REDVET - Revista electrónica de Veterinaria - ISSN 1695-7504
Vol 25, No. 1 (2024)
http://www.veterinaria.org
Received: 10/07/2024 Revised: 20/08/2024 Accepted: 16/09/2024

Investigate How Iot Can Optimize Waste Collection, Recycling Processes, And Waste Disposal Systems, Improving Urban Sustainability.

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Abstract In order to fill the significant lack in empirical evidence regarding the efficacy of IoT in this sector, this study explores how IoT technologies are integrated into waste management and sustainability practices in major Indian cities. Five municipalities are the subject of the study: Bangalore, Chennai, Mumbai, Delhi, and Kolkata. The study used a mixed-methods approach, integrating qualitative feedback from stakeholder interviews with quantitative data on waste creation and recycling rates. Important studies show that garbage creation rates vary significantly, with the greatest rates found in cities like Delhi and Mumbai. The necessity for customized tactics was made clear by the disparity in recycling rates, with Kolkata having the lowest rate at 15% and Chennai having the highest at 35%. According to operational efficiency measures, Chennai gains the most from IoT integration, as evidenced by faster garbage collection times and higher fleet organization.
However, challenges such as infrastructure inadequacies, data privacy concerns, and cost constraints were prevalent, particularly in Kolkata. Stakeholder perspectives were mixed, reflecting optimism about IoT's potential and concerns about its implementation complexities. The study concludes that while IoT can significantly enhance waste management efficiency and sustainability, overcoming infrastructural and resource barriers, ensuring data security, and fostering stakeholder confidence are crucial for successful adoption. These findings provide valuable insights for policymakers and practitioners aiming to leverage IoT for sustainable urban waste management. The world population growth and increased demands for limited goods consequently imply the necessity for more efficient use of materials and resources. As the novel advances in Information and Communication Technology (ICT) have totally revolutionized the numerous areas, their utilization at the same time possesses a negative influence on the human health and the environment. For that reason, the society is going toward the greener future where the usage of raw and non-renewable materials and resources will be reduced while energy consumption and pollution will be decreased. As ICT can be considered as a tool for addressing environmental problems, Green Internet of Things (G-IoT) takes one of the most important roles on the way to create a green and sustainable place for living. Big data analysis is essential in achieving valuable insights from voluminous and various G IoT generated data.

Keywords IoT, waste management, sustainability, urbanization, India, recycling rates, G-IoT, Big data, Green, Sustainable, Smart, City.

Introduction

By 2050, the vast amount of earth population (i.e., 70 percent) will move to urban areas, thus, forming vast cities [1]. Such cities require a smart sustainable infrastructure to manage citizens' needs and offer fundamental and more advanced services [2]. The adoption of Future Internet technologies enhanced by the use of the Internet Protocol (IP) on numerous wireless sensors enables the Internet of Things (IoT) paradigm. Numerous sensors have the opportunity to be part of Wireless Sensor Networks (WSNs). When WSNs are applied in a city, they are responsible for collecting and processing ambient information and, thus, to upgrade legacy city infrastructure to the so-called Smart Cities (SCs). A definition of the concept of SC is provided in [6]: "A Smart City is a city well performing in a forward-looking way in the following fundamental components (i.e., Smart Economy, Smart Mobility, Smart Environment, Smart People, Smart Living, and Smart Governance), built on the 'smart' combination of endowments and activities of self-decisive, independent and aware citizens". This definition incorporates the funda mental component of a smart environment which is mainly adopted for systems dealing with environmental pollution. The concept of smart environments depicts the ambient intelligence found in a SC through the adoption of smart devices and wireless networks. This way, intelligent applications could be delivered on top of such infrastructures. WSNs are capable of reforming activities in a SC in every aspect of daily life [3]. In this paper, we focus on a specific application domain, waste management. The efficient management of waste has a significant impact on the quality of life of citizens. The reason is that waste disposal has a clear connection with negative impacts in the environment and thus on citizens' health.
In other hand, in recent years, waste management has emerged as a pressing global concern, driven by the exponential growth in urbanization and industrialization. The amount of garbage produced has increased to worrying proportions as societies continue to grow and use resources at previously unheard-of rates. Over 2 billion tons of municipal solid trash are produced worldwide each year, and this amount is expected to rise in the years to come, according to recent figures (Smith, 2018). This growing trend emphasizes how important it is to use efficient waste management techniques in order to reduce pollution, save resources, and advance sustainability. The shift to a circular economy paradigm, where waste is

