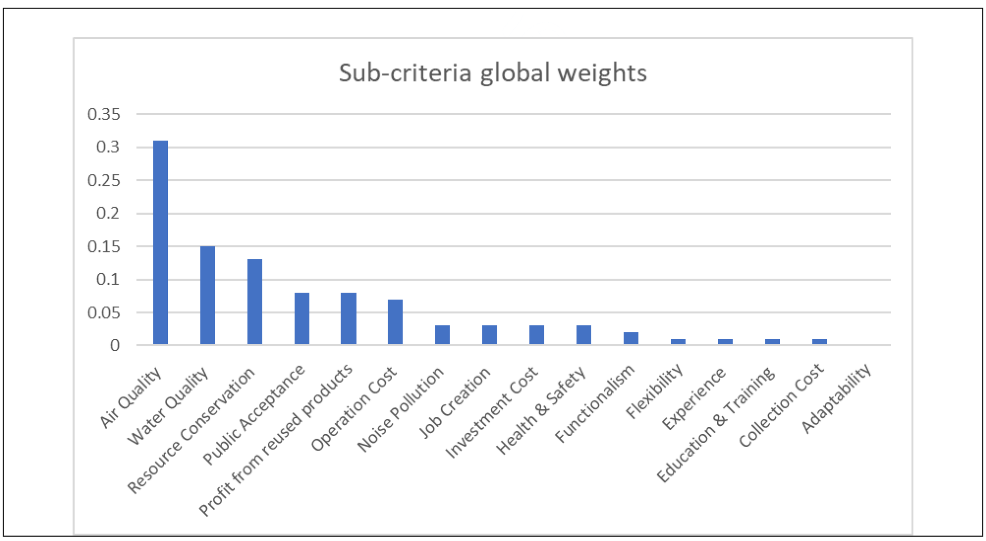



FIGURE 5 Global priority vectors for sub-criteria

criteria and sub-criteria are calculated individually through the global and local weights of the criteria and priority weights of alternatives in terms of each criterion (Tables 6–9).

Overall weights of the studied criteria and sub-criteria are presented in the results. Of the study criteria in the processing section, the environmental criterion was the most influential (global weight of 0.58), and the technical criterion had the least effect (global weight of 0.05). The environmental criteria imply that respondents' primary concern in selecting the most beneficial alternative for processing e-waste is environmental issues. Three sub-criteria (ET, CC, and AD) exhibited the lowest priority. The respondents pointed out the need to educate the public on waste generation, lifestyle, source separation, waste recycling, and other benefits such as waste to energy conversion. Moreover, the high weight of social factors (e.g., health and safety) for e-waste processing systems emphasizes the role of citizens in a successful EWM system. Raising public awareness regarding environmental and health issues associated with e-waste is considered one of the most effective methods for achieving the highest participation.

Furthermore, the results indicated that recycling had the highest priority in processing options. Additionally, landfilling was determined to be the least favorable alternative in processing options according to the perspective of respondents. Additionally, e-waste exports achieved a noticeable priority. Finally, evaluating processing alternatives as environmental criteria (the most influential criterion in the processing section) reveals that recycling and exporting have equal priority, and landfilling has comparably little importance. The negative environmental impacts of landfilling compared with the benefits of proper recycling are the cause of this attribute (Shaikh, 2020). E-waste importers, which are usually located in developing countries, recycle imported e-waste under uncontrolled recycling conditions that are potentially hazardous to the environment (Chandrashekhar et al., 2020). The results also show that recycling is highly preferred because of the economic aspects of e-waste processing, which are recognized as another important criterion. Waste recycling, particularly e-waste recycling, can result in beneficial economic effects, such as recovering valuable and precious materials, conserving natural resources, saving energy, creating new jobs, and saving landfills (Fuldauer et al., 2019). Notably, recycling has a negligible priority in FM preferences. A wide variety of materials contained in e-waste requires varied, separate, and advanced treatment processes and state-of-the-art technologies to achieve appropriate recovery rates (Xu, Fan, et al., 2020), and access to these innovative technologies is limited in the studied area (Wiesmeth, 2020).

## 5 | DISCUSSION AND CONCLUSION

We have demonstrated that e-waste in the UAE is problematic and threatens the ecological environment and human health. Thus, a management system with environmental benefits must be designed rationally (Mawed, 2020). This study employed a well-known decision-making method to select the best EWM system. According to the comprehensive literature review and experts, three management scenarios in e-waste processing were chosen as alternatives and various influencing criteria. The priority of each alternative for each criterion was evaluated for further analyses. The overall results revealed the top priority of the options by recycling. E-waste recycling is rudimentary. To compare the results of this study holistically with similar investigations in this area, several studies consider recycling the most effective strategy compared to other methods, including exporting and landfilling (Abdallah et al., 2021; Chowdhury & Paul, 2020). Likewise, by using the AHP method in the current study, recycling gained the highest priority among other alternatives and landfilling was the least favorable option. For instance, e-waste recycling conserves natural resources, protects the environment, contributes to economic growth, and saves landfills (Wieland, 2021). Landfilling is the most conventional disposal technique for various waste streams, including e-waste in the UAE. De Guimarães et al. (2020) also observed that 77.5% of waste is burned or buried in informal landfills in the countryside or deserts near cities. This can also be attributed to the fact that e-waste recycling is significantly influenced by social, economic, technical, and environmental conditions, as revealed.

