Innovations

Exploring Blockchain Technology for Enhancing Waste Source Tracking and Data Transparency in the Philippines

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Abstract: The Philippines faces increasing challenges in waste management due to rapid urbanization, industrialization, and population growth. One major issue is the lack of accurate, real-time data on garbage sources, which limits the effectiveness of policies and programs. Existing waste monitoring systems are often outdated, fragmented, and poorly integrated across government units and industries. This review explores the feasibility of using blockchain technology to enhance waste source tracking and improve data transparency in the country. The study aims to analyze trends in waste generation and identify key sources, evaluate limitations in current data collection systems, and assess how blockchain can be applied to address these challenges. Methods used include documentary analysis, trend and gap analysis, and a literature review of global and local studies on blockchain in environmental management. Findings reveal that regions such as CALBARZON and Metro Manila generate the most waste, especially from industrial activities. However, critical gaps exist in how waste data is recorded, shared, and verified. Blockchain technology offers potential benefits such as data security, real-time tracking, and decentralization, which could significantly improve waste management systems. The study concludes that a blockchain-based web application is a feasible solution for improving transparency and coordination among stakeholders. It recommends piloting such systems in high-waste urban areas and integrating them into national waste reporting frameworks to support Sustainable Development Goals on sustainable cities and communities, responsible consumption, and climate action.

Keywords: Blockchain Technology, Data Transparency, Web Application, Solid Waste Monitoring, Digital Waste Solutions

1. Introduction

Solid waste management has become a big challenge as it critically affects the environment, health, and economy globally. According to the World Bank's What a Waste 2.0 report, the municipal solid waste, or MSW, can be projected to reach 3.4 billion tons by 2050, considering the 2.01 billion tons of MSW generated from 2016

and persist. Besides the amount of waste generated, the problem of a lack of means to determine its source accurately, consistently, and in a real-time manner, its type, and its management systems remains a gap until today, particularly in most developing regions. As cities progress, so does the number of consumers of a particular product, which contributes to the waste production in addition to other waste contributors, like urban areas. The study of Kaza et al. (2018), also indicated that the high-income countries, despite comprising only 16% of the global population, generate over one-third of the world's waste. Industrial development has added complex waste streams, such as electronic waste, or commonly known nowadays as e-waste, which significantly contributes to waste containing hazardous substances. According to the Global E-Waste Monitoring 2020, only 17.4% of the 53.6 million metric tons of e-waste that were produced in 2019 were correctly recycled. Furthermore, many regions lack appropriate infrastructure for proper waste segregation, collection, and disposal. With this concern, countries, especially those low-income countries, eventually result in open dumping or even waste burning, affecting human health and the environment.

In addition, one of the main barriers to effective waste management is the absence of standardized and real-time data collection systems. Most countries rely on outdated methods such as manual surveys or incomplete self-reporting by municipalities. Meanwhile, there are advanced technologies like Geographic Information Systems or GIS, Internet of Things or IoT, and mobile-based applications that has the potential to revolutionize data collection but are underutilized. According to UN Habitat, only a small number of cities use smart tools for waste monitoring. In many regions, a large portion of waste is handled by informal sectors like scabengers and unregistered recyclers, which leads to unrecorded waste streams. This further complicates efforts to understand where and how waste is generated.

Several implications of the data gap can be considered in the current situation. First, there is a policy and planning deficiency. Without accurate data, governments cannot design effective waste reduction strategies or allocate resources efficiently. Second, there are environmental risks. Unknown waste origins make identifying pollution sources, aggravating air, water, and soil contamination harder. And also, threats to public health. Improperly managed waste increases the risk of disease, especially in densely populated urban areas with limited access to basic services and infrastructure, and in the developing nations.

According to the Philippine Statistics Authority and DENR, waste generation has significantly increased over the past five years, especially in highly urbanized and industrial regions such as CALBARZON and Metro Manila. Similar to the cited information above, a major constraint in addressing this problem is the lack of accurate, disaggregated, and real-time data on the sources of waste. This deficiency in data undermines the effectiveness of solid waste management policies and hinders the implementation of targeted interventions. Existing systems used by local

government units (LGUs) and industries often rely on manual reporting and fragmented databases, which are vulnerable to inconsistencies and inefficiencies. As waste volumes continue to rise, there is an urgent need for transparent and reliable mechanisms to track waste generation and movement from source to disposal. In response to this growing concern, emerging technologies like blockchain offer a promising solution. Blockchain's decentralized and tamper-proof architecture can ensure secure, verifiable, and real-time recording of waste-related transactions across multiple stakeholders. This technology has already shown potential in various fields such as supply chain management and energy monitoring, and its application in environmental systems, particularly in waste tracking, warrants further exploration. This study investigates the feasibility of using a blockchain-based web application to enhance data transparency and traceability in waste management systems in the Philippines, with the aim of supporting more effective environmental governance and aligning with global sustainability goals.