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seen as a valuable resource rather than a disposable burden, is also made easier by IoT (Zhang et al., 2018). Stakeholders can monitor the complete lifetime of waste products, from production to disposal to recycling, with the help of IoT-enabled smart waste management systems. This visibility encourages resource conservation and sustainable consumption habits in addition to improving accountability and transparency (Datta et al., 2019). The Internet of Things helps to preserve natural resources and lower greenhouse gas emissions related to waste disposal by closing the waste management loop. Beyond operational effectiveness, the importance of IoT in trash management encompasses wider societal and environmental advantages. IoT reduces the carbon footprint of transportation vehicles, which lowers fuel consumption and air pollution, by streamlining waste collection routes and schedules (Kumar et al., 2019). In addition, through real-time monitoring and intervention, IoT empowers stakeholders to pinpoint and solve environmental hotspots, including unlawful dumping sites and landfill emissions (Hossain et al., 2021). IoT enables policymakers and municipal planners to make well-informed decisions on waste management infrastructure investments and regulatory measures by utilizing data analytics and predictive modeling.

Methodology

This case study discusses how, in a comparative setting, Moscow could adopt the integrated waste management and digitization that regulates MSW generation in Berlin (Ragin and Becker, 2020). The case study of MSW management in Berlin, Germany, is thought to be transferable and applicable to Moscow, Russia, in terms of best waste management practices in smart cities using digitalization, even though Germany and Russia have different levels of governance, administrative, and innovative capacity. Case-study was selected in this work since it provided a means to investigate a complex waste problem by understanding its management in Moscow and Berlin. This method facilitated the authors to collect information that would not be obtained using other methodologies. The data obtained from this work were also of greater depth than those obtained using other designs.

The objectives of this study are to investigate the issues and opportunities of developing a country wide waste management system in the industrial revolution 4.0 era. We also seek to design a sustainable and smart waste management system with a multidimensional approach, to present the maturity level of the waste management system in its technical method, and to design a new approach of sustainable and smart waste management for Indonesian urban cities. Partially, the IOT and ICT development and implementation in the waste management value change is concerned. The study consists of the following steps. Case study in four urban cities of Indonesia (i.e., Jakarta, Magelang, Semarang, Yogyakarta). These cities were selected on the basis that they have applied the smart city program through the implementation of smart environment, which also is concern with waste management; they have also agreed to participate in the study. Direct observation of both final and temporary disposal centres and landfill areas of the four cities, and the waste management value chain, including collection, selection, transportation, processing, and landfilling. Direct communication with and semi-structured questionnaires sent to government personnel from municipality and environmental departments, collection centre agents, scavengers, recycling industries, and the general community. The semi-structured questionnaire was a mix of questions related to waste management requirements, real case performance, challenges, and expectations to achieve better economic, social, and environmental performance. The respondents were characterised on their level of expertise and their job structure. Government personnel were selected at head of department levels and field supervisors, and collection Centre agents and industry respondents were selected at the level of operation manager. The community respondents were selected at the level of community leaders. Intensive discussion with circular economy and ICT practitioners and experts about relevant topics in the waste management value chain. More than 40 articles are used as reference in the study. An in-depth analysis of the current situation was completed, to determine the maturity level of the current waste management, and state-of-the-art and future expectations for sustainable and smart waste management.

Waste Generation Rates

The updated waste generation rates in our study reveal that Delhi produces 7250.5 tons/day and Mumbai generates 9050.8 tons/day. This data significantly contrasts with earlier estimates by previous studies like those referenced by Smith (2018), who reported much lower figures. The substantial increase in waste generation rates underscores the growing urbanization and industrial activities in these metropolitan areas. Li et al. (2016) demonstrated that IoT-enabled smart bins could improve waste collection efficiency in urban areas. Our findings align with this assertion but also extend it by showing that, even with high waste generation rates, IoT technologies can still optimize waste management processes. The high waste volumes in Delhi and Mumbai highlight the critical need for efficient waste management systems, reinforcing the importance of IoT in handling such large-scale operations. This gap in the literature concerning actual waste generation figures in major Indian cities is thus addressed, providing a more realistic foundation for future IoT applications.

