E-Waste Tracker: A Platform To Monitor E-Waste From Collection To Recycling

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Sara Artang
Norwegian University of Science and Technology

Afshin Ghasemian

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Sara Artang
Ibrahim A. Hameed*
Department of ICT and Natural Sciences
Norwegian University of Science and Technology
Larsgårdsvegen 2, 6009 Ålesund, Norway

Afshin Ghasemian
Crayon
Gullhaug Torg 5, 0484 Oslo, Norway

*Corresponding author: ibib@ntnu.no

KEYWORDS

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ABSTRACT

E-waste stands for electronic devices, such as phones, computers, and televisions, that are disposed of when they reach the end of their useful lives. E-waste is becoming one of the most rapidly growing waste streams globally. The production of e-waste is rapidly increasing due to various factors, including the rapid advancement of technology, changing customer preferences, the widespread use of non-repairable parts, and deliberate planned obsolescence during the design of such products to encourage consumers to replace their products more often, boosting sales and profits. E-waste contains precious and rare metals such as gold, silver, copper, indium, and palladium. When these materials are not properly recovered, recycled, and reused, the production of new electronics will require the mining of finite natural resources, leading to environmental damage and the depletion of resources.

As of early 2019, Norway has established an Extended Producer Responsibility (EPR) system, which requires producers and importers to finance and ensure proper collection and recycling of end-of-life (EoL) e-waste, resulting in an increase in the e-waste recycling rate to approximately 91% in Norway. However, electronic waste such as mobile phones and computers often goes unrecycled. Currently, 82% of Norwegian households have at least one extra mobile phone that they are not using. People may hesitate to dispose of their electronic waste and tend to stockpile it at home for several reasons. These include feeling emotionally attached to the item due to personal memories, not knowing where or how to dispose of it, being unaware of the potential environmental and health hazards associated with improper disposal and having concerns about the data security and personal information stored on the device.

To address these issues, the paper introduces a cutting-edge tracking and tracing platform that features an intuitive user interface for both users and administrators. With the proposed platform, users and administrators can easily access essential information regarding their e-waste disposal. This convenient and efficient system offers a practical solution for tracking e-waste, thereby promoting trust between device owners and the disposal process. Furthermore, the platform incentivizes users by providing them with valuable information regarding their e-waste disposal, creating a positive impact on environmental sustainability.

I. INTRODUCTION

E-waste, a critical issue of the modern era, is often disregarded, even though it poses a significant threat to our environment and health. The improper disposal of e-waste, which is continuously increasing in volume, results in the release of toxic chemicals that endanger both the environment and human life. Moreover, it leads to the loss of valuable and precious metals that can be reused (Andeobu et al., 2021; Forti et al., 2020). Therefore, the global issue of e-waste has become a serious problem that requires urgent attention and action. In 2019, the amount of e-waste generated worldwide was 53.6 million tons (Mt), which is a staggering amount that exceeds previously predicted figures. According to Forti et al., the volume of e-waste generated globally is expected to exceed 74 million tons (Mt) by 2030 (Forti et al., 2020). Unfortunately, the rate of recycling is not keeping up with the rate of e-waste production, which exacerbates the problem further. Moreover, the current rate of e-waste generation is increasing at an alarming rate of 3–5%, posing a significant challenge to our environment and health. Therefore, it is essential to take concrete steps towards better e-waste management and responsible disposal practices to mitigate the adverse effects of this growing problem.

The rate of e-waste generation has been increasing at an alarming pace and is outpacing the global population's growth. In fact, the amount of e-waste produced globally has increased three times faster than the global population (Andeobu et al., 2021). Despite this, only a mere 17.4% of electronic waste was formally collected and recycled across the globe in 2019 (Van Yken et al., 2021).

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Measures implemented to improve global e-waste recycling have not been sufficient to keep up with the rate of e-waste generation (Ilankoon et al., 2018). In fact, the recycling rate has only slightly increased since it was last calculated in 2014 (17%) (Andeobu et al., 2021) This means that the remaining 82.6% of e-waste is either not recycled or not formally tracked, leading to their sale on black markets and eventual disposal in landfills (Forti et al., 2020; Li et al., 2013) Such practices are extremely harmful to the environment and human health, as e-waste contains hazardous materials such as lead, cadmium, and mercury, which can leach into the soil and groundwater, polluting the ecosystem and posing a threat to human life. Therefore, it is crucial to implement more effective and sustainable measures for e-waste management to mitigate the adverse effects of this growing problem.