1.1. Objectives

This study aims to (1) analyze trends in waste generation and identify major garbage sources; (2) evaluate the limitations in current data systems on waste streams; and (3) assess the feasibility of using blockchain technology to improve waste tracking and transparency.

1.2. Literature Review

Recent studies have highlighted the growing potential of blockchain technology to revolutionize waste management systems by enhancing transparency, traceability, and accountability. Ahmad et al. (2021) conducted a comprehensive survey on blockchain applications in smart city waste management, emphasizing how blockchain's decentralized ledger and smart contracts can automate waste tracking processes, reduce fraud, and provide real-time data access to stakeholders. Similarly, Taylor, et al. (2020) explored blockchain's role in sustainable waste management, focusing on its ability to create immutable records that incentivize recycling behavior and improve privacy and data security. These findings align with Bai and Sarkis (2021), who analyzed various blockchain use cases in waste management and provided practical guidance for initiating blockchain projects, underscoring the technology's capacity to address inefficiencies in traditional waste data systems.

Moreover, Mollah, Zhao, and Wang (2021) conducted a comprehensive review of the application of blockchain technology in sustainable waste management, highlighting its potential to address systemic inefficiencies in existing waste handling processes. The study emphasized that traditional waste management systems suffer from issues such as lack of transparency, poor data integrity, and fragmented stakeholder coordination. The authors propose blockchain as a viable technological intervention to counter these challenges due to its decentralized, immutable, and transparent architecture. Their analysis identifies how blockchain can support real-time waste tracking, facilitate the traceability of waste transactions, and ensure secure data

exchange among government agencies, waste collectors, industries, and citizens. Their review also explores various pilot implementations and theoretical frameworks across countries, demonstrating the feasibility of using smart contracts and digital tokens to incentivize proper waste disposal and recycling. However, the authors also caution that successfully implementing blockchain systems in waste management requires overcoming barriers such as high deployment costs, energy consumption, regulatory uncertainty, and technical skill gaps. Despite these challenges, the study concludes that blockchain promises to enhance waste accountability, reduce illegal dumping, and enable more sustainable waste ecosystems, especially when combined with IoT and mobile technologies. Mollah et al.'s work is a key foundation for further exploration into blockchain-based waste solutions. It provides relevant insights for countries like the Philippines, where data transparency and waste source tracking remain critical issues in urban and industrial settings.

Furthermore, the integration of blockchain with Internet of Things (IoT) devices has been proposed to enable real-time monitoring of waste streams, as discussed in the International Journal for Research in Applied Science & Engineering Technology (IJRASET, 2024), which presented a conceptual blockchain framework for innovative city waste management to improve operational efficiency and stakeholder accountability. Cost and optimization analyses by other researchers also demonstrate the economic feasibility of blockchain-based solid waste management systems, highlighting potential benefits such as reduced operational costs and enhanced data accuracy.

Despite these promising developments, several studies note existing challenges, including technological adoption barriers, scalability issues, and the need for regulatory support (Ahmad et al., 2021; Taylor et al., 2020). These limitations are particularly relevant in developing country contexts like the Philippines, where current waste data systems often suffer from fragmentation, lack of transparency, and limited stakeholder engagement. Therefore, the literature collectively suggests that blockchain technology holds significant promise for improving waste source tracking and data transparency, but its successful implementation requires a thorough understanding of local waste generation trends, system limitations, and stakeholder readiness.

1.3. Conceptual Framework

Based on the synthesis of the reviewed literature, this conceptual framework is proposed to illustrate the potential integration of blockchain technology within the waste management system in the Philippines. It encapsulates the key components and relationships identified throughout the review, including waste generation sources, data collection mechanisms, blockchain-enabled data management, and stakeholder engagement. The framework serves not only as a visual summary of how blockchain can enhance waste source tracking and data transparency, but also as a strategic guide for future research and policy development. By highlighting critical system elements and their interactions, this framework aims to inform the

design of more transparent, accountable, and efficient waste management solutions, addressing current limitations and fostering sustainable environmental governance.

