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A Survey of IoT and Blockchain Solutions for Advancements in E-Waste Management

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Abstract
Electronic waste (e-waste) is a pressing environmental and logistical concern, particularly in smart cities. Current e-waste management systems face challenges due to high computational overhead, impacting scalability and efficiency. This survey examines the shortcomings of existing e-waste management in smart-cities, highlighting requirement of efficient solutions. This work introduces a Lightweight and Efficient Decision-Support System designed for e-waste management in smart-cities. This system aims to reduce computational demands, enhance scalability, and improve responsiveness. By leveraging lightweight design principles and efficient decision-making processes, the proposed system promises to revolutionize e-waste management. Key aspects include minimizing computational overhead, optimizing resource allocation, and promoting sustainability in urban environments.

Keywords-Electronic Waste, Smart City, Internet of Things, Blockchain, Decision-Support System.

INTRODUCTION

To keep up with the ever-increasing requirements of urbanization, “smart cities” use a variety of innovations to design, implement, and support for environmentally friendly development methods [1]. Sustainable smart-cities prioritize reducing energy consumption and their overall carbon footprint [2]. The Smart-City Index (SCI) evaluates a variety of metrics, including healthcare, transportation, security, and garbage collection, in an effort to enhance resident's standard of life. Increased waste production can be attributed to more people, more cities, and a better economy [3]. Plasma Gasification [4], incineration [5] and bioremediation [6] are some of the more cutting-edge waste management and disposal alternatives because of the negative effects waste may have on human health, the atmosphere, and the environment [7]. Moreover, in recent years the rate of e-waste has been increasing [8].

The term "e-waste" is utilized for describing nearly functional electronic products which have been rejected, consisting of mobile phones, computers, and various other electronic products. In 2014, only about fifteen percent of e-waste had been collected and reused worldwide; the other eighty-five percent was either landfilled or burned [9]. As per the findings of the study conducted by [10], it was observed that in the year 2019, worldwide production of e-waste amounted to approximately 53.6 million-tons (MT), which represents an increase of 21% when compared with the data from last 5 years. Considering this increase, just 17.4% of e-waste actually got reused, meaning that most of its valuable recyclable substances and precious metals were just thrown away. As per the United-Nations study [11], the worldwide burden of e-waste production has experienced a significant surge, rising to 53.6 million MTs in 2019 (a 21% rise since 2015). It is anticipated to approach 120 million MTs by 2050. Also, according to the findings of the research [12], it has been projected that the typical capacity to handle e-waste (specifically through recycling and tearing down) will amount to approximately 163,563.15 MTs during the period from 2023 to 2030. The research further indicates that this capacity is expected to exhibit a consistent upward trend over the course of time, eventually resulting in a total of 248 recycling facilities by 2030. Examining the growth rate of e-waste processing facilities from 2023 to 2030 indicates a potential yearly increase of 6.86%. This finding further emphasizes the extent of entrepreneurial activities within the e-waste recycling sector, as evidenced by the observed average annual growth rate of recycling facilities amounting to 7.23%. An overall overview of what components exist in E-waste and E-waste generation per capita is presented in Figure 1 and Figure 2 respectively.

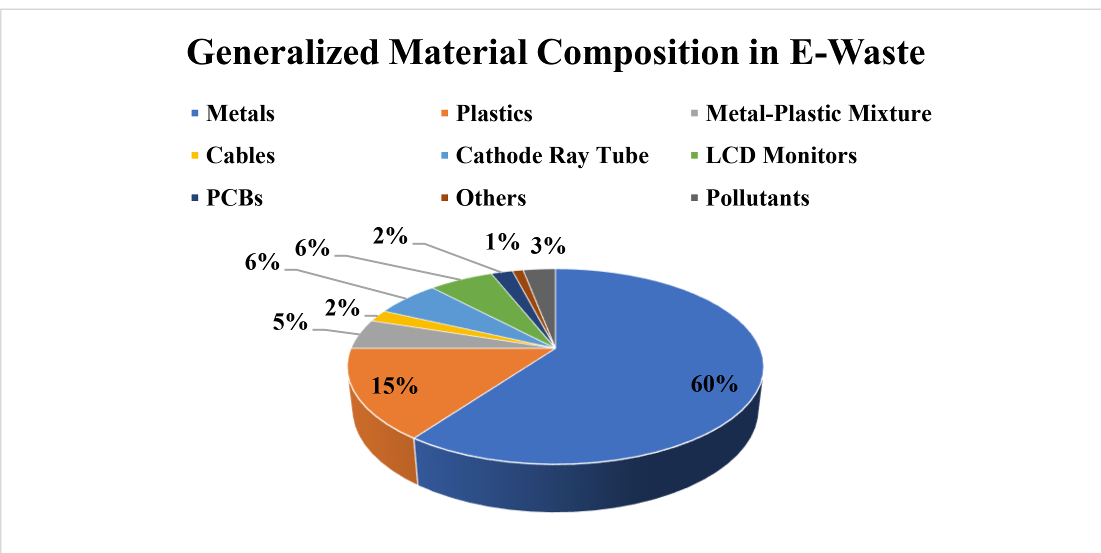

Figure 1. E-Waste Material Composition [13].

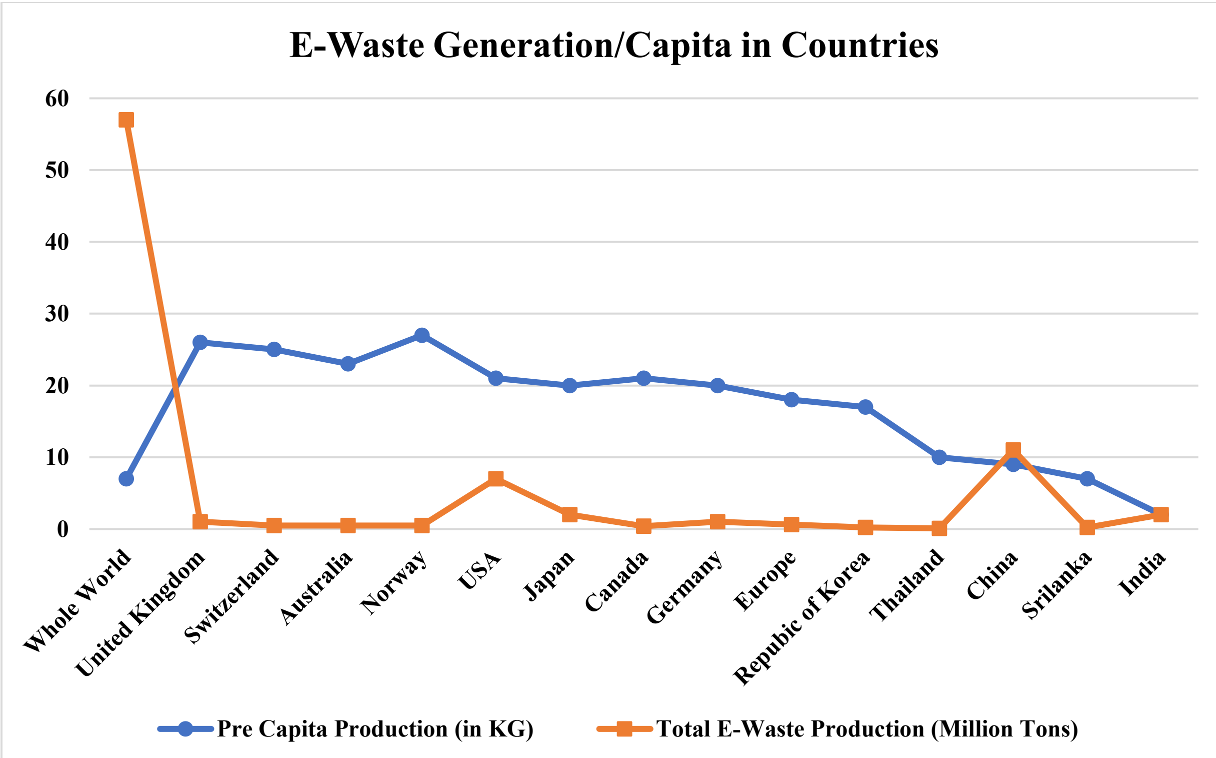

Figure 2. Production of E-Waste in Various Countries [13].

