

Bridging the gap between e-waste producers and recyclers: a digital approach

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Keywords: E-waste management system, Middleware platform, Digital waste collection, Recycling transparency, Sustainable

Abstract

E-Waste is a rapidly growing environmental problem, where pollution and inappropriate disposal for praise of resources contributes. Traditional e-waste management systems often lack transparency and efficiency, making it difficult for users to take responsibility for disposing of electronic devices. This study introduces a middleware-based e-waste management system that combines users and certified recyclers to ensure proper collection and processing. The platform developed by Mern Stack Technology allows users to submit e-waste enquiries, submit recyclers to inspect elements, and dynamically adapt pricing before payment. The system integrates real-time tracking, verified recycling participation, and secure transactions, improving transparency and preventing unauthorized disposal. By using digital solutions, the platform improves sustainable waste management, promotes responsible e-waste disposal, and ensures fair pricing. This study highlights the role of technological operation platforms in optimizing e-waste recycling processes, contributing to ecological sustainability.

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1 Introduction

1.1 Definition and Environmental Impact of E-waste

Electronic waste or e-waste refers to electrical or electronic devices such as smartphones, laptops, televisions, and home appliances. Fast technological advances and reduced product lifespans have made E-Waste the fastest growing waste stream in the world [1]. In contrast to traditional waste, electronic waste consists of hazardous elements like lead, mercury, cadmium, and brominated flame retardants. In landfills and disposal of informal recycling methods, these substances seep into environments polluting ecosystems and affect human health [3]. However, e-waste also contains valuable materials such as gold, silver, palladium and rare earth metals. This can be recovered through sustainable recycling, reducing the demand for raw materials acquisition and minimizing environmental damage.

1.2 Global and Regional E-Waste Statistics

The growing e-waste crisis is due to global statistics. According to Global E-Waste Monitor 2020, the world achieved 53.6 million tonnes (MT) e-Waste waste in 2019, with this number expected to reach 74.7 MT by 2030 [4]. What's shocking is that just 17.4% of E-Waste has been officially recorded and recycled, while the rest has been unloaded, burned or treated by an informal recycling network that is missing from proper safety measures [5].

Regional Asia, Asia produced the highest amount of electricity waste, with contributions of about 24.9 mt in 2019 followed by Europe (12 mt), America (13.1 mt), Africa (2.9 mt), Oceania (continued by 0.7 mt) [4]. Europe has the highest per capita waste generation, but has the highest recycling rate (42.5%), while Africa has the lowest (0.9%) due to insufficient waste management infrastructure [6]. In developing countries, informal sectors are often unstable and environmentally harmful, such as extracting valuable metals with unstable and environmentally harmful technologies such as acid baths and burns. plays an important role in technology [7].

1.3 Challenges in Existing E-Waste Management Systems

Despite various initiatives for e-waste treatment, there are several challenges. One of the main issues is lack of awareness, as many people are not informed of the correct disposal methods and environmental hazards of e-waste management. This means that critical parts of discarded electronics are not properly addressed, increasing contamination and health risks. Furthermore, limited collection infrastructure exacerbates the problem as accessible waste points or organized collection services in many regions are inaccessible. Countries where electricity waste is often treated by unregulated channels. Informal recyclers use uncertain methods to extract valuable materials, expose them to dangerous chemicals, and contribute to contamination. Furthermore, formal recycling is often expensive and prevents recycling from implementing eco-

friendly processes, so economic obstacles prevent the introduction of sustainable recycling practices. , including illegal dumping and unauthorized processing. It is difficult to ensure that e-waste reaches certified recycling, as many platforms do not offer tracing mechanisms. Addressing these challenges requires a structured, technology-driven approach that promotes responsive disposal, improves detection efficiency, and ensures ethical recycling practices.

1.4 Research Objective and Contribution

To address these issues, this study proposes a intermediary-based electrical waste management system that acts as an intermediary between users and certified recycling. In contrast to traditional disposal services, the system does not deal with e-waste, but offers a digital platform that allows licensed recycling to combine responsible disposal. By closing the gap between users and recyclers, the platform ensures that E-Waste is processed through the correct channels and reduces the risk of inappropriate disposal. - Uses an interface that allows users to submit waste disposal inquiries. This eliminates the inconvenience of searching that promotes proper recycling facilities and responsible disposal practices. Additionally, the platform provides fair pricing by inspecting elements, offers based on terms, dynamically demanding demand and material value, and users can recycle or overpay low wages. Prevents the situation. Time tracking, reviews of recycling participation, and ethical disposal of electricity waste. Users can monitor the condition of waste electronics and reduce the likelihood of illegal dumping or unethical recycling practices. Additionally, the system helps reduce environmental impact by promoting proper recycling methods, minimizing landfill waste, and encouraging recyclers to use sustainable practices . Waste management. The system uses the latest web technologies to optimize interactions, automate processes, and provide a seamless user experience. This approach creates structural and responsible methods for E-Waste treatment that not only contributes to a cleaner environment, but also benefits both individuals and ecosystems.