Recycling and resource recovery of electronic waste is a critical issue due to the potential hazards it poses to both the environment and human health (Mmereki, 2016). Improper disposal of electronic waste can lead to massive environmental and health problems, making it crucial to address this issue urgently (Balde et al., 2015; Zuo et al., 2020; Sharma and Jain, 2020; Andrade et al., 2019; Schumacher and Agbemabiese, 2019). In fact, electronic waste is the fastest-growing waste category worldwide, and its impact on the environment is becoming increasingly significant (Islam and Huda, 2020).

While recycling electronic waste can produce tangible byproducts, it also contains hazardous substances that must be treated before the waste is destroyed (Islam and Huda, 2020; Kumar et al., 2017; Thakur and Kumar, 2022). Such substances include lead, mercury, and cadmium, among others, which are harmful to the environment and human health if not handled appropriately. Therefore, proper management and disposal of electronic waste are critical to mitigate the adverse effects of this growing problem. Measures such as improved collection and recycling systems, responsible disposal practices, and public awareness campaigns can help reduce the negative impact of electronic waste on the environment and human health.

Despite numerous attempts to manage e-waste, there is a lack of long-term sustainability plans, including collection, segregation, storage, transportation, and treatment methods, as well as laws and regulations to support them (Adanu et al., 2020; Al-Salem et al., 2022). This has contributed to the ongoing issue of improper disposal of electronic waste worldwide.

Figure 1 presents the expected projection of electronic waste from now until 2030, highlighting the urgent need for effective management and disposal strategies. It is estimated that electronic waste currently accounts for 5% of global solid waste (SW), making it a significant contributor to the overall waste problem (Hazra et al., 2019). Clearly articulating the issue of e-waste is a critical first step in addressing the problem. Measures such as establishing effective collection and recycling systems, implementing regulations and laws to ensure responsible disposal practices, and increasing public awareness about the importance of proper e-waste management are essential to reducing the impact of electronic waste on the environment and human health.

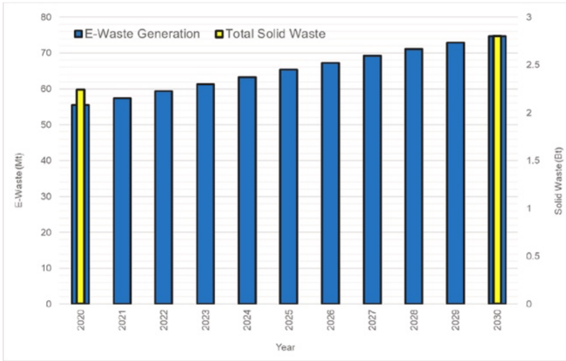


Figure 1: The projected generation of e-waste and total solid waste, in millions and billions of tons respectively, is estimated to occur between 2020 and 2030 (Forti et al., 2020; Kazancoglu et al., 2021).

A. Definition of e-waste

The word "electronic waste" (e-waste) is used when electrical and electronic equipment (EEE) reaches the end of its useful lifetime. There are a total of 54 different product types that fall under the classification of e-waste, but they are categorized into six categories: large equipment, small equipment, temperature exchange equipment, screens and monitors, small information exchange equipment, and lamps (Forti et al., 2020). The term "WEEE" refers to any electrical and electronic equipment (EEE) and its associated components that have been discarded or are intended for such disposal without the owner's intention of reuse (European Union, 2012).

B. E-waste regulation and legislation

Many nations have taken steps to curb the growth of electronic waste and profit from the advantages of this potentially valuable secondary resource. More than 2000 sections of legislation from more than 90 jurisdictions are currently in force worldwide to regulate the negative effects of WEEEs (Ilankoon et al., 2018). In the past, environmental protection was the driving force behind most regulations and strategies, but nowadays, human health concerns are at the forefront of most management strategies (Thakur and Kumar, 2022). There have been several international groups and initiatives that have advanced the cause of proper monitoring and recycling. Each of these groups is working together to inform consumers and investigate potential e-waste management solutions (Thakur and Kumar, 2022; Patil and Ramakrishna, 2020).

The structure of the paper is organized as follows: the related works are reviewed in Section II. Section III briefly recalls the current challenges for e-waste tracking.

A detailed description of our methodology and platform are presented in Sections IV and V, respectively. Section VI describes the test scenarios with the proposed platform. Section VII presents some offers for future work. Finally, Section VIII concludes our work.