As seen from Figure 2, it can be seen that countries all over the world are struggling to find effective solutions for issue of e-waste. Because of presence of potentially dangerous substances including poisonous chemicals in addition to radioactive substances as well as potentially insecure storage media as shown in Figure 1, e-waste becomes more challenging to handle than regular waste. Inappropriate disposal of storage media devices could lead to their acquisition by adversaries who can buy these devices in large quantities in order to examine them to steal confidential data [14]. Significant data including encryption keys, cryptocurrency wallets, identification numbers, architectural designs, and possibly government secrets might be extracted in this manner [15], [16]. Hence, electronic goods need to be traced, destroyed, and recycled in a way that leaves a paper trail. In recent years, Internet-of-Things (IoT) has become an essential element in smart-cities which can aid in the management of e-waste [17]. For an added layer of security against e-waste ending through the black-market, blockchain technology can enable organizations to conduct evidence-backed monitoring, tracking, recycling and destruction of e-waste [18].

Moreover, the IoT and cloud-based computing constitute the foundations for numerous of today's approaches to problems in managing supply chains and waste disposal [19]. To encourage people to bring their trash to the specifically specified areas, several of these approaches include financial rewards in the way of vouchers [20]. This is done because there will always be a possibility that e-waste will end up being sold on the black-market, from which thieves might access potentially dangerous sensitive data by breaking into the electronic devices [21]. This happens usually because monitoring functions are rarely included in these products. These centrally managed systems also have difficulties with expansion and reliability due to their reliance on just one point of failure. In addition, many of these systems are missing crucial components like transparency, traceability, accountability, and privacy etc. [22].

In light of the problems associated with centrally managed solutions, experts have high-lighted the use of blockchain-based approaches in a variety of purposes [23], [24], one of which is waste management. Thus, several blockchain-based methods for waste management exist alongside traditional alternatives. Nevertheless, these strategies are primarily intended for managing waste of one type or another, be it clinical or other kind of waste. Several blockchain-based approaches have been recommended for electronics like mobile devices, but they only address a small section within the entire supply chain [25], [26]. Several crucial features are missing from these approaches. These include the ability to monitor and trace devices from production to reuse and recycling, to verify the legitimacy of all parties present and their permits, to handle the credibility of the stakeholders, and to issue certificates attesting to the disposal of storage media devices. An example of the blockchain system is presented in Figure 3 [27].

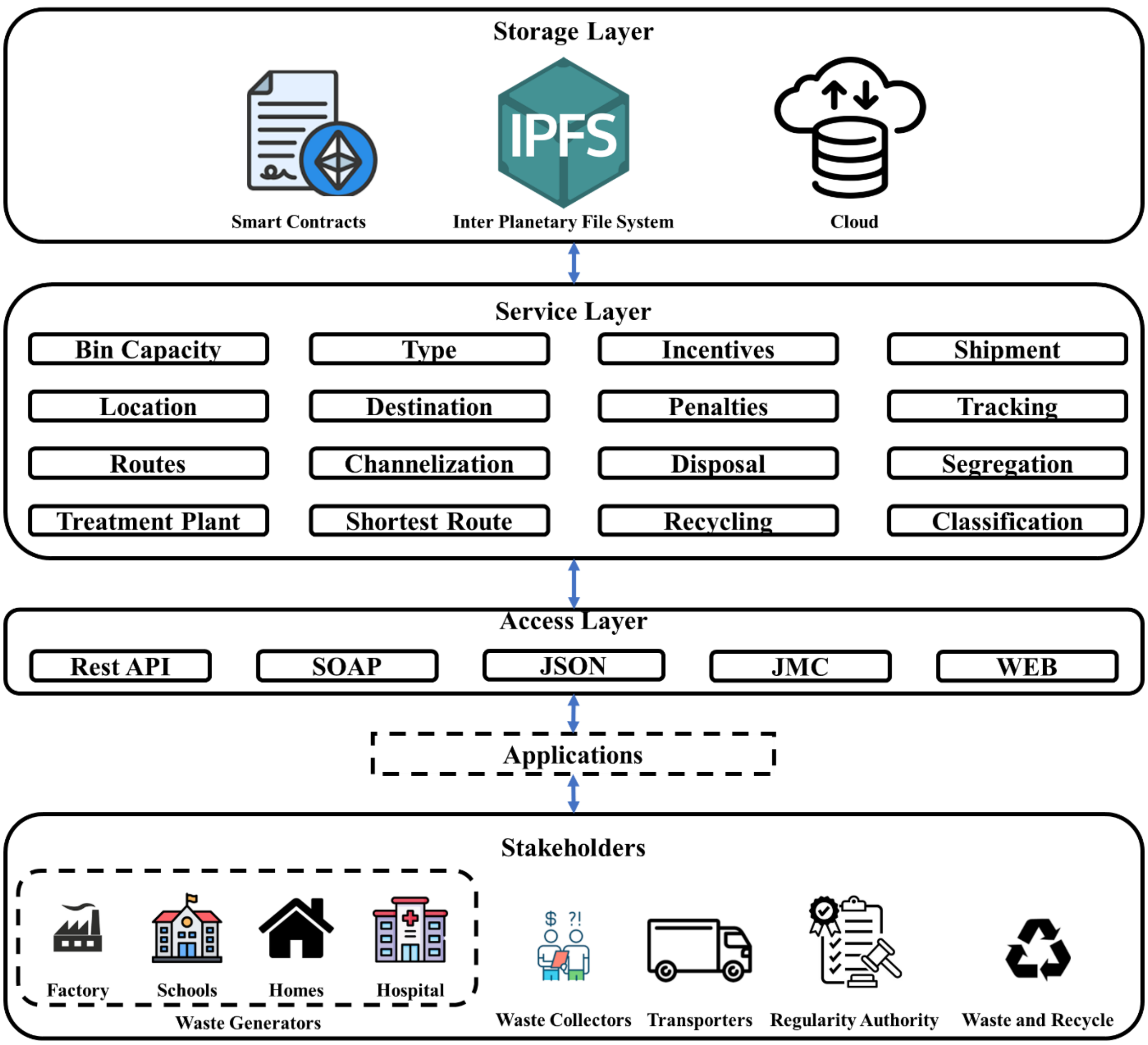

Figure 3. Blockchain Framework for E-Waste Management (EWM) System [27].

As seen from the previous work [27], there is still a gap in existing framework of collection of e-waste and recycling-management systems. The gap includes analysis of power consumed by various entities to transfer the data, delay caused due to obstacles, cost for handling various entities etc. Hence, to solve all these problems, this works conducts a survey to understand the current collection and recycling methods used for E-Waste Management (EWM). Hence, in next section, various works about the collection, tracking, recycling, and segregation methods for EWM are discussed.

LITERATURE SURVEY

The initial step in the EWM procedure involves the gathering of e-waste items or materials from diverse origins, including residential areas, commercial establishments, and industrial sectors. These items are then sorted and itemized into categories based on their type and composition. Once categorized, the e-waste is securely transported to e-waste delivery plants to ensure safe handling during transit. At the delivery plants, the e-waste undergoes initial disassembly where different parts like batteries, circuit boards, plastics, and metals are segregated to minimize the harmful impact on the environment. The batteries are sent for recycling separately to extract valuable materials and prevent hazardous substances from entering the environment. The remaining components are shredded, and further segregation is carried out to prepare them for recycling. Paper work for each shredded item are made and sent to higher authorities for approval and oversight. This comprehensive process is illustrated in Figure 4, depicting the systematic and environmentally conscious approach to managing e-waste from collection to recycling. Hence, this literature survey section first dives into the collection and tracking system approaches currently being used using blockchain and IoT. Then this section further explores the recycling and segregation approaches.