2. Literature Review

2.1 Overview of E-waste Management

With the increasing number of electronic devices disposal, E-Waste Management has been a critical challenge around the world. Research shows that the global generation of E-Waste reached 53.6 million tonnes in 2019, with only 17.4% being officially recycled [8]. Improper handling of e-waste contributes to pollution and health risks in developing countries, particularly those dominated by informal recycling methods [9].

2.2 Traditional vs Modern Approaches to E-waste Management

Traditional E-waste management systems primarily involve landfilling, burning and informal recycling. Landfilling are the most common disposal method, but lead to the environmental manifestation of hazardous substances like

lead, mercury, and cadmium [10]. Another method, combustion, reduces the amount of waste, but fills up harmful gases such as dioxins and furans that contribute to air pollution [11]. and digital solutions. Many developed countries have implemented EPR guidelines that denounce manufacturers for managing e-waste disposal [12]. Furthermore, digital platforms have been developed to promote e-waste collection, improve traceability, combine recycling with consumers, reduce illegal dumping, and ensure responsible recycling [13].

2.3 Digital Solutions For E-waste Management

The latest research findings highlight the integration of Internet of Things, Artificial Intelligence, and blockchain in e-waste management to improve transparency and efficiency. AI-controlled image identification technology plays an important role in improving e-waste regulations by automating the identification and classification of e-waste. This automation improves recycling efficiency by reducing manual tasks, improving the accuracy of material separation, ensuring that reusable components are effectively recovered [15]. Furthermore, blockchain technology was proposed as a solution to pursue e-waste from waste to recycling to ensure accountability and transparency throughout the process. By maintaining an unchangeable main register, blockchain prevents illegal exports, unethical disposal practices, and fraudulent disposal of electricity waste, and improves trust in recycling ecosystems [16]. Despite major obstacles like ineffective selection processes and a lack of traceability, these digital solutions help manage e-waste more effectively and responsibly.

2.4 Identified Gaps in Existing Systems

Despite advances in e-waste management, there are several challenges that hinder efficient disposal and recycling processes. The main issue is the lack of consumer awareness as many people still refuse to abolish regular trash due to limited knowledge of the correct disposal methods [17]. Furthermore, limited transparency on existing platforms prevents users from tracking discard elements in real time, leading to unethical recycling practices and unauthorized use of e-waste [18]. Another important challenge is that most digital platforms do not offer dynamic pricing based on the actual state of disposal devices, which often lead to conflicts between users and recyclers [19]. To close these gaps, this study proposes a middleware-based electrical waste management system that ensures fair pricing, validated recycling participation, and safe transactions. By integrating real-time tracking and dynamic pricing adjustments, the proposed platform will increase transparency, improve efficiency in e-waste disposal and promote responsible recycling practices.

3 Methodology

In this section, we elaborate on the research design for the planned middleware-based e-waste management system and its system architecture, workflow, data collection, and validation approach. We aim to create a simple and effective

platform that pairs users with recyclers, while guaranteeing fair pricing and transparent exchanges.

3.1 System Architecture

The platform will be built using MERN Stack to ensure efficiency and scalability.

- MongoDB stores e-waste that user listed, recycler details and transaction history.
- Express.js manages backend operations and API requests.
- React.js provides responsive front end for users and recyclers.
- Node.js provides run time environment and ensures server side processing and handles business logic.

This system includes:

- User dashboard which allows users to post their e waste disposal requests.
- Recycler dashboard which allows recyclers to accept request and adjust prices according to inspections.
- Transactions and Tracking modules which tracks transactions and status of e-waste collection.

3.2 Workflow

The process follows these steps:

1. User submits info about their e-waste like type, condition and pickup location.
2. Recycler review request and gives an offer.
3. Upon agreement, recyclers goes to pick up location to review item and set final price.
4. Then recycler collects item for disposal.
5. Transaction logged for future reference.