II. LITERATURE REVIEW

The flow of e-waste has also been the subject of various studies. Some studies have attempted to quantify the transboundary movement of e-waste (Breivik et al., 2014; Lee et al., 2018; Lepawsky and McNabb, 2010; Lepawsky, 2015; Shinkuma and Nguyen Thi Minh Huong, 2009; Song et al., 2017a; Song et al., 2017b; Tong et al., 2018), while others have focused on the domestic flow of e-waste through tracking and tracing the flow of e-waste (Dwivedy and Mittal, 2012; Kahhat and Williams, 2012; Miller et al., 2016; Mishima et al., 2016; Veenstra et al., 2010; Yoshida et al., 2009). To effectively manage e-waste, it is necessary to embrace appropriate technological solutions that address the following aspects:

- Transparency in the electronic waste movement.
- Extended producer responsibility (EPR) implementation.
- Traceability of e-products across their entire life cycle, from manufacturing to e-waste conversion to recycling back into raw materials.
- Constructing appropriate channels for reaching out to e-waste.
- A sufficient number of recycling facilities and their connectivity to a technology-driven e-waste management system is essential (Sahoo et al., 2021). According to the literature, it is evident that there is a gap in the field of electrical and electronic waste collection, particularly concerning the implementation of track-and-trace technologies and smart collection systems (Lopez Alvarez et al., 2008; Rada et al., 2013; Martin and Leurent, 2017; Kazancoglu et al., 2021).

III. CURRENT CHALLENGES FOR E-WASTE TRACKING

Particularly in developing countries, the tremendous volume of waste and the lack of information about waste movement are the greatest challenges to the waste management sector. By 2025, it is expected that 2.2 billion metric tons of solid waste will have been produced. E-waste is expanding at a rate three times that of traditional waste types. Less than a quarter of all electronic waste was collected for formal recycling in 2016. In 2017, the raw materials in e-waste were worth \$47 million, as reported in (Baldé et al., 2017; Yadav et al., 2021). Based on waste generation data in 2019, metals could be recycled worth \$57 billion and used to meet metal demand brought on by the manufacture of new electrical equipment (Forti et al., 2020).

Of all the countries in the world, only 41 countries have provided official statistics on their e-waste. Furthermore, statistics from previous studies for 16 countries were obtained, explaining the low collection rate for e-waste and leaving 34.1 metric tons of WEEE unaccounted for (Baldé et al., 2017). Although many countries provide information on their e-waste, there is no guarantee that this information is correct. When it comes to recycling waste electrical and electronic equipment (WEEE), many third-world countries have relied heavily on the informal sector (Ackah, 2017). This means that official statistics on e-waste may not provide a useful step toward a long-term solution to the problems associated with disposing of e-waste. Strong legislation is needed to prevent the informal sector from collecting WEEE. To dispose of their illegal e-waste, developed countries often ship it to developing countries with weak or average economies (Rais, 2022). This occurs because either the guidelines are inadequate, or law enforcement is ineffective. In addition, undocumented electronic waste poses a risk to personal confidentiality. Data and information security are at risk from the many types of storage devices that make up e-waste (Rais, 2022; Debnath, 2023).

IV. METHODOLOGY

In this paper, a qualitative review of the literature in the area of e-waste and its tracking system has been done. Use cases of tracking system implementations were studied in detail, and application development experts were consulted to take input related to developing the architectural framework for tracking implementation in e-waste management. Figure 2 shows the research methodology, and Figure 3 presents the architectural framework for tracking implementation.

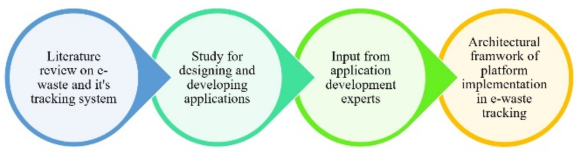


Figure 2: The applied research methodology.

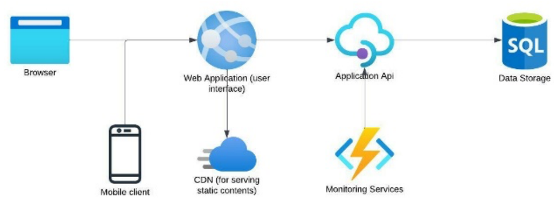


Figure 3: Architectural framework for tracking implementation.

V. PLATFORM DESCRIPTION

The process for creating an e-waste tracking platform includes four steps, as shown in Figure 4. The 4 steps are presented in detail in the following subsections.

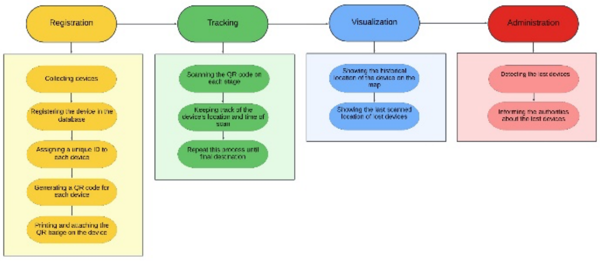


Figure 4: The process of creating an E-waste tracking platform.

A. The first step: Registration

This step, as shown in Figure 5, includes collecting devices as e-waste during their end-of-life period (EOL) and then recording the device's specifications. Then the device is registered in the database, and a unique ID is assigned to each device. In this paper, a unique QR code is generated for each device, as shown in Figure 6.