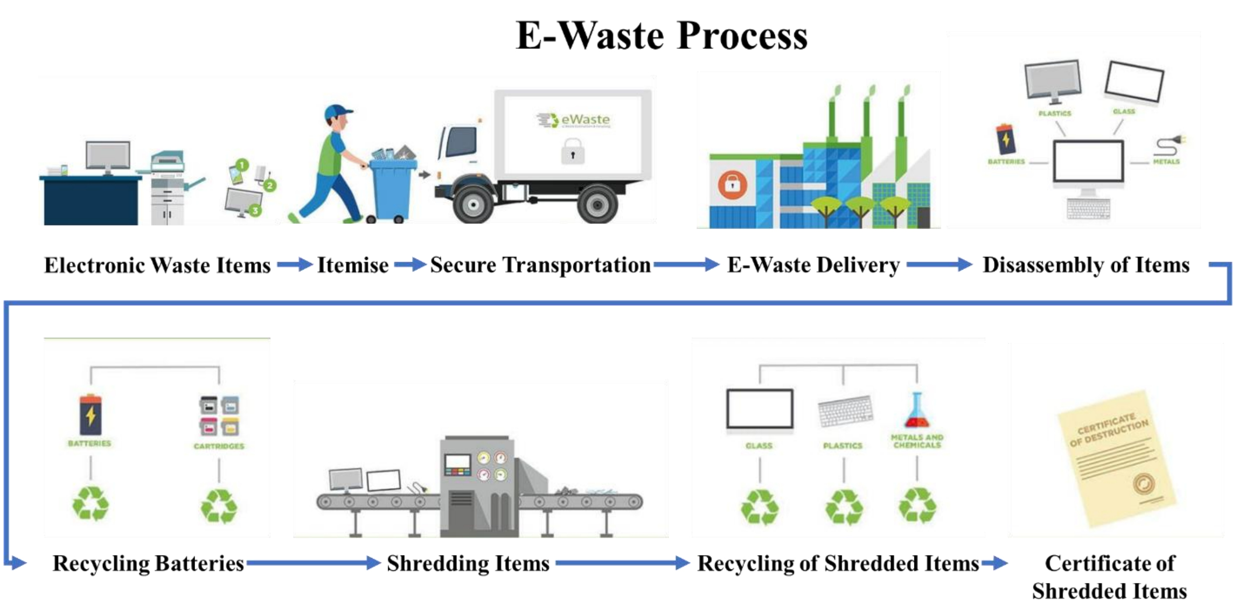

Figure 4. Process of EWM System.

E-Waste Collection and Tracking System Methodologies

In this section, the e-waste collection and different tracking systems currently being used by utilizing blockchain and IoT systems are discussed. An innovative method for EWM based on smart contracts and the blockchain was presented and addressed in [28]. The study in [29] aimed to create an intelligent waste handling system by utilizing the LoRa network protocol along with a Deep-Learning (DL) approach using TensorFlow. TensorFlow was able to identify and classify objects in real-time using information received by LoRa sensors. The waste was separated into various sections within the bin using servomotors to manage the paper, metal, plastic, and other waste elements. Using a pre-trained object identification approach, the TensorFlow platform was utilized to accomplish the task of identifying objects and waste categorization. Using a camera linked to a Raspberry-Pi 3 Model B+ as its processor, this item recognition strategy was trained using photos of waste to create a reasoning graph that is utilized for identifying objects. To keep track of how full each trash can was, an ultrasonic-sensor was placed inside. A GPS tracker was installed to track the bin's exact position in real-time. The position, real-time status, along with volume of the bin's loading were transmitted using the LoRa networking protocol. A Radio-Frequency Identification (RFID) component was integrated to facilitate identification of waste handling staff. Further, in [30], the primary objective of the study was to create an advanced waste handling system by leveraging the capabilities of DL approaches. The proposed approach aimed to enhance the waste separation procedure and facilitated real-time tracking of bin position within an IoT framework. The study employed the utilization of an SSD-MobileNetV2-Quantized model, which was trained using a dataset encompassing various waste materials such as plastic, glass, paper, metal and cardboard. This dataset was employed for the purpose of identifying waste and classification. Through the integration of a model trained on the Lite version of TensorFlow along with Raspberry-Pi 4, the camera component successfully identified waste materials. Subsequently, the waste materials were sorted into the appropriate waste compartments by means of a servomotor attached to a plastic board. A GPS component collected the current coordinates in instantaneously, while an ultrasonic sensor tracked the proportion of garbage fill. The LoRa module installed on the intelligent bin successfully transmitted the current position of the smart bin to an external LoRa receiver operating at a frequency of 915 MHz. The smart bin's electrical parts were safeguarded by a locker system that utilized RFID technology. This ensured that only authorized individuals with enrolled RFID tags were able to access the system for servicing or upgrades.

In [31], the researchers carried out a comprehensive examination on Extended-Production-Responsibility (EPR) through the standpoint of operational management. With precision, the researchers undertook the task of categorizing the existing body of work on EPR, encompassing simultaneously non-e-wastes and e-wastes categories. This categorization was based on the study's techniques employed, namely subjective case reports, numerical empirical investigations, and statistical modelling research. Furthermore, the researchers engaged in a comprehensive discussion of the results derived from each specific research approach. Within the scope of their study, the researchers not only conducted a comprehensive examination of the current research landscape in the field of EPR, but also delved into relevant topics including the practical application of EPR, the establishment of EPR management platforms, the administration of supply chains in relation to EPR, and various operational aspects associated with EPR. The authors emphasized several creative approaches and suggestions pertaining to EPR across five distinct subjects: technology, policy, process, product, and supply chain. Ultimately, the researchers engaged in a comprehensive analysis regarding prospective investigations and put forth a final conceptual framework illustrating the potential of EPR in facilitating the implementation of novel operational strategies aimed at enhancing environmental sustainability. In [32] presented a novel approach that utilizes blockchain technology in combination with IoT to create a framework capable of tracking various after-production business procedures, tasks, and activities related to e-waste. The suggested system aimed to enhance the efficiency and transparency of the EWM procedure. The framework was facilitated by a set of five electronic contracts, which served as programmable agreements that documented and stored the activities performed by consumers on the unchangeable distributed-ledger. These smart-contracts played a crucial role in guaranteeing that each of the company procedures executed by everyone involved were characterized by transparency, traceability, and security. In order to effectively manage and preserve substantial data, including high-resolution images of e-waste materials, different items, and authorizations pertaining to participants, the researchers seamlessly incorporated their current setup with an online data storage system. The experimental evaluation involved the utilization of the Ethereum distributed ledger as the underlying infrastructure to assess the consumption of gas associated with the various functions implemented within the smart-contracts. The security and cost evaluation conducted in this study revealed that the system under consideration exhibited longevity.To automate the process of achieving a smart and efficient system for handling waste through the use of IoTs, they presented an approach for forecasting the likelihood of e-waste in [33]. Utilizing IoT smart-bins dispersed around the city, they constantly tracked their capacities for waste, gas levels, and metal levels. Machine Learning (ML) classification algorithms like Support-Vector Machines (SVM), Logistic-Regression (LR), Random-Forest (RF) and Linear-Regression were then used to evaluate their suggested solution. Using ML methods for categorization, they analysed the suggested approach's accuracy and runtime. The accuracy was 92.15% along with its time utilization which was 0.2 milliseconds according to the RF approach. In comparison with previous methods of classification, their suggested solution using the RF approach performed considerably better, according to this investigation. A smart approach for managing e-waste was suggested in [34]. To keep track of and oversee the e-waste gathering, sorting, and dumping processes, this framework made utilization of IoT and sensors devices. IoT components used in this framework frequently had sensors built that were capable of measuring and tracking the concentration of e-waste in a specific location. E-waste removal and collection was made more efficient with the assistance of real-time data provided through these sensors. The researchers used ML to identify different types of e-waste, which resulted in improvements in sorting plastics from metals, creating bio- charcoal as a result of burning, and developing solar power sources from recycled metals. They made the most of it while reducing its negative effects on the surroundings; additionally, it offered hope for long-term waste disposal and resources recovery. To further aid in the analysis of information patterns and trends, their suggested solution also made use of cloud-based systems. They were able to optimize our waste pickup routines and enhance the entire procedure by using the cloud-based Autoregressive-Integrated Moving-Average analytical approach, allowing an understanding of upcoming waste quantities.