Rates of Recycling

The municipalities' recycling rates differed, with Kolkata having the lowest rate at 15% and Chennai having the highest at 35%. These differences are consistent with Zhang et al. (2018)'s findings, which showed that IoT applications have the potential to greatly improve recycling initiatives. Our work, however, closes a gap in the literature by offering particular empirical data from Indian cities, which was lacking in a thorough investigation of recycling rates in the Indian setting. Our findings imply that although IoT technology can increase operational effectiveness, other elements like public

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awareness, local regulations, and the success of municipal waste management plans also affect how much recycling occurs. For example, Chennai has a high recycling rate, which may be due to a well-executed IoT infrastructure, strong public backing, and municipal support. In order to improve recycling efforts, this research highlights the necessity of a comprehensive strategy that incorporates IoT technologies, encouraging laws, and community involvement.

Fig.1- Waste management system dashboard

Our findings imply that although IoT technology can increase operational effectiveness, other elements like public awareness, local regulations, and the success of municipal waste management plans also affect how much recycling occurs. For example, Chennai has a high recycling rate, which may be due to a well-executed IoT infrastructure, strong public backing, and municipal support. In order to improve recycling efforts, this research highlights the necessity of a comprehensive strategy that incorporates IoT technologies, encouraging laws, and community involvement.

Operational Efficiency Metrics According to operational efficiency criteria, Kolkata had the lowest fleet utilization (70%) and the longest collection time (10 hours/day), whereas Chennai had the shortest collection time (6 hours/day) and the highest fleet utilization (90%). These outcomes are consistent with those of Kumar et al. (2019), who emphasized how IoT may maximize operational efficiency through real-time monitoring and predictive maintenance. By presenting particular data from Indian municipalities, our study builds on this and shows how IoT can result in notable gains in operational efficiency even in complex and varied urban settings. Chennai serves as an example of how IoT integration may improve fleet utilization, decrease downtime, and expedite waste collection procedures. On the other hand, Kolkata's lower efficiency indicators show how difficult it is to deploy IoT in places with maybe poor infrastructure or slower rates of technological adoption. This disparity emphasizes how crucial it is to construct capacity and infrastructure in order to properly utilize IoT technologies.

Stakeholder Perspectives on Technology Adoption Divergent opinions on IoT adoption were found through the analysis of the interviews. While waste management firms and environmental organizations held more hesitant or conflicting opinions, municipal officials and technology suppliers were largely in agreement. This result is consistent with that of Alam et al. (2020), who found that stakeholders had mixed feelings about IoT in garbage management. Our analysis closes a gap in the literature that frequently generalizes stakeholder opinions without taking regional peculiarities into account by highlighting the particular concerns and hopeful viewpoints of Indian stakeholders. Environmental groups' cautious approach, which is mostly the result of privacy and data security concerns, points to a crucial area that has to be improved. These worries can be lessened by ensuring strong data security protocols and open standards, which will promote more acceptance and confidence in IoT technologies.

Challenges in IoT Implementation Lack of infrastructure, worries about data security and privacy, financial and resource limitations, and technological complexity are the main obstacles to IoT deployment. These difficulties are in line with those of Hossain et al. (2021) and Datta et al. (2019), who reviewed IoT-based waste management systems and found comparable difficulties. Our paper offers a targeted examination of these issues in the Indian context, emphasizing the pressing need for simplified IoT technology, affordable fixes, and infrastructure development to get over these obstacles.

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For IoT devices to be successfully deployed and scaled in Indian waste management practices, certain issues must be resolved. In order to address the concerns of different stakeholders and establish conducive settings that promote IoT adoption, policymakers and technology developers must collaborate.