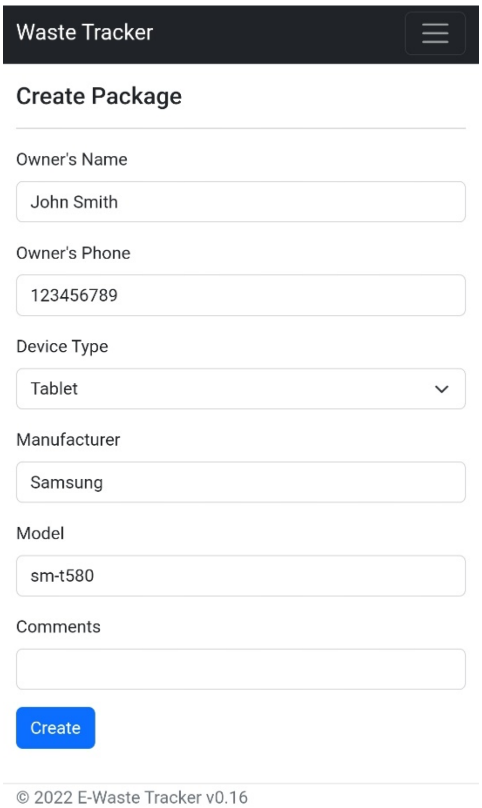


Figure 5: Device Registration user interface in the Platform.

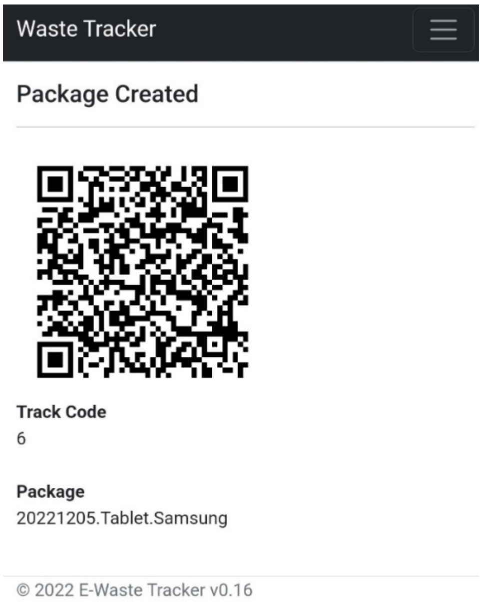


Figure 6: QR code generate of an e-waste device.

This QR code can be printed and attached as a badge on each device. More often, e-waste recognition can be performed by either a machine-learning or deep-learning approach, but for simplicity, these methods have been ignored.

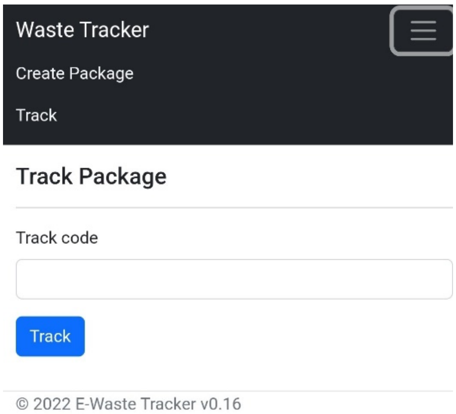


Figure 7: User interface design for E-waste tracking.