Recycling Management Approaches using IoT and Blockchain

In this section, the existing recycling approaches utilizing the IoT and blockchain are discussed. The study in [27] delved into the examination of the pivotal function of the blockchain system within the effective management of e-waste throughout smart urban areas. The method had the potential to provide transparency, traceability, audit capabilities and immutability in a distributed, trusted, and safe way. The researchers engaged in a comprehensive discussion regarding the possible advantages that had emerged as a result of the integration of blockchain-based technology within the realm of managing waste. This discourse encompassed a wide range of uses and practical situations, such as the ability to facilitate real-time tracking and monitoring of waste, ensuring the accurate channelling of e-waste in accordance with e-waste disposal regulations, enabling effective utilization of e-waste resources, safeguarding the integrity of e-waste handling paperwork, and optimizing company management processes. The researchers presented an innovative structure that utilized blockchain-based contract technology to automate and streamline the vital functions involved in EWM within smart-cities. The researchers conducted a comparative analysis of the currently available waste management methods that utilized blockchain technology. This analysis focused on evaluating these options according to a set of significant factors. The Figure 5 depicts a recycling process facilitated by smart contracts, which are self-executing contracts that streamline transactions between participants. The process begins with waste collectors submitting a request to purchase recyclable materials, followed by depositing collateral in the form of cryptocurrency or tokens to ensure agreement fulfilment. Once the buy request is approved, waste collectors request shipment of the recyclables, and upon receipt, the recycling centre confirms it on the blockchain network. Subsequently, the waste collector initiates a request to release the deposited collateral, which is verified and approved by the recycling centre. Manufacturers can then purchase the recycled materials using smart contracts, and after shipping and confirming receipt on the blockchain, the transaction is complete. This system ensures secure, transparent, and efficient recycling transactions while automating tasks and fostering trust through immutable records. Potential advantages include better transparency, improved efficiency, reduced costs, and enhanced trust, though issues such as blockchain scalability and smart contract errors should be considered.

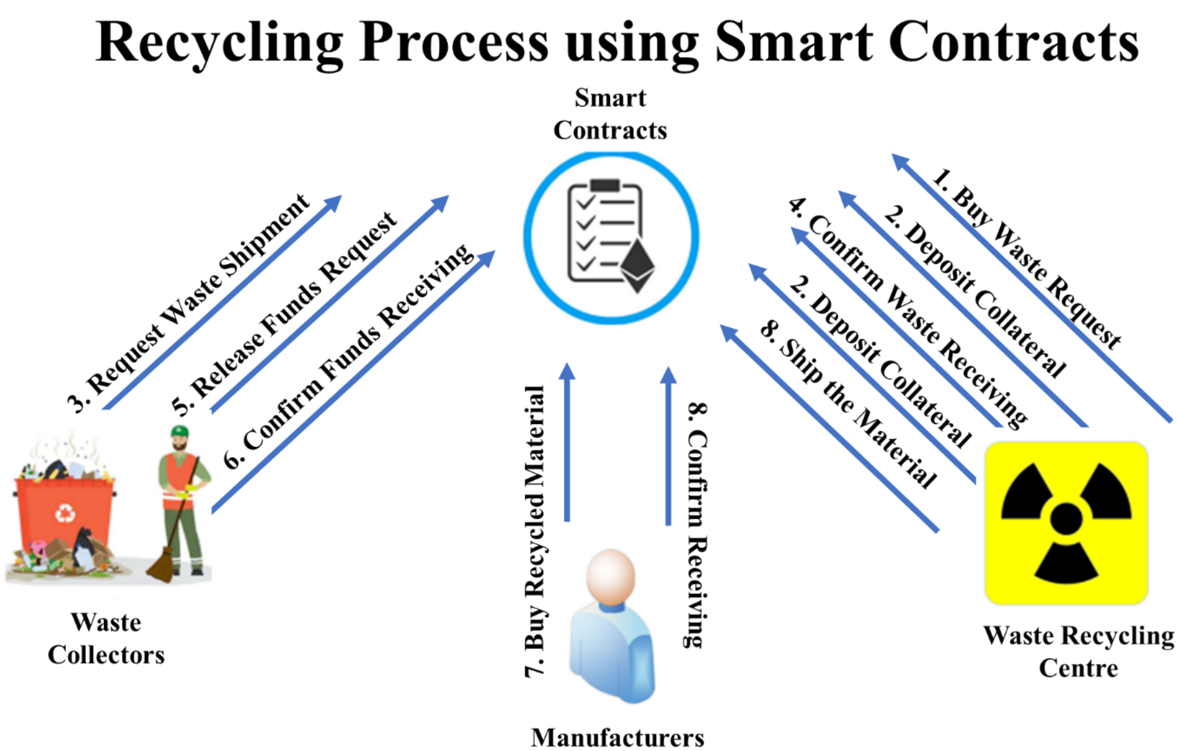

Figure 5. Recycling process using smart contracts [27].

The Figure 6 depicts a blockchain-based recycling process, illustrating a step-by-step breakdown. It begins with users depositing e-waste into a smart bin that shares data about the waste type, quantity, bin identification, and fullness level. The blockchain platform then facilitates communication for waste shipment requests, where a waste transporter accepts the request, picks up the e-waste, and updates its location on the platform. Upon receiving the e-waste, the recycling plant confirms receipt and issues tokens to the transporter, representing a digital record or form of payment. This process showcases blockchain's potential in offering a secure and transparent tracking system for recycling materials. Potential advantages include better transparency, enhanced efficiency, and efficient traceability. However, issues like scalability, technical expertise, and initial costs should be considered for widespread implementation.

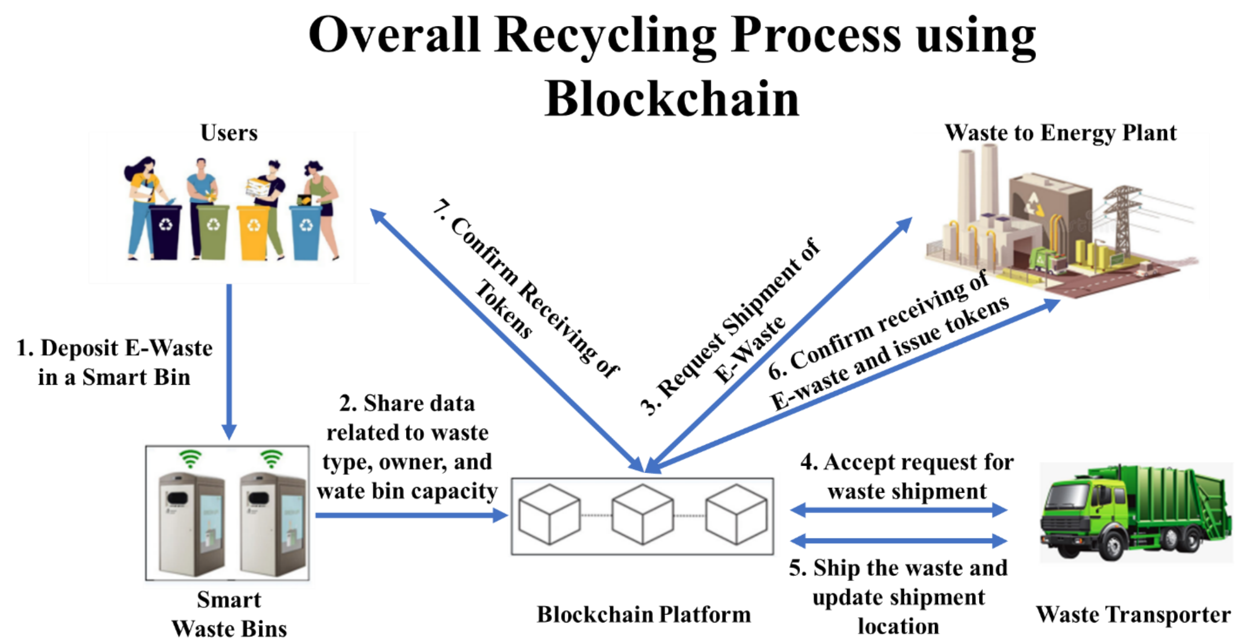

Figure 6. Overall Recycling Process using Blockchain [27].