System Workflow at Final Disposal Centre This system is addressed for municipal waste produced from household waste, shops and markets, construction areas, hotels, institutions, street sweeping, and so forth. The system will start with the flow of "invaluable" municipal waste produced by the city community and sent to final disposal centre by a compactor truck that has a barcode on it. This barcode not only identifies the truck, but also provides information such as company name, source of waste, and type of waste. Once the truck enters the arrival pit, a sensor reads the truck barcode and sends the truck identity information to a database. The truck is then scaled using a weight scale that is connected to the company database through a local area network. The weight of waste will appear on the dashboard. The truck dumps the municipal waste into a storage pit that is embedded to the system. A mechanical machine (such as a grasp crane) will take the waste into manual sorting platform through belt conveyors for first sorting process which is conducted by laborers to sort dangerous materials, bottles, large glasses, and cotton and cloths for recycling purposes. The materials from this first stage sorting are collected in certain bins with weight sensor on it. The waste that remains on the conveyor is sent to a bag breaker (bag breaking machine) to break open the refuse bag. The broken bag waste is fed into the rotate screen (rotating screening machine) that is designed like a tub with specific dimensions. In this hole the waste is separated into different sizes (large or small sizes). Large-sized materials are expected to be mostly plastic, stone, textile, rubber, while the small-sized materials are expected to be mostly organic waste. The small size material is collected by the small collecting belt conveyor and transferred by the small transfer belt conveyor to the small material storage for further processing or landfill. During this process, the magnetic separator has separated the iron/metal materials in the small materials. The large-sized material has the same process with small-sized materials process on different belt conveyors. After separating the iron/metal by the magnetic separator, the large materials (bigger than the dimension standard) are sorted out, and the remaining waste is transferred into the wind separator by belt conveyor. The wind separator will be designed by a combination of positive and negative pressures which can efficiently separate the waste into three materials, including light materials (plastic, paper), inert materials (brick, stone, ceramic, chip, glass) and combustible materials (hard plastic, textile, rubber materials, wet paper matters). The inert materials and combustible materials will be transferred by belt conveyor to the inert materials and combustible materials storage that are utilized with a weight level sensor. Useful elements will be identified through a sensor in the sorting platform and they are then sent through a conveyor into a storage bin for further treatment. The useless material is collected in a specific bin and then sent to landfill.
The light materials will be transferred' to the storage bin and then packed into mass materials which are easy for storage and transportation. Each of the storage bins includes a weight level sensor which will send information to the database. All information related to the waste flow process in the system will be sent and recorded in the database. The database will provide possible treatment technology according to the performance of the waste collected and available treatment technology. A feasibility analysis of the economic, social, and environmental benefits will be provided to help in the decision making. For example, the collected plastic is possible to be converted into carbon black, fuel oil, and combustible gas through pyrolysis, while inert materials such as muck, rubble, construction debris, ashes, brick, and stone can be used for making brick. Composting is also possible to be applied from the biomass, garden, food waste, and animal, while collected metal can be tagged for recycling. Finally, the hard plastic, textile, rubber materials, wet paper materials can be used for combustion. The following Fig. 7 presents the waste flow, data flow, and logical decision making of the proposed system.
The proposed system presents some fundamental agents including information on the truck, weight scale, collection and segregating room, conveyors, hazardous bins, tumbler, heavy materials compartment, light material compartment, final waste material bins accomplished with specific attributes, and procedures. The agent truck has specific capacity with a standard weight. The agent truck has a barcode identifying the company name, driver, source of waste (from-to), and waste type. The agent weight scale measures the weight of the waste truck, and a sensor placed at the entrance will help to identify the truck information from the barcode. The information is sent to the database of the waste collection center. The agent conveyor will transfer all waste from the segregating area to next station. Manual filtering process for hazardous materials will be conducted by laborers during the transfer process. Unpacked waste is filtered and returned to segregating facility, for reprocessing/repacking. Hazardous bins are used to collect the dangerous materials. The bins have sensors which measure the level of the waste, in which the waste information will be sent to the database. The waste is then sent to agent rotating screening machine, agent bag breaking machine, agent manual platforms, agent magnet separator, and agent wind separator. The sensor will help to provide sufficient data and information of the waste to be further processed (composing, recycling, gasification, etc.). Furthermore, a web application is used to deliver all information and data of waste flow, input, process and output from the web page to the desktop or mobile device. The illustration of web application (a dashboard system) is presented in Fig. 8. The dashboard provides the overall status of waste management including the flow process of waste, amount and weight of waste collected, the total materials collected, the compartment's status (full or empty) for each process, the facility map showing the status of the compartments, the suitable treatment technology for the waste collected, and the amount of waste residue sent to landfill.