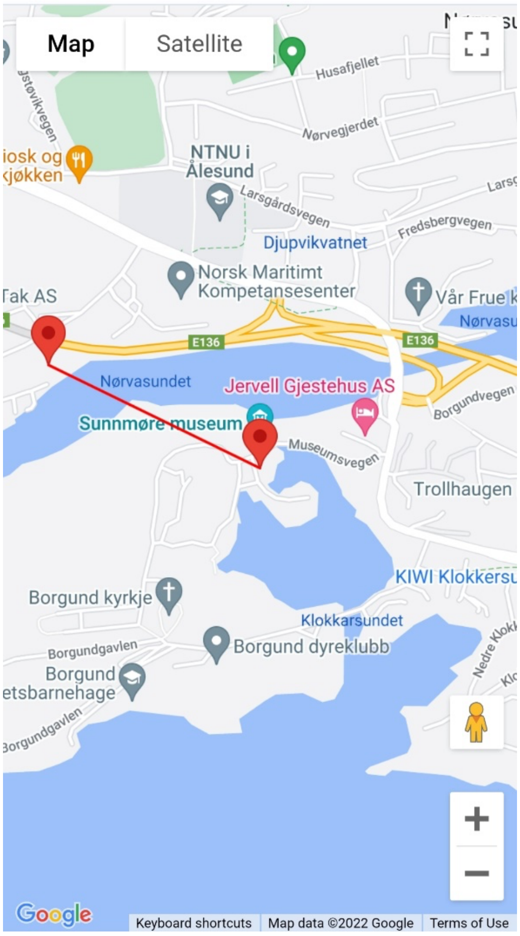
B. Second step: Tracking

The process of tracking e-waste is made simple with the QR code on each stage, such as the collection station, which can be scanned using a mobile phone. This platform enables the association of tracked e-waste with the location of the mobile device that scanned the QR code and the time log of this action. This procedure is repeated until the e-waste device reaches its final destination, which can be specified by the user. All tracking data is saved at each destination in a database, providing a complete record of the disposal journey. The end user can easily track each device by entering the tracking code created during the registration step. The tracking information of each device, including its current location, is then displayed on the platform, as shown in Figure 7.

C. Third step: Visualization

When the e-waste movement is tracked, the platform retrieves this information, including the location at various checkpoints, and visualizes it based on time logs, as shown in Figure 8. The platform offers a dynamic and user-friendly dashboard that allows users to track the movement of e-waste in real-time on an interactive map. With our intuitive visualizations, users can easily monitor the location of their e-waste at every stage of the disposal process.

This innovative feature provides a comprehensive overview of the e-waste disposal journey, ensuring transparency and accountability throughout the entire process. If a device is lost at any stage, the application can show the latest scanned location of the missing object and send an alert to the tracking party. For example, if no new location data for a device is received after a certain period of time, the system could conclude that the device has disappeared.



Figures 8: Visualizing dashboard to track the movement of e-waste in real-time on an interactive map.

D. Fourth step: Administration

The purpose of developing this part is to provide system administrators with an overall perspective of the system states and devices that are currently being tracked. The pseudocode for the tracking platform, shown in Figure 9, is designed to monitor the movement of e-waste through the recycling process.

```
Algorithm 1: Function to register e-waste
  Data: device specifications
  Result: device ID and QR code
  begin
    device_id ← generate_device_id(device_specifications);
    database.add_device(device_id, device_specifications);
    qr_code ← generate_qr_code(device_id);
    return device_id, qr_code;
  end
```

```
Algorithm 2: Function to track e-waste
  Data: device ID, location
  Result: location
  begin
    database.add_location(device_id, location);
    if is_device_lost(device_id, location) then
      send_alert(device_id, location);
    end
    return location;
  end
```

```
Algorithm 3: Function to visualize the movement of e-waste
  Data: device ID
  Result: location history
  begin
    location_history ← database.get_location_history(device_id);
    plot_locations(location_history);
    return location_history;
  end
```

```
Algorithm 4: Function to administer the system
  Result: system status and list of devices
  begin
    system_status, devices ← database.get_system_status();
    return system_status, devices;
  end
```

Figures 9: Pseudocode of the e-waste tracking platform.

The pseudocode is presented in a series of steps, beginning with the creation of a new transaction to record the initial movement of the e-waste. The transaction includes information about the origin, destination, and type of e-waste being moved.

The next step involves validating the transaction, which involves verifying the authenticity of the information provided and ensuring that the transaction complies with the regulations and standards for e-waste management.

The ledger can be accessed by authorized parties, such as government regulators and recycling companies, to track the movement of e-waste and ensure compliance with environmental regulations.

Additional steps in the pseudocode include monitoring the storage and disposal of e-waste, as well as the issuance of certificates of destruction to confirm that the e-waste has been properly disposed of.

Overall, the pseudocode of the tracking platform provides a clear and structured overview of the processes involved in monitoring the movement of e-waste through the recycling process.

VI. FUTURE WORK

Waste management operations are becoming more sustainable and advantageous for the future thanks to digital innovations like robotic systems, smart tracking, sensors, RFID applications, mobile apps, and autonomous vehicles. Tracking is one of the most lost stages and needs to be integrated with digitalization, especially in the e-waste category. The proposed platform will be implemented and disseminated to track e-waste practices in future studies. In addition, the asserted benefits can be improved with blockchain technology to save tracking data with a privacy-focused identity validation process while maintaining privacy and safety. Another research topic would be to integrate this tracking method with the circular economy approaches of the proposed platform in order to evaluate the effect of the black market for e-waste. Comparative studies can be conducted through the counties of Norway in order to reveal the common and differentiating issues among them. In future studies, the tools, and techniques, especially blockchain technology, will be embedded within the proposed platform.