In [35], introduced a pioneering methodology for e-waste recycling that leveraged blockchain technology and smart-contracts. The utilization of smart-contracts in the context of EPR for Electrical and Electronic Equipment's (EEEs) facilitated improved collaboration between various stakeholders, including manufacturers, buyers, sellers, and recyclers. This collaboration was achieved through the implementation of EWM systems, which leveraged the capabilities of smart-contracts to streamline and automate various processes involved in the management of EEEs. The implementation of this policy allowed authorities to exercise control over the process of e-waste gathering, reuse and recycling. Furthermore, the reduction of imbalance among both the regulated and unregulated industries was expected to result in heightened transparency across the entire process. In [36], a novel approach utilizing blockchain technology was introduced as an efficient method for EWM in the context of 5G networks. The suggested approach involved the implementation of a tracking system to monitor the generation of e-waste. Additionally, it aimed to incentivize individuals to properly manage and recycle their e-waste by offering rewards. These rewards would be provided through government-managed organizations that specialize in the environmentally-friendly disposal of e-waste. Consequently, a suggested collaboration approach was put forth to facilitate the execution of this strategy. This approach resulted in an important rise in job opportunities and the establishment of a well-structured system for managing unanticipated setups, which exhibited significant possibilities for future development.

In [37], they put forward a novel approach to address the challenges of e-waste Reverse-Logistics (RL) operations. Their suggested structure leveraged the blockchain system to ensure a secure, trust less and distributed environment. The researchers explored the possibility of utilizing the refurbishing/remanufacturing recovery approach for cell phones. In order to facilitate this method, they devised a sophisticated back-end sharing of information framework that operated independently and efficiently. This framework was built upon blockchain system and smart-contracts, which enabled comprehensive monitoring and documentation of all refurbishing/remanufacturing procedures. In order to showcase the practicality of their methodology, the researchers successfully constructed a fully operational collection of smart-contracts alongside a confined, internal blockchain network. In [38], provided a comprehensive examination of the possible ways and novel prospects which could be generated by the increased adoption of arising environmentally friendly materials and resource-effective production methods. A concise overview was provided regarding the historical progression in global waste polychlorinated biphenyls (PCBs) (WPCBs) management and the corresponding legal framework across the course of the last two decades. Additionally, an examination of the presently utilized substances in PCBs was carried out. The description of the health and environmental evaluations pertaining to the utilization of these substances in conjunction with PCBs was also expounded upon. A thorough examination of the current methods used for analyzing WPCB was also presented. In [39], the main objective of this study was to develop an innovative strategy for identifying recycling collaborators for WEEE (Waste-Electrical and Electronic-Equipment) with unknown weight data. The approach relied on Technique-for-Order of Preference-by-Similarity to Ideal-Solution (TOPSIS), an AI (Artificial-Intelligence) method, alongside a feed-back neural network. In order to address unpredictability associated with decision-making issues, an innovative idea called Complex-Pythagorean Fuzzy-Rough-Sets (CPyFRSs) was introduced. A novel and comprehensive distance metric was formulated to compute the relative weights of professionals and standards in a general way. The Dombi operators, characterized by their functioning variables, exhibited a remarkable degree of adaptability. Given the high degree of flexibility exhibited by the Dombi operation variables, a set of Dombi-Aggregation Operators (AOps) were developed to facilitate the establishment of an ideal Data Mining (DM) strategy. Furthermore, the approach that was established in this study was implemented in a practical setting to tackle the issue of selecting suitable partners for e-waste recycling. As a means of showcasing the efficacy and uniformity of the suggested method, a concise evaluation was conducted, comparing the suggested strategy with various pre-existing techniques.

SEGREGATION MANAGEMENT APPROACHES

The Figure 7 illustrates an overall process for e-waste segregation, which involves separating e-waste into different material categories. The process begins with users disposing of their e-waste into designated smart bins, likely equipped for collecting information on the type and quantity of e-waste deposited. This data is then analysed and uploaded to a web or mobile application for visualization and further analysis. Authorities can use this information to inform waste collection needs and dispatch personnel to pick up the segregated waste. Upon collection, the waste is delivered to a recycling facility for further segregation into materials like plastic, metal, glass, and organic waste. The figure suggests a potential role for smart bins in improving EWM by enhancing data collection, optimizing collection routes, and potentially increasing recycling rates. However, issues like initial costs, and technical expertise have to be addressed for widespread implementation and success in this approach. Hence, in the next subsections, the various existing methods used for segregation are discussed.

Figure 7. Process of E-Waste Segregation.

USING IOT DEVICES

In [40], presented an approach for EWM that utilized DL and IoT technologies. The approach presents a novel approach for e-waste sorting by leveraging the capabilities of a Convolutional-Neural-Network (CNN), which is a widely adopted DL framework. The approach additionally presented a novel architectural layout of an intelligent waste bin, which incorporated a microcontroller equipped with a multitude of sensors. The suggested approach utilized Bluetooth and IoT technology to facilitate the tracking of information. The IoT allowed for the remote management of real-time data coming from any location, whereas Bluetooth technology facilitated the tracking of short-term information by means of an Android app. In order to assess the effectiveness of the framework that was established, they conducted an evaluation of several key factors. These factors included the preciseness of waste label categorization, calculation of information from sensors, and the ease of use of the system's functionality as measured by the System-Usability-Scale (SUS). The results of these evaluations were carefully stated and determined. The rate of classification achieved by the suggested design, which was reliant on CNN, found to be 95.3125%. Additionally, the SUS score obtained for the design was 86%. Nevertheless, this intelligent system exhibited adaptability to domestic tasks through the implementation of real-time waste tracking. In [41], presented a novel approach for the development and deployment of a mobile robot. This robot was designed to effectively identify common e-waste by leveraging Transfer-Learning (TL) techniques. Furthermore, it was intended to function as a supplement to the pre-existing trash trucks utilized by municipalities. The robot was capable of autonomous movement along with was equipped with the ability to detect e-wastes. Once recognized, the robot utilized its arm-based move and storing process to segregate the detected materials. An identification system built around CNN was utilized to categorize the e-wastes, resulting in an accuracy of 96%. The work represented a pioneering initiative, particularly within the context of India, aimed at the collection and categorization of e-wastes originating from residential households and individuals. The method implemented in this study effectively decreased the need for untrained workers to engage in the potentially dangerous process. Furthermore, it was found that the implementation of this system resulted in a notable reduction of approximately 20% in expenses over a span of five years.

In [42], they put forward recommendations for households to ensure the sustainability of the IoT in the context of EWM. The purpose of this recommendations was to provide assistance for regulatory organizations and administrators in Malaysia with regards to their methods, preparation, creation, and execution of environmentally friendly household IoT EWM efforts. The current investigation employed an exploratory technique, utilizing a qualitative case-study methodology. The development of the recommendations was predicated upon the utilization of the integrated Sustainable-Waste-Management (ISWM) system. This recommendation played a significant role in supporting Malaysia's environmental sustainability goals by aiming to reduce greenhouse gas magnitude by 45% by the year 2030. In [43], a comprehensive structure was introduced that combined the principles of gathering and categorization processes for handling e-waste and smart technologies. This structure aimed to address the challenges associated with managing e-waste and intelligent technologies by providing a systematic approach to their gathering and categorization. The established standards encompassed three primary components, namely social, environmental, and economic standards. The study discovered several intelligent technologies, including automation, multiagent networks, self-sufficient devices, intelligent automobiles, data-driven methods, IoT, and cloud computing. The relative importance for every standards were determined through the application of the Fuzzy-Analytic-Network procedure (ANP), a widely used method for multi-criteria decision making. Subsequently, the ratings of smart methods, specifically those pertaining to collecting and categorizing of e-waste, were computed employing the Fuzzy Vlse-Kriterijumska-Optimizacija I-Kompromisno-Resenje (VIKOR) technique, which has been recognized for its effectiveness in handling complex decision problems. Upon careful examination, it was determined that the primary factor of utmost significance was the expense of gathering cost in the process of e-waste gathering and categorization. This was closely monitored by contamination control and prevention, and finally by holding/storage cost. Additionally, emissions of greenhouse gases during the gathering and categorization phases were also identified as a noteworthy consideration. The research findings indicated that self-sufficient devices have emerged as the most effective technological advances for the purpose of collecting and classifying e-waste. This follows closely by automation and intelligent automobiles, which also show promising potential in this domain.