Furthermore, landfilling was evaluated to be the worst potential option from a sustainable point of view. These study sites have evaluated unregulated or open dumps, which host invisible informal recyclers. The results of this study support those of most previous studies that have determined landfilling as the least favorable option in e-waste processing options because of related environmental disadvantages (Thakur et al., 2021). The results indicate that the economic and environmental dimensions are the most influential criteria in e-waste processing. This finding is consistent with the development of a roadmap for proper EWM. Zeng et al. (2019) demonstrated that the disposal of e-waste to landfills and incinerators causes irreversible ecological damage by polluting water and soil and contaminating the air.

On the one hand, a study conducted by Wang, Wang, et al. (2020) addressed that exporting does not induce the encumbrance of recycling processes and their associated problems. On the other hand, it has economic merits for the exporter. The e-wastes importers are usually among developing countries; they recycle the imported e-wastes under uncontrolled recycling conditions, which can be potentially hazardous for the environment.

In the case of economic impacts, implementing regulations on investment and OCs to ensure sustainability is necessary. A recent study by (Ahirwar & Tripathi, 2021) suggested that a deposit refund system provides an incentive plan for consumers who pay at the time of purchase, helps to achieve zero waste, and minimizes environmental degradation.

Moreover, findings strongly depend on the social priority suggest that engaging the public in raising awareness concerning e-waste pollution and citizens' role in successful management is necessary. These findings indicate that consumers' targeting requires improvement to promote their participation in EWM practices in the UAE. (O'Brien et al., 2021) conducted a case study of the remediation of a contaminated site to remove hazardous waste in the United States that mainly required public participation. In conclusion, EWM systems consist of many intricate and various parts and factors. Thus, with these techniques, the focus has moved upstream to address the problem from its origin. Producing e-waste, preventing e-waste, reducing the quantity and use of hazardous substances, and adopting techniques such as multicriteria decision analysis would be helpful and invaluable in successful EWM. The results show the need for integration among manufacturers, community participation, and technological innovations in collecting, disposal, and recycling to develop an effective, efficient EWM. This study's research finding also highlight that stakeholders should strategically emphasize the causal group of aspects, which significantly influences the effect of enablers in the implementation process. Furthermore, the electronics industry must design and manufacture eco-friendly products that are increasingly sustainable and contribute to achieving the zero-waste objective. The findings of this study have several implications for advancing theory and practice and are discussed in detail in the following section.

## 5.1 | Theoretical implications

Analysis of the relationship between the aspect criteria and the alternatives of EWM processing options shows that the applied framework is robust. Its underpinnings amplify the criteria considered in this study. First, this study identified EWM sustainability aspects perceived by multiple stakeholders (such as Adnoc, Daman, Mubadala, Tadweer, and Abu Dhabi Municipality). According to our review of the literature, this study is the first attempt to explore and evaluate the aspects influencing EWM processing options in the UAE from stakeholders' perspectives. This study responds to a research call for further investigation into the influence of e-waste recycling intention. It covers an e-waste research gap in the context of the UAE, where the lifespan of electronics is one of the shortest globally, and the level of e-waste per resident is twice that of the global average. A study by (Wiesmeth, 2020) highlighted the importance of incorporating all the stakeholders in policy formulation related to e-waste recycling, resourcing government agencies for effective monitoring and education, provision of tax stimulus packages, provision of training programs to equip e-waste recyclers with new technology, and tool application to enhance the adoption and implementation of formal EWM.

Second, the application of MCDM methods, especially the AHP, in the EWM area is limited. Nevertheless, the presented methodology allows decision-makers, investors, researchers, legislators, and authorities to reach the most effective, comprehensive strategy. This study shows that decision-makers can adopt the AHP methodology in the waste management sector. Additionally, it provides in-depth insights into model application procedures in an integrated manner, particularly multiplicity models for ratings to solve specific problems. This paper proposes that the AHP method is a prospective method for the sustainability assessment of waste treatment scenarios and can be used in cases where there is no or insufficient data or when working with non-numeric data. Furthermore, as suggested in this study, several studies (e.g., Cui et al., 2019) have proposed solutions resonating with the functional pathways essential for implementing e-waste formalization management in India-China.