CONCLUSION

E-waste has become a significant environmental problem because of the high pace of production and its massive volume. This study initially defines "e-waste," which is separated into six major categories in order to better understand and manage it. Following that, it describes the current e-waste regulations and legislation that apply throughout the world. Then, e-waste's tracking procedure and its challenges are evaluated, and the current official statistics on countries' e-waste tracking are reviewed. Ultimately, it focuses on the design and development of a tracking system by scanning the e-waste and visualizing the trend of its movement in order to avoid any disappearances along its journey, which is our motivation for minimizing the quantity of information stolen. This platform is a more simple, user-friendly, and cost-effective tracking system for dealing with e-waste, particularly e-waste flow, which addresses the issue of personal confidentiality, and finally, as a future solution, this paper proposes the blockchain method for increased safety and privacy protection.

REFERENCES

Ackah, M. (2017). "Informal E-waste recycling in developing countries: review of metal(loid)s pollution, environmental impacts and transport pathways". In *Environmental Science and Pollution Research*, 24(31), 24,092–24,101. https://doi.org/10.1007/s11356-017-0273-y

Adanu, S. K., Gbedemah, S. F., & Attah, M. K. (2020). "Challenges of adopting sustainable technologies in e-waste management at Agbogbloshie, Ghana". In *Heliyon,* 6(8), e04548. https://doi.org/10.1016/j.heliyon.2020.e04548

Al-Salem, S., Leeke, G. A., El-Eskandarany, M. S., Van Haute, M., Constantinou, A., Dewil, R., & Baeyens, J. (2022). "On the implementation of the circular economy route for E-waste management: A critical review and an analysis for the case of the state of Kuwait". In *Journal of Environmental Management*, 323, 116181. https://doi.org/10.1016/j.jenvman.2022.116181

Andeobu, L., Wibowo, S., & Grandhi, S. (2021). "A Systematic Review of E-Waste Generation and Environmental Management of Asia Pacific Countries". In *International Journal of Environmental Research and Public Health*, 18(17), 9051. https://doi.org/10.3390/ijerph18179051

Andrade, D. F., Romanelli, J. P., & Pereira-Filho, E. R. (2019). "Past and emerging topics related to electronic waste management: top countries, trends, and perspectives". In *Environmental Science and Pollution Research*, 26(17), 17135–17151. https://doi.org/10.1007/s11356-019-05089-y

Baldé, C. P., Wang, F., Kuehr, R., & Huisman, J. (2015). The global e-waste monitor–2014, United Nations University, IAS–SCYCLE, Bonn, Germany. ISBN Print, 978-92.

Baldé, C. P., Forti, V., Gray, V., Kuehr, R., & Stegmann, P. (2017). The global ewaste monitor 2017: Quantities, flows and resources. United Nations University, International Telecommunication Union, and International Solid Waste Association, 2017. https://ewastemonitor.info/gem-2017/

Breivik, K., Armitage, J. M., Wania, F., & Jones, K. C. (2014). "Tracking the global generation and exports of e-waste. Do existing estimates add up?". In *Environmental Science & Technology*, 48(15), 8735–8743. https://doi.org/10.1021/es5021313

Chaudhary, K., Padmanabhan, P., Verma, D., & Yadav, P. D. (2021). "Blockchain: a game changer in electronic waste management in India". In *International Journal of Integrated Supply Management*, 14(2), 167-182. https://doi.org/10.1504/IJISM.2021.115680

Debnath, B., Alghazo, J. M., Latif, G., Roychoudhuri, R., & Ghosh, S. K. (2020). An Analysis of Data Security and Potential Threat from IT Assets for Middle Card Players, Institutions and Individuals. In *Sustainable Waste Management: Policies and Case Studies: 7th IconSWM—ISWMAW 2017, Volume 1* (pp. 403-419). Springer Singapore. https://doi.org/10.1007/978-981-13-7071-7_36

Directive, E. C. (2012). "Directive 2012/19/EU of the European Parliament and of the Council of 4 July 2012 on waste electrical and electronic equipment, WEEE". *Official Journal of the European Union* L, 197, 38-71. https://doi.org/10.5040/9781782258674.0030

Dwivedy, M., & Mittal, R.K (2012). "An investigation into e-waste flows in India". In *Journal of Cleaner Production*, 37, 229–242. https://doi.org/10.1016/j.jclepro.2012.07.017

Forti, V., Balde, C. P., Kuehr, R., & Bel, G. (2020). "The Global E-waste Monitor 2020: Quantities, flows and the circular economy potential". United Nations University/United Nations Institute for Training and

Research, Internationa Telecommunication Union, and International Solid Waste Association.