An approach called Energy-Aware Fractional-Henry Gas-Optimization (FHGO) was suggested in [44] for the purpose of forecasting the best route that e-waste images should take. At the end of the phase of pre-processing, a median filtering technique was applied to remove characteristics such as Histogram-Oriented-Gradient (HOG), Local-Gabor Binary-Pattern (LGBP and Gray-Level Co-Occurence Matrix (GLCM). In addition, a deep CNN trained with an FHGO method was used for the e-waste categorization. FHGO was demonstrated by combining the method of fractional-calculus (FC) with the Henry-Gas Solubility-Optimization (HGSO) method. The suggested solution outperformed various current methods in terms of accuracy: 19.49% for DL, 18.05% for TensorFlow DL, 12.77% for Cuckoo Neural Network, and 7.89% for ML. In order to categorize e-wastes within an IoT-cloud system, a strong and efficient method was developed in [45] called Fractional-Horse Herd-Gas-Optimization (FrHHGO)-based Shepherd CNN (FrHHGO-based ShCNN). Here, IoT nodes gathered e-waste photos, all of which were subsequently saved in online storage spaces. The suggested FrHHGO method was subsequently employed to carry out the data-routing procedure. In addition, the e-waste categorization approach involved extracting and augmenting significant characteristics. A hybrid of Fractional-Henry Gas-Optimization (FHGO) and Horse-Herd Optimization approach (HOA), for e-waste categorization method was developed. With an average energy consumption of 0.301 J along with a latency of 0.666 s, alongside an ultimate accuracy of 0.950, sensitiveness of 0.934, and specificity of 0.967, their created approach surpassed multiple previous methods. Hence, in developing nations, the e-waste categorization method that was created improved the sustainability of the economy, society, and the environment because of FrHHGO-based ShCNN. Using ML approaches for air quality grade categorization, an intelligent waste handling approach was implemented in [46]. Additionally, this technique protects trash collectors from serious health problems brought on by breathing in toxic gasses released by the e-waste. The suggested method improved the efficiency of managing e-waste while reducing costs. It does this by sorting trash into three separate kinds: moist, metallic and dry. In the end, they were able to separate the state of the air and trash volume using ML approaches. Because it allowed for continuous reporting and evaluation of air-quality to appropriate municipalities, this technology proved helpful in enhancing the health of those live near waste-bins.

Using Artificial Intelligent Methodologies

In [47] introduced an AI approach aimed at analysing dangerous chemicals found in e-waste. The study also investigated the impact of these contaminants on the environment and health among people, in addition to the EWM strategies implemented in specific nations. In accordance with the findings of this study, it was imperative to establish eco-design structures within the EWM industry. This study entailed the development of structures that facilitated the correct processing, recycling, and reusing of e-waste employing secure approaches. Additionally, they also mentioned that it is crucial to ensure the correct disposal of e-waste by means of the utilization of appropriate procedures. Furthermore, it is essential to avoid the shipment of recycled electronics into developing nations. Lastly, their study concluded that efforts have to be made to raise the responsibility and accountability for managing the environmental impact of e-waste. In [48], they focused on the incorrect handling of e-waste, which is currently emerging as a significant concern for both the surroundings and the health of society. E-waste has witnessed a substantial surge in its contribution towards the overall municipal garbage flow worldwide, making it the fastest-growing section. Not only e-waste poses a significant challenge, but it also presents an opportunity due to its abundance of valuable metallic materials. These precious metals are capable of being extracted from the e-waste and reintroduced into the manufacturing process, allowing for their usage in various every day applications. Therefore, it is imperative to implement effective e-waste categorization and management practices in order to extract valuable substances from such e-waste. This research introduces a novel approach utilizing the NVIDIA Jetson-Nano advancement kit to construct a DL approach. The objective of this system was to precisely categorize e-waste materials into two separate groups: non-precious metals and precious metals, according to their presence in the e-waste substance. The prototype approach, which was been established, effectively separated e-waste with excellent precision and minimal time usage.

The development of CNN image-recognition method, was proposed in [49], aimed to achieve a high level of accuracy in classifying e-waste) into multiple types. A comprehensive image records consisting of four distinct categories of e-waste was meticulously curated, ensuring a diverse representation of the different categories. Additionally, an example setup was meticulously created to showcase the functionalities and capabilities of the dataset. The discussion revolved around the pre-processing of images, the choice of hyper-parameters, along with the accuracy evaluation of the CNN approach. The CNN approach that was created demonstrated an accuracy in training of 96.9% along with an accuracy for validation of 93.9%. Experiments were conducted to investigate the impact of various factors on the accuracy of the framework. Specifically, distinctive image dimensions, data augmentation through movement, and background noise removal strategies were explored as potential methods to enhance the strategy efficiency. In [50], surveyed the use of AI in various garbage-related domains, including but not limited to: intelligent bins, waste-sorting machines, prototypes for garbage generation, monitoring and tracking of garbage, plastic burning, transportation, destruction, illegal disposal, recovering resources, intelligent cities, handling effectiveness, savings in costs, along with safety for the public. With the use of AI, transportation was cut by 36.8%, expenses by 13.35%, and duration by 28.22%, according to the survey. With the help of AI, trash was identified and sorted having an accuracy of 72.8% to 99.5%. Enhancements to waste burning, carbon dioxide calculation, and energy utilization were achieved through the integration of AI with chemical testing. Additionally, they detailed how smart-city garbage disposal systems might benefit from AI in terms of improved effectiveness and decreased costs.

A smart EWM solution was created and developed utilizing the IoT and object identification utilizing DL in [51]. In order to identify objects in e-waste, this research used three cutting-edge object identification approaches: YOLOv8s, YOLOv5s, and YOLOv7-tiny. A mean-average precision @50 of 72% and a mean-average precision @50-95 of 52% were the best findings obtained by YOLOv8s. Promoting greener city activities and encouraging long-term viability this novel method presented the opportunity for improved management of e-waste. In [52] presented a device designed for the purpose of segregating waste into various components. The device utilized an intelligent object identification method, called the ConvoWaste method, which was based on the principles of depp CNN (DCNN) and methods for image processing. The present study focused on the application of image-processing and DL approaches for the precise classification of e-waste. Furthermore, a servo motor-based structure was employed to facilitate the placement of all the identified waste into the appropriate bins. The aforementioned device was equipped with ultrasonic detectors positioned within every bin, which allowed for the detection of waste levels. This information was then communicated to the accountable responsibilities through a dual-band GSM-based communication protocol. This feature enabled timely notifications about the need to empty bins that have reached their capacity with trash. The entire thing was managed remotely by means of an Android application, allowing for the automated disposal of separated trash in a specified location. The utilization of this system had the potential to facilitate the reuse and recycling for materials that were originally intended to be discarded as waste. By harnessing natural assets, these assets could be transformed into fresh items that are suitable for use. Therefore, the system facilitated the fulfillment of the requirements of the sustainable economy by promoting efficient use of resources and extraction. Ultimately, the system was designed to offer amenities at a reduced cost while achieving an increased degree of accuracy, leveraging the advancements in AI technology. The ConvoWaste DL approach achieved an impressive accuracy rate of 98%.

Limitations

Reference	Limitations
[27]	The framework lacks detailed consideration of scalability issues as blockchain technology scales up to manage large-scale waste management operations.
[28]	The proposed waste tracking solution may face challenges related to integration of blockchain-technology into existing EWM infrastructures, including compatibility issues and cost concerns.