3.3 Data Collection

In this platform, data is collected from:

- User requests
- Recycler updates
- System logs

3.4 Validation Approach

To ensure security and efficiency this platform implements:

- User and recycler verification
- Secure transactions
- Tracking and status updates
- User feedback mechanism

By keeping this system simple, this platform aims to bridge gap between users and recyclers by acting as a middleware promoting e-waste disposal without much complexity.

4 Proposed Solution

The proposed solution is middleware based e-waste management system which connects users with verified recyclers. It ensures fair pricing, secure transactions and responsible disposal. Unlike traditional services, this doesn't directly process e-waste but acts like an intermediary

between consumers and recyclers ensuring seamless communication.

4.1 Addressing Key Challenges

The system is designed to solve current problems of e-waste management:

Streamlined Disposal Process: A user-friendly interface enables users to request the disposal of e-waste.

Dynamic Price Model: Instead of vendors offering fixed prices, recyclers inspect items for condition and provide a dynamic offer, which the user can then accept or decline.

Verified Recycler Network: A guarantee that only authorized recyclers can be accessed—the way to dispose responsibly.

User Participation Until Handing Over: Unlike complex tracking systems, the user's task is finished the moment a recycler takes the object off their hands and doesn't involve real-time tracking.

4.2 Role of the platform

For Users: This platform serves as a centralized point where users can list their unwanted electronics items and get fair price.

For Recyclers: Recyclers can utilize this system by browse listings and can make offers to buy them.

For Admins: Admins monitors various activities of this platform like recycler verification, system performance and user feedbacks.

4.3 Secure and Transparent Transactions

- Users and recyclers should verify their credentials before accessing platform. This prevents unauthorized access.
- Transactions occurs securely through this platform after price is finalized.
- Users and recyclers can view their past transactions which promotes transparency and trust.

4.4 Scalability and Future Expansion

MERN Stack Development in a Module way: Future scalability is built into the architecture — adding more partnerships with recyclers or sophisticated analytics is something to consider in the future.

Practicality of Application: Adhering to the principle of selective change enables the satisfaction of practical application across areas such as e-waste handovers, and possibly impact tracking or automated recommendations for disposal in further iterations of the system.

5 Expected Results and Feasibility

5.1 Expected Results

Greater Responsible E-Waste Disposal: The easy-to-use platform will encourage people to dispose of electronic waste responsibly rather than discarding them indiscriminately.

Smarter User-Recycler Matching: The user will be directly matched with an authorized recycler to eliminate delay and manage e-waste better.

Dynamic Pricing Adjustment Mechanism: A dynamic pricing adjustment mechanism to be introduced by recycler inspection will enhance the fairness of e-waste pricing and avoid e-waste being undervalued or overpriced.

Secure Transactions: By ensuring secure payment processing, the solution will also reduce the potential risk of fraud and other unauthorized transactions.

Simplified workflow: Users do not need to execute complex processes to join in e-waste management as they have to just fill a request and hand over the items to recyclers.

5.2 Feasibility

5.2.1 Technical Feasibility

The proposed e-waste management system will be built using technologies like MongoDB, Express.js, React.js and Node.js, and is technically viable. This is often used in scalable web applications. The system requires a stable database to store user and recycler information, transaction history and element lists. It can be provided to ensure accessibility and performance using cloud hosting services such as AWS, FireBase, and Vercel. The platform acts as middleware without actual tracking or direct recycling processes, allowing for medium resource implementations as technical requirements remain minimal. Additionally, basic authentication and review mechanisms (such as OTP-based reviews) are integrated to ensure the security of the platform.

5.2.2 Economic Feasibility

From a financial perspective, the project is economically viable as it does not require high infrastructure costs. Development costs are reduced by using open-source technologies, and cloud services with free-tier options can be leveraged initially. Monetization can be achieved through listing fees for recyclers, premium features, or partnerships with e-waste collection agencies, ensuring a sustainable business model. The platform eliminates the need for physical infrastructure for waste collection, making it more cost-effective than traditional e-waste management solutions.

5.2.3 Operational Feasibility

Operationally, the system is a user-friendly, ensuring smooth interaction between the user and the recycle. With the platform, users submit e-waste details, submit recyclers to confirm and adapt pricing before completing the transaction, ensuring secure communications through communication

between the two parties You can do it. The process remains complex and reduces operational complexity as users only participate until the recycler acquires the elements. The middleware model simplifies waste collection logistics and eliminates unnecessary intermediaries with direct-connected and verified recyclers. Users and recycling require minimal training, making it easier to accept.