Hazra, A., Das, S., Ganguly, A., Das, P., Chatterjee, P. K., Murmu, N. C., & Banerjee, P. (2019). “Plasma Arc Technology: A Potential Solution Toward Waste to Energy Conversion and of GHGs Mitigation”. In *Waste Valorisation and Recycling 7th IconSWM—ISWMAW 2017, Volume 2* (pp. 203-217). Springer Singapore. https://doi.org/10.1007/978-981-13-2784-1_19

Ilankoon, I. M. S. K., Ghorbani, Y., Chong, M. N., Herath, G., Moyo, T., & Petersen, J. (2018). “E-waste in the international context–A review of trade flows, regulations, hazards, waste management strategies and technologies for value recovery”. In *Waste management*, *82*, 258-275. https://doi.org/10.1016/j.wasman.2018.10.018

Islam, M. T., & Huda, N. (2020). “Assessing the recycling potential of "unregulated" e-waste in Australia”. In *Resources, Conservation and Recycling*, 152, 104526. https://doi.org/10.1016/j.resconrec.2019.104526

Kahhat, R., & Williams, E. (2012). “Materials flow analysis of e-waste: Domestic flows and exports of used computers from the United States.” In *Resources, Conservation and Recycling*, 67, 67–74. https://doi.org/10.1016/j.resconrec.2012.07.008

Kazancoglu, Y., Ozbiltekin, M., Ozkan Ozen, Y. D., & Sagnak, M. (2021). “A proposed sustainable and digital collection and classification center model to manage e-waste in emerging economies”. In *Journal of Enterprise Information Management*, 34(1), 267–291. https://doi.org/10.1108/JEIM-02-2020-0043

Kumar, A., Holuszko, M., & Espinosa, D. C. R. (2017). “E-waste: An overview on generation, collection, legislation and recycling practices”. In *Resources, Conservation and Recycling*, 122, 32– https://doi.org/10.1016/j.resconrec.2017.01.018

Lee, D., Offenhuber, D., Duarte, F., Biderman, A., & Ratti, C. (2018). “Monitour: Tracking global routes of electronic waste”. In *Waste Management*, 72, 362–370. https://doi.org/10.1016/j.wasman.2017.11.014

Lepawsky, J., & McNabb, C. (2010). “Mapping international flows of electronic waste”. *The Canadian Geographer / Le Géographe canadien*, 54(2), 177–195. https://doi.org/10.1111/j.1541-0064.2009.00279.x

Lepawsky, J. (2015). “The changing geography of global trade in electronic discards: Time to rethink the e-waste problem”. In *The Geographical Journal*, 181(2), 147– https://doi.org/10.1111/geoj.12077

Li, J., Lopez, B. N., Liu, L., Zhao, N., Yu, K., & Zheng, L. (2013). “Regional or global WEEE recycling. Where to go?”. In *Waste Management*, 33(4), 923–934. https://doi.org/10.1016/j.wasman.2012.11.011

Lopez Alvarez, J. L., Aguilar Larrucea, M., Fernandez-CarriÅLon Quero, S., & Jimenez del Valle, A. (2008). “Optimizing the collection of used paper from small businesses through GIS techniques: The LeganÅLes case (Madrid, Spain)”. In *Waste Management*, 28(2), 282–293. https://doi.org/10.1016/j.wasman.2007.02.036

Martin, C., & Leurent, H. (2017). “Technology and Innovation for the Future of Production: Accelerating Value Creation (Tech. Rep.)”. In *World Economic Forum*. (pp. 1-38).

Miller, T. R., Duan, H., Gregory, J., Kahhat, R., & Kirchain, R. (2016). “Quantifying Domestic Used Electronics Flows using a Combination of Material Flow Methodologies: A US Case Study”. In *Environmental Science & Technology*, 50(11), 5711–5719. https://doi.org/10.1021/acs.est.6b00079

Mishima, K., Rosano, M., Mishima, N., & Nishimura, H. (2016). “End-of-Life Strategies for Used Mobile Phones Using Material Flow Modeling”. In *Recycling*, 1(1), 122–135. https://www.mdpi.com/2313-4321/1/1/122

Mmereki, D., Li, B., Baldwin, A., & Hong, L. (2016). “The Generation, Composition, Collection, Treatment and Disposal System, and Impact of E-Waste”. In *E-Waste in Transition - From Pollution to Resource* (pp. 65–93). https://dx.doi.org/10.5772/61332

Patil, R. A., & Ramakrishna, S. (2020). “A comprehensive analysis of e-waste legislation worldwide”. In *Environmental Science and Pollution Research*, 27(13), 14412–14431. https://doi.org/10.1007/s11356-020-07992-1

Rada, E., Ragazzi, M., & Fedrizzi, P. (2013). “Web-GIS oriented systems viability for municipal solid waste selective collection optimization in developed and transient economies”. In *Waste Management*, 33(4), 785–792. https://doi.org/10.1016/j.wasman.2013.01.002