Third, there is a gap in the literature on the complexity of sustainability in e-waste sectors. This research aims to fill this gap by introducing a new sustainability framework. The ISSWM concept is applied to develop a framework based on economic, technical, social, and environmental dimensions for researchers. However, few studies have been conducted on the affecting dimension, which is critical and requires further research immediately. The implementation of sustainability in e-waste sectors is challenging. It is imperative to state that many studies such as Xu, Yeh, et al. (2020) highlighting barriers to sustainable EWM in developing and emerging countries are similar to this study. For instance, studies by Wang (2019) and Wang et al. (2017) underscored the lack of financial constraints as a critical barrier impeding e-waste recycling in China. This assertion resonates with our findings as a critical factor in the UAE context. In the study by Bhatia and Srivastava (2018), it was indicated that the lack of economic incentives and tax preference, imperfect legal system, and insufficient channels to collect used e-waste products are the key barriers that significantly impede stainable e-waste management in India. Many studies, such as (Masud et al., 2019), have highlighted that the lack of environmental laws and regulations is a critical barrier to e-waste formalization management; these observations are similar to those of this study. However, the services' decision-makers must design their policies and strategic goals to align with sustainability's internal and external dimensions. This study not only presents information on sustainability instruments but also ranks them. This study was imperative because it compared these concepts' dimensions and revealed the UAE's most critical aspects and dimensions.

## 5.2 | Implications for practice

This study's outcome indicates that the aspects of EWM processing options are interconnected; therefore, they require absolute commitment from the government, industry actors, and major stakeholders, including managers, consumers, and recyclers, to address these concerns. First, recycling, reuse, and reducing consumption are essential to sustainable development and should be started in the product manufacturing stage (Park & Lin, 2020). The government must conduct a multistakeholder consultation with the public sector, formal and informal e-waste processing sectors, civil societies, and academics to develop an EWM system and should promote information, education, and communication activities in, for example, schools, colleges, and industry. Additionally, "E-waste awareness champions" must be instituted in educational campuses to spread the message. Many countries, such as Canada and the USA, have provided environmental education in schools from as early as the 1980s (Wang, Qu, et al., 2020). However, such environmental education is still non-existent in UAE schools. Therefore, proper promotion and education of e-waste recycling should be initiated in China to enhance the recycling rate for e-waste.

Second, external entities, such as the media and environmental protection agencies, are critical. Therefore, governments should collaborate and involve these agencies in policy development. Moreover, several developed countries have authorized compulsory laws and regulations on e-waste recycling practices by applying the principles of a national scheme such as extended producer responsibility (EPR) to solve the growing e-waste problems. EPR is an excellent policy tool that recognizes the producers' responsibility in reducing the impacts of their products throughout their entire life cycle, including designs for environmental and waste management. Consumers need to pay advanced recycling fees when buying new appliances supporting this recycling system (Wang, Wang et al., 2020). Regardless of how well the policies are introduced and implemented, benefits will be realized if end-users accept the proposed policies and adhere to them.

Third, financial constraints were ranked first among all barriers to implementing EWM practices in the UAE. Therefore, the government should allocate economic resources to cushion e-waste entrepreneurs at the initial stage of integrating EWM practices to stimulate a significant proportion of informal e-waste entrepreneurs and operators to implement formal EWM systems. According to Ikhlayel (2018), practicing deposit refunds system implementation helps consumers actively participate in zero e-waste management by reimbursing their funds when an already purchased electronic product becomes obsolete and returned to the manufacturers. This incentive plan helps dissuade consumers from auctioning their unwanted electronic products to informal recyclers. Establishing appropriate and sustainable EWM is capital-intensive for installing new facilities, training, technology, and transportation, particularly in the initial stage. The UAE government is advised to design a compelling legislation vendor to initiate a take-back and recycle mechanism.

## 5.3 | Limitations and future research

This research employed a well-known decision-making method to select the best EWM system. This section presents the critical limitations of this study and suggestions for further research. First, this study extends the insights explored from the UAE perspective. It could be replicated in other developing and emerging nations, such as the Arabian Gulf Countries, to analyze Middle Eastern and North Africa. Second, an increased sample size than that of this study could be adopted by including experts at the regional and international levels. Third, the model derived from this study may be tested further in the real world for different economies, confirming whether the results match those in the literature. Advanced MCDM methods, such as the VIKOR method, are also recommended to understand the context of the proposed model's relationships in further research to provide a complete overview of the decision context. Finally, structural equation modeling can verify the validity of this model in the future. As a concluding remark, EWM systems consist of many complex and various parts and factors. Using techniques like multi-criteria decision analysis would be helpful and invaluable to achieving successful EWM. Upcoming research may also consider qualitative methods (e.g., grounding theory) to obtain in-depth knowledge about e-waste recycling in a non-western context. Besides, a longitudinal approach in future research will offer more comparative discernments into EWM and recycling behaviors at various time logs.

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