[29]	While the smart waste management approach using TensorFlow and LoRa shows promise, it may encounter restrictions in terms of scalability and adaptability to different waste management scenarios.
[30]	The DL-based waste segregation system may not adequately address the challenges of real-time monitoring and efficient waste collection on a larger scale.
[31]	The systematic review on EPR may lack practical implementation strategies and solutions for addressing EPR challenges effectively in waste management.
[32]	The blockchain-based IoT approach for tracking e-waste post-production procedures may not fully address the complexity of integrating blockchain into existing waste management workflows.
[33]	The IoT-based EWM approach reliance on ML categorization approach may face challenges in accurately predicting e-waste possibilities and optimizing waste management processes.
[34]	While the smart EWM system shows promise, issues regarding data analysis, scalability, and integration with existing EWM infrastructure need to be addressed.
[35]	The proposed e-waste recycling approach using smart contracts may face challenges related to regulatory compliance, stakeholder coordination, and scalability for widespread adoption.
[36]	The EWM approach for 5G scenario may face challenges related to infrastructure readiness, regulatory frameworks, and stakeholder collaboration.
[37]	The blockchain-based framework for electrical devices RL activities may encounter challenges in terms of industry-wide adoption, interoperability, and scalability.
[38]	The overview of potential solutions for WPCBs processing may lack specific implementation strategies and actionable recommendations for sustainable waste management practices.
[39]	The proposed method for determining WEEE recycling partners may face challenges related to data accuracy, stakeholder engagement, and scalability.
[40]	The EWM system relied on DL and IoT may encounter challenges related to data privacy, algorithm accuracy, and system reliability in real-world environments.
[41]	While the mobile robot for e-waste segregation shows promise, challenges such as operational efficiency, maintenance costs, and scalability need to be addressed for widespread deployment.
[42]	The Sustainable IoT EWM guideline may lack detailed implementation strategies, regulatory frameworks, and stakeholder engagement plans for effective adoption.
[43]	The framework integrating collection and classification mechanisms may face challenges in terms of technological integration, data accuracy, and stakeholder collaboration.
[44]	The proposed path prediction algorithm may face challenges related to real-time data processing, algorithm accuracy, and scalability for different waste management scenarios.
[45]	The FrHHGO-based ShCNN method for e-waste categorization may encounter challenges in terms of energy efficiency, algorithm complexity, and scalability for large-scale implementation.
[46]	The Smart EWM using ML approaches may face challenges in real-time data analysis, hardware reliability, and stakeholder engagement for sustainable implementation.
[47]	The AIT for hazardous pollutants analysis may lack comprehensive solutions for effective waste management policies, stakeholder coordination, and regulatory compliance.
[48]	The DL model for e-waste segregation may face challenges related to data accuracy, algorithm scalability, and practical implementation in waste management facilities.

[49]	The CNN image-recognition algorithm for e-waste classification may encounter challenges in terms of algorithm robustness, data variability, and real-world applicability.
[50]	The review of AI applications in waste management may lack detailed case studies, scalability assessments, and industry-wide adoption strategies for AI technologies.
[51]	While the smart EWM system using IoT and DL shows potential, challenges such as algorithm accuracy, data privacy, and regulatory compliance need to be addressed.
[52]	The machine for waste segregation may face challenges related to hardware reliability, maintenance costs, and scalability for widespread deployment in waste management facilities.

Issues and Challenges

The following issues and challenges were identified from the above literature survey

- Complexity of Integration: Integrating IoT sensors, blockchain technology, and smart contracts into a cohesive EWM system can be complex and require specialized technical expertise.
- Scalability: Scaling up the e-waste collection and recycling framework to handle large volumes of e-waste across different regions can be challenging, especially regarding network scalability for IoT devices and blockchain transactions.
- Interoperability: Ensuring interoperability between different IoT devices, sensors, and blockchain platforms from various manufacturers is essential for seamless data exchange and system functionality.
- Cost of Implementation: Developing and deploying an integrated EWM system using IoT and blockchain technologies can involve significant upfront costs for hardware, software, infrastructure, and personnel training.
    - Initial Investment: The initial investment required for setting up IoT sensors, smart bins, blockchain infrastructure, and AI systems for e-waste collection and recycling can be substantial.
    - Operational Costs: Ongoing operational costs include maintenance, monitoring, software updates, data storage, and personnel training, which contribute to the overall cost of EWM.
    - Transportation Costs: Transporting e-waste from collection points to recycling facilities incurs additional costs, especially for long-distance transportation or specialized handling of hazardous materials.
    - Recycling Technology Costs: Implementing advanced recycling technologies for different types of e-waste, such as pyrolysis or chemical processes, can be expensive but essential for sustainable recycling practices.
    - Compliance and Certification Costs: Obtaining certifications, licenses, and complying with environmental regulations may involve fees and ongoing expenses for e-waste recycling facilities.

The solutions for enhancing the EWM are as follows

- Smart Object Detection: AI-powered object detection models, such as CNNs, can accurately identify and classify different types of e-waste materials based on visual cues captured by IoT-connected cameras.

- Data Analytics: IoT sensors can collect real-time data on e-waste fill levels, material composition, and other relevant parameters, which AI algorithms can analyze to optimize waste segregation processes.
- Automation: AI-driven automation can streamline waste sorting and categorization tasks, reducing manual labour and improving efficiency in e-waste recycling facilities.
- Predictive Maintenance: IoT sensors can monitor the condition of recycling equipment, and AI algorithms can predict maintenance needs, minimizing downtime and operational disruptions.
- Decision Support Systems: AI-based decision support systems can analyse vast amounts of data to provide insights into optimal recycling strategies, resource allocation, and waste management policies.
- Quality Control: AI algorithms can perform quality control checks on recycled materials to ensure they meet industry standards and are suitable for reuse in manufacturing processes.
- Integration with Blockchain: AI and IoT systems can integrate with blockchain technology to create transparent and auditable records of e-waste collection, recycling processes, and supply chain transactions, enhancing traceability and accountability.

By leveraging AI and IoT technologies in EWM, organizations can improve the accuracy, efficiency, and sustainability of waste segregation, leading to better resource recovery and environmental conservation. Hence, in the next section, a novel lightweight and efficient decision support system is presented for solving the issues identified from the previous works.

Proposed Approach

Using the distributed ledger technology (blockchain), the IoT, and artificial intelligence (AI), this work presents a lightweight and efficient decision support system for managing e-waste which has been shown in Figure 8.

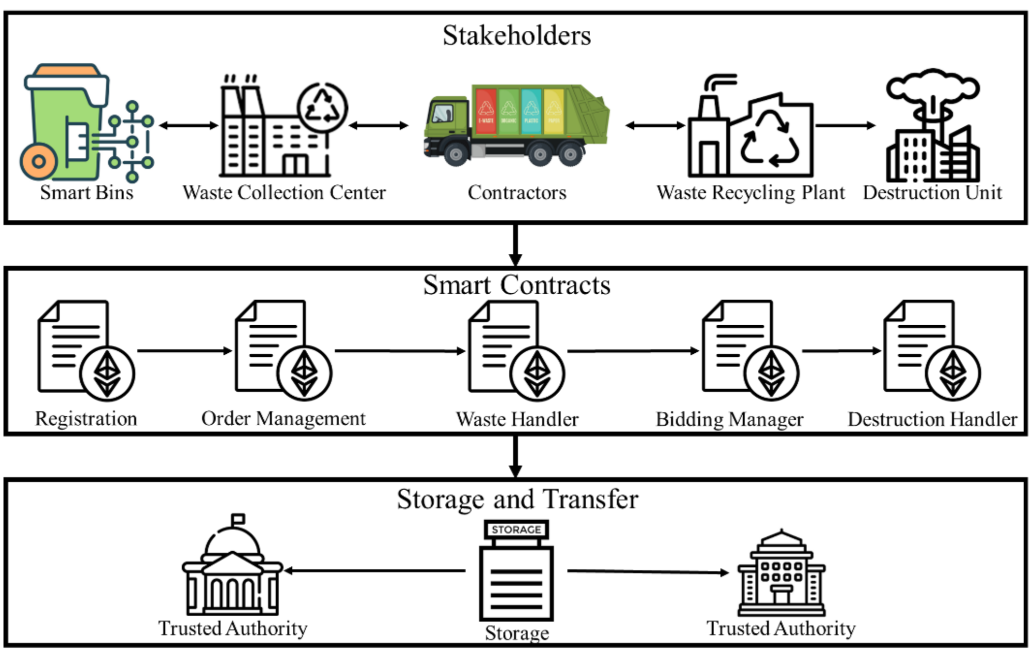

Figure 8. Lightweight and Efficient Decision Support System.

The presented Figure 8 has three sections, where in the first section, the stakeholders are present. In the second phase, smart contracts (trust, blockchain) are used for connecting the different stakeholders. Finally, in the last phase, the storage and transfer of information among the different trusted authority is present. The detailed explanation of the Lightweight and Efficient Decision Support System is given below.