Rais, M. U. (2022). “Smart E-waste Tracking and Monitoring Model: A Modern Approach to Counter E-waste Management Issues”. In *Technology Innovation in Mechanical Engineering*: *Select Proceedings of TIME 2021* (pp. 757-765). Singapore: Springer Nature Singapore https://doi.org/10.1007/978-981-16-7909-4_69

Sahoo, S., Mukherjee, A., & Halder, R. (2021). “A unified blockchain-based platform for global e-waste management”. In *International Journal of Web Information Systems,* 17(5), 449–479. https://doi.org/10.1108/IJWIS-03-2021-0024

Schumacher, K. A., & Agbemabiese, L. (2019). “Towards comprehensive ewaste legislation in the United States: Design considerations based on quantitative and qualitative assessments”. In *Resources, Conservation and Recycling*, 149, 605–621. https://doi.org/10.1016/j.resconrec.2019.06.033

Sharma, K. D., & Jain, S. (2020). “Municipal solid waste generation, composition, and management: the global scenario”. In Social Responsibility Journal, 16(6), 917–948. https://doi.org/10.1108/SRJ-06-2019-0210

Shinkuma, T., & Nguyen Thi Minh Huong. (2009). “The flow of E-waste material in the Asian region and a reconsideration of international trade policies on E-waste”. In *Environmental Impact Assessment Review*, 29(1), 25–31. https://doi.org/10.1016/j.eiar.2008.04.004

Song, Q., Wang, Z., Li, J., Duan, H., Yu, D., & Zeng, X. (2017a). “Characterizing the transboundary movements of UEEE/WEEE: Is Macau a regional transfer center?”. In Journal of Cleaner Production, 157, 243–253. https://doi.org/10.1016/j.jclepro.2017.04.149

Song, X., Hu, S., Chen, D., & Zhu, B. (2017b). “Estimation of waste battery generation and analysis of the waste battery recycling system in China”. In *Journal of Industrial Ecology*, 21(1), 57–69. https://doi.org/10.1111/jiec.12407

Thakur, P., & Kumar, S. (2022). "Evaluation of e-waste status, management strategies, and legislations". In *International Journal of Environmental Science and Technology*, 19(7), 6957–6966. https://doi.org/10.1007/s13762-021-03383-2

Tong, X., Wang, T., Chen, Y., & Wang, Y. (2018). "Towards an inclusive circular economy: Quantifying the spatial flows of e-waste through the informal sector in China". In *Resources, Conservation and Recycling*, 135, 163–171. https://doi.org/10.1016/j.resconrec.2017.10.039

Van Yken, J., Boxall, N. J., Cheng, K. Y., Nikoloski, A. N., Moheimani, N. R., & Kaksonen, A. H. (2021). "E-Waste Recycling and Resource Recovery: A Review on Technologies, Barriers and Enablers with a Focus on Oceania". In *Metals*, 11(8), 1313. https://doi.org/10.3390/met11081313

Veenstra, A., Wang, C., Fan, W., & Ru, Y. (2010). "An analysis of E-waste flows in China". In *The International Journal of Advanced Manufacturing Technology*, 47(5-8), 449–459. https://doi.org/10.1007/s00170-009-2356-5

Yoshida, A., Tasaki, T., & Terazono, A. (2009). "Material flow analysis of used personal computers in Japan". In *Waste Management*, 29(5), 1602–1614. https://doi.org/10.1016/j.wasman.2008.10.021

Zuo, L., Wang, C., & Sun, Q. (2020). "Sustaining WEEE collection business in China: The case of online to offline (O2O) development strategies". In *Waste Management*, 101, 222–230. https://doi.org/10.1016/j.wasman.2019.10.008

AUTHOR BIOGRAPHIES

IBRAHIM A. HAMEED is a Professor at the Department of ICT and Natural Sciences, Faculty of Information Technology and Electrical Engineering, Norwegian University of Science, and Technology (NTNU), Norway. Hameed is an IEEE senior member, elected chair of the IEEE Computational Intelligence Society (CIS) Norway section, and ACM member. Hameed has a PhD degree in Industrial Systems and Information Engineering from Korea University, Seoul, South Korea and a PhD degree in Mechanical Engineering from Aarhus University, Aarhus, Denmark. He is the author of many journal and conference articles in areas of AI, machine learning, robotics, and automation. His e-mail address is: `ibib@ntnu.no` and his Webpage can be found at `https://www.ntnu.edu/employees/ibib`.

SARA ARTANG is an MSc student at the international master program in simulation and visualization, Department of ICT and Natural Sciences, Faculty of Information Technology and Electrical Engineering, Norwegian University of Science, and Technology (NTNU), Norway.

AFSHIN GHASEMIAN is a senior developer at Crayon, Norway.