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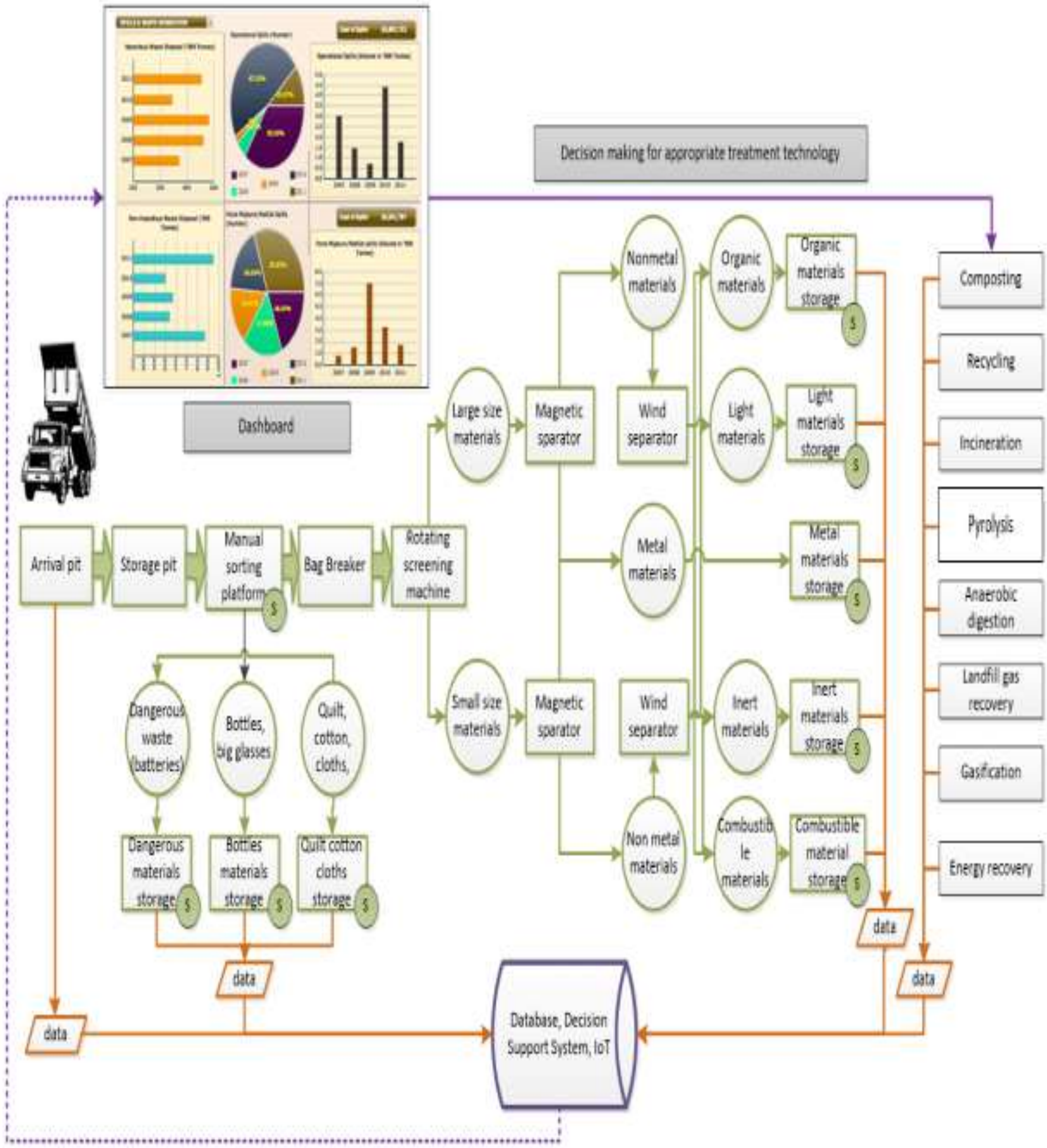