6 Conclusion and Future Scope

6.2.1 Conclusion

Electronic waste management is a critical environmental challenge that requires efficient and transparent solutions to minimize adverse effects. This study presents a middleware-based electronic waste management system that combines users with certified recyclers to ensure proper disposal and responsible recycling. By using a MERN stack-based digital platform, the system simplifies e-waste collections, improves transaction transparency, and ensures fair pricing through recycler inspections. The digital nature of the platform increases accessibility and encourages users without logistical obstacles.

6.2.2 Future Scope

While the current system can provide efficient solution, several improvements and enhancements can be considered for future:

- Platform can be expanded to more regions
- A mobile application can be developed
- Advanced verification for recyclers
- Data analytics can be integrated to provide valuable insights into e-waste.
- Reward mechanism like discounts for users who actively participate in e-waste disposal.
- Collaboration with NGOs and other businesses to enhance awareness and managing e-waste on large scale.

7 References

- [1] Forti, V., Baldé, C. P., Kuehr, R., & Bel, G. (2020). The Global E-Waste Monitor 2020. United Nations University.
- [2] Robinson, B. H. (2009). "E-waste: An assessment of global production and environmental impacts." *Science of the Total Environment*, 408(2), 183-191.
- [3] Garlapati, V. K. (2016). "E-waste in India and developed countries: Management, recycling, business, and biotechnological initiatives." *Renewable and Sustainable Energy Reviews*, 54, 874-881.

- [4] Baldé, C. P., Forti, V., Gray, V., Kuehr, R., & Stegmann, P. (2017). *The Global E-Waste Monitor 2017*. United Nations University.
- [5] Perkins, D. N., Brune Drisse, M. N., Nxele, T., & Sly, P. D. (2014). "E-waste: A global hazard." *The Lancet Global Health*, 2(12), e512-e513.
- [6] Widmer, R., Oswald-Krapf, H., Sinha-Khetriwal, D., Schnellmann, M., & Böni, H. (2005). "Global perspectives on e-waste." *Environmental Impact Assessment Review*, 25(5), 436-458.
- [7] Schmidt, C. W. (2006). "Unfair trade: E-waste in Africa." *Environmental Health Perspectives*, 114(4), A232-A235.
- [8] Forti, V., Baldé, C. P., Kuehr, R., & Bel, G. (2020). *The Global E-Waste Monitor 2020*. United Nations University.
- [9] Garlapati, V. K. (2016). "E-waste in India and developed countries: Management, recycling, business, and biotechnological initiatives." *Renewable and Sustainable Energy Reviews*, 54, 874-881.
- [10] Robinson, B. H. (2009). "E-waste: An assessment of global production and environmental impacts." *Science of the Total Environment*, 408(2), 183-191.
- [11] Perkins, D. N., Brune Drisse, M. N., Nxele, T., & Sly, P. D. (2014). "E-waste: A global hazard." *The Lancet Global Health*, 2(12), e512-e513.
- [12] Widmer, R., Oswald-Krapf, H., Sinha-Khetriwal, D., Schnellmann, M., & Böni, H. (2005). "Global perspectives on e-waste." *Environmental Impact Assessment Review*, 25(5), 436-458.
- [13] Baldé, C. P., Forti, V., Gray, V., Kuehr, R., & Stegmann, P. (2017). *The Global E-Waste Monitor 2017*. United Nations University.
- [14] Zhang, L., Xu, Z., & He, Y. (2017). "Design and application of an intelligent monitoring system for e-waste recycling based on IoT." *Journal of Cleaner Production*, 164, 1031-1038.
- [15] Wang, C., & Lin, H. (2020). "AI-assisted automatic sorting of electronic waste for improved recycling efficiency." *Sustainable Materials and Technologies*, 25, e00190.
- [16] Yildirim, U., & Guney, B. (2021). "Blockchain applications in waste management: A review and future directions." *Waste Management*, 125, 362-374.
- [17] Schmidt, C. W. (2006). "Unfair trade: E-waste in Africa." *Environmental Health Perspectives*, 114(4), A232-A235.
- [18] Kumar, A., Holuszko, M., & Espinosa, D. C. (2017). "E-waste: An overview on generation, collection, legislation, and recycling practices." *Resources, Conservation and Recycling*, 122, 32-42.
- [19] M. T., Huda, N., & Baek, K. (2021). "A circular economy approach to e-waste management: Current challenges and future outlook." *Journal of Cleaner Production*, 292, 126068.