- User: Discards electronic waste (e-waste) into designated smart bins.
- Smart Bins:
  - Classifies the type of e-waste deposited using built-in sensors or RFID tags.
  - Stores data on the type and amount of waste deposited.
  - Shares this data with the trusted authority through a secure communication channel.
  - Notifies the trusted authority when the bin is full and requires emptying.
- Waste Collection Centre:
  - Get initiation to collect data from smart bins or trusted authority.
  - Selects contractors to collect the data using order management contracts.
  - Receives e-waste collected by contractors.
  - Sorts the e-waste into different categories for further processing.
  - Initiates bidding for e-waste destined for recycling through a bidding process managed by smart contracts.
  - Selects a destruction plant for e-waste that cannot be recycled.
  - Shares data on e-waste sorting and destination with the trusted authority.
- Waste Collection Contractor:
  - Responds to waste collection requests issued by the waste collection centre or trusted authority.
  - Bids on e-waste collection contracts through a bidding process managed by smart contracts.
  - Collects e-waste from designated smart bins upon being awarded a contract.
  - Transports the collected e-waste to a waste collection centre.
  - Shares data on e-waste collection with the trusted authority.

- Destruction Plant:
  - Receives e-waste designated for destruction from the waste collection centre.
  - Destroys the e-waste using appropriate methods that comply with environmental regulations.
  - Shares data on e-waste destruction with the trusted authority.

- Trusted Authority:
  - Receives data from smart bins regarding the type, amount, location, and fullness level of the deposited waste.
  - Stores this data on a secure blockchain ledger.
  - Monitors the data to identify waste collection needs and potential inefficiencies in the system.
  - Triggers waste collection based on the data received from smart bins.
  - Manages contracts between waste collection contractors and destruction plants.

- Smart Contracts:
  - Manage the bidding process for e-waste collection and transportation between waste collection contractors and the trusted authority.
  - Manage the bidding process for e-waste recycling between waste collection centres and destruction plants.
  - Securely store and manage contracts between all participants in the system.
  - Facilitate automated payments between contractors, destruction plants, and the trusted authority based on the terms of the contracts.

The different contracts are as follows

1. Registration Smart Contract:
   - Manages the registration process for users.
   - This contract requires users to provide relevant information for verification and ensure they meet specific criteria to participate.
   - It also stores user information securely on the blockchain ledger.

2. Order Management Smart Contract:
   - Tracks the movement and processing of e-waste throughout the system.
   - This contract receives data from smart bins regarding the type and amount of e-waste deposited.
   - It triggers the creation of "orders" for waste collection based on data received from smart bins and instructions from the trusted authority.
   - The order includes details like the location of the full bin, and type of e-waste.
   - This contract also tracks the progress of the order as the e-waste is collected, transported, sorted, and processed.

3. Waste Management Smart Contract:
   - This contract encompasses functionalities related to various waste management activities, potentially including:
     - Waste Segregation Tracking: Tracks the sorting and categorization of e-waste at the collection centre.
     - Recycling Management: Manages the bidding process for e-waste designated for recycling, facilitating selection of a destruction plant, and potentially tracking the recycling process.
     - Destruction Management: Manages the selection of a destruction plant for e-waste that cannot be recycled, and tracks the destruction process to ensure compliance with regulations.

4. Bidding Management Smart Contract:
   - Facilitates a secure and transparent bidding process for:
     - Waste collection contracts between waste collection contractors and the trusted authority.

        - Recycling contracts between waste collection centres and destruction plants.
    - This contract allows contractors/plants to submit bids, evaluates them based on pre-defined criteria (e.g., cost, distance, sustainability practices), and automatically selects the winning bid.
    - It ensures secure transactions by holding funds in escrow until specific milestones are met (e.g., e-waste collection completion).

5. Data Destruction Unit Management Contract:
    - Manages the registration and verification of destruction plants within the system.
    - This contract defines specific requirements for destruction plants to ensure they comply with environmental regulations and secure data destruction practices.
    - It also facilitates secure communication between the waste collection centre and the destruction plant regarding the type and amount of e-waste for destruction.

These smart contracts work together to automate various processes in the waste management system, enhancing transparency, efficiency, and security. They streamline communication, facilitate secure transactions, and ensure all participants adhere to the established rules. A complete overview above explained proposed approach is presented using the activity diagram presented in Figure 9.

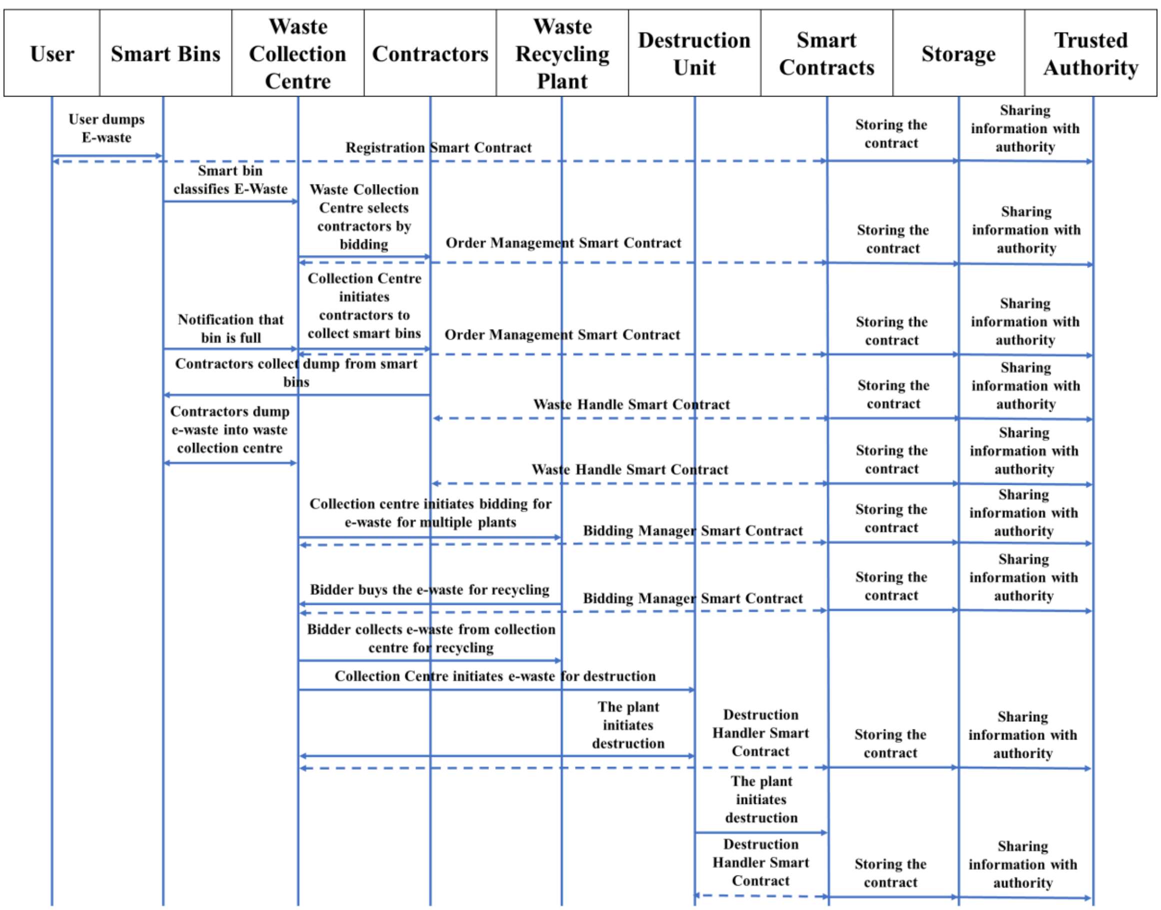

Figure 9. Activity diagram of proposed approach.

CONCLUSION

This survey delves into the intricate realm of e-waste and its profound impact on the global landscape. It explores how the exponential growth of e-waste is affecting various facets of the world, including environmental sustainability, resource depletion, and public health concerns. Furthermore, the survey delves into the innovative utilization of IoT and blockchain technologies in revolutionizing EWM practices. Through an extensive literature survey, the survey investigates existing methodologies and technologies employed in e-waste collection, tracking, recycling, and segregation. Despite the advancements in these areas, this work critically analyses the limitations inherent in current approaches, ranging from scalability issues to regulatory compliance challenges. Building upon the identified limitations and challenges, the work delineates specific issues and challenges that hinder the seamless integration of IoT and blockchain in EWM. To address these challenges and pave the way for enhanced efficiency and sustainability, this work proposes a novel lightweight and efficient decision support system. This system aims to streamline EWM processes, optimize resource utilization, reducing cost, and ensure regulatory adherence, thus fostering a more sustainable and responsible approach to EWM on a global scale.

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