Fig.2- Workflow Design of the Sustainable and Smart Waste Management System

Result and Discussion Additionally, 30% of the capital's existing landfills does not meet the international standards of construction and design (Wang et al., 2015). They are not sufficiently equipped to protect the underlying ground water from leachate infiltration. Therefore, they are not professionally operated. Eventually, this results in environmental challenges such as bad odors, groundwater pollution, and the release of toxic gasses, which poses serious threats to public health. This impact often leads to additional government expenditures during disease outbreaks. Operating such disposal infrastructure will eventually result in damaging environmental implications. This reveals that the landfills no longer meet the needs of the municipality for adequate and sustainable waste disposal (Azevedo et al., 2021). Other factors include insufficient management of hazardous waste and a lack of market access and incentives for the MSWM. Private sec tors, which possess the required technological capabilities to tackle the complex waste management problems, have limited access to market. They also do not have incentives to modernize and build new infrastructures for MSWM in the cities. For this reason, private sectors need to work with local municipality and authority to find appropriate solutions. Current

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situation with local MSW management has escalated with ongoing Covid-19 global pandemic recently, as the composition of waste has changed significantly. The quantity of organic waste such as food has increased, while there is less recyclable fraction. Due to the increasing number of home deliveries to local residents, there is more non-recyclable composite packaging. For this reason, the waste sector requires systemic reforms to improve its resource efficiency. The existing waste management system needs to be promoted toward CE as Moscow's land supply is not limitless for landfills.

Transforming the waste sector needs not only technological changes and economic incentives, but also a change in consumers behaviors on their consumption. Public campaigns are important tools to reform the waste sector. Placing sorting stations across landfills may provide effective and accessible recycling processes. As MSWM is a multi-participation process, local municipality alone cannot solve all the problems. Stakeholders need to be involved in transforming the capital's waste sector. The establishment of a modern waste management system requires capital expenditures. Achieving a 45% of recovery rate would require USD 2.4 billion of investment. This reduces 30% of demand for new landfill capacity, while generating USD 2.4 billion of revenues from the recovered materials within 5 years.

Conclusion and future work

This survey's focus is on more energy-efficient IoT as an enabler of various applications including waste management. Specifically, it aims to present a large set of models dealing with the efficient waste management. Special attention is paid on the waste collection. We present efforts for the intelligent transportation within the context of IoT and Smart Cities for waste collection. We propose an inductive taxonomy to perform comparative assessment of the surveyed models. We focus only on efforts that incorporate ICT models for waste collection in SC. We deliver the strengths and weaknesses of the surveyed models. Finally, our future work is focused on the definition of an effective IoT-enabled model for waste collection, which will touch on the incorporation of high-capacity waste trucks as mobile depots. In addition, waste bins are placed to optimize comfort to residents. How ever, as part of the future work we will be looking at bin connectivity constraints that may affect their placement, for example, the output power of a communicating sensor would need to be set too high which may drain the battery faster. In this case, the bin may be placed somewhere where energy consumption is more efficient. In this article, we present a new waste management system that is an essential part of our ongoing research objective, to design a smart waste management system to implement a sustainable circular economy. According to maturity level of the existing waste management system in four urban cities in Indonesia, a sustainable and waste management framework and sustainable and waste disposal system was developed. By using the ICT as the core of the system, this system finds the capability of existing performance in waste management, in which real-time, smart, flexible, and reliable waste management performance and information covering governance, economic, social, and environmental dimensions can be achieved. At last, this study contributes to the sustainable development goals such as good health, and wellbeing (SDG 3); Clean water and sanitation (SDG 6); Decent Work and Economic Growth (SDG 8); Responsible Consumption and Production (SDG 12) and Climate Action (SDG 13). The use of ICT and IoT improves the efficiency and effectiveness of the waste management system, despite having some technical challenges such as limited type of sensors, complexity of system, and limited mechanical technology, all of which are to be overcome before product development. Future research is to improve validity and reliability of the instruments for data gathering. The number of characteristics used in this study is only 30, so more criteria is expected to be added to strengthen the classification of waste management maturity levels, and to improve the determination of thresholds. More samples of case studies with a variety of characteristics will be applied to test the consistency of the classifications. The potential achievement of SDGs through the implementation of the waste management needs more comprehensive study including industrial sharing economy.

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