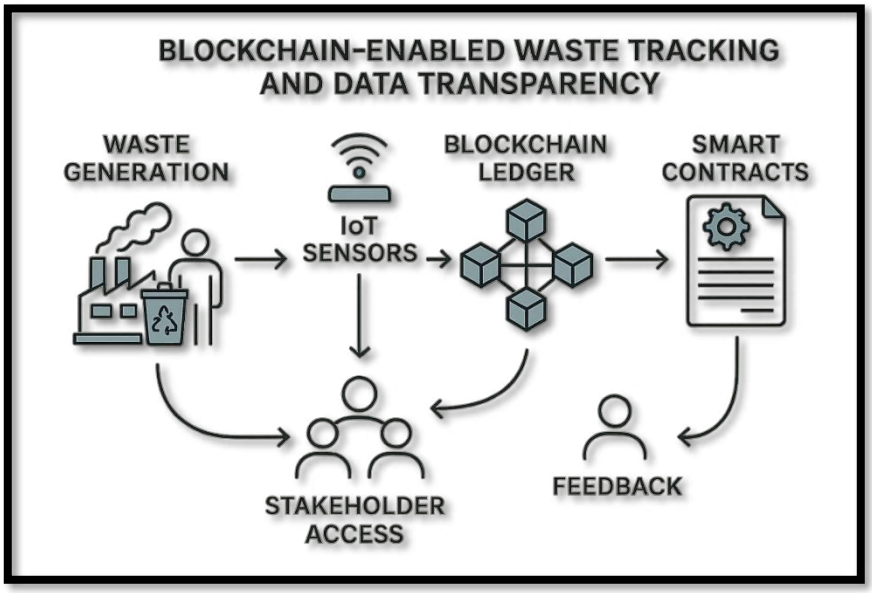

Figure 1. Conceptual Framework for Blockchain-Enabled Waste Tracking and Data Transparency

Figure 1 begins with identifying waste generation sources, such as households, businesses, and industrial facilities. These sources are equipped with IoT sensors and data collection mechanisms that capture real-time information on the type, quantity, and origin of waste. This data is then transmitted to a blockchain platform, where it is securely stored and managed.

Within the blockchain platform, smart contracts automate various processes, including waste collection scheduling, payment transactions, and regulatory compliance checks. The immutable ledger ensures that all records are tamper-proof and can be audited at any time, thereby fostering trust among stakeholders. Stakeholder access is facilitated through permissioned blockchain channels, allowing authorized entities such as government regulators, waste management companies, and community organizations, to view and verify waste data in real time.

The integration of these components results in enhanced waste tracking and data transparency, as every transaction and movement of waste is recorded and traceable. This transparency not only improves accountability but also provides valuable insights for informed decision-making and policy development. Ultimately, the framework supports the creation of a more sustainable and efficient waste management system in the Philippines, addressing current challenges and paving the way for innovative solutions in environmental governance.

2. Methodology

This study explores the feasibility of implementing a blockchain-based garbage tracking system in the Philippines through a qualitative, documentary-based research approach. The methodology is structured around three key objectives: analyzing waste generation trends, assessing gaps in current waste data systems,

and conducting a systematic literature review on blockchain applications in waste management. This multi-faceted approach ensures a comprehensive understanding of both the contextual realities and technological potential relevant to the Philippine setting.

2.1. Waste Trend Analysis

To establish a foundational understanding of waste generation patterns, relevant data from 2018 to 2023 were collected from reputable national and international sources, including the Philippine Statistics Authority (PSA), the Department of Environment and Natural Resources (DENR), and the World Bank. The data encompassed metrics on waste volume, composition, and sources across various regions, with a particular focus on urban and industrialized areas such as Metro Manila and CALABARZON. Descriptive and trend analyses were conducted to identify significant changes and key contributors to waste generation, providing critical insights into areas where blockchain-enabled tracking could have the most impact.

2.2. Gap Analysis of Current Data Systems

A comparative assessment was performed on the existing waste data collection and monitoring systems utilized by Local Government Units (LGUs) and national environmental agencies. This analysis focused on identifying limitations related to data accuracy, transparency, frequency of reporting, and interoperability between systems. By examining official reports, system documentation, and stakeholder feedback, the study highlighted systematic weaknesses such as fragmented data sources, inconsistent reporting standards, and a lack of real-time data access. These findings underscore the need for innovative solutions like blockchain to address these challenges.

2.3. Systematic Literature Review

A systematic review of scholarly articles, case studies, and international report was undertaken to evaluate the current state of blockchain applications in waste management. The review prioritized studies that detailed blockchain implementations, assessed technical feasibility, and discussed socio-political factors influencing adoption. Key references, including Mollah, et al. (2021), provided conceptual frameworks and empirical evidence on blockchain's role in enhancing environmental data transparency and traceability. This comprehensive review informed the study's assessment of blockchain's potential benefits and barriers within the Philippine Context.

3. Results and Discussion

3.1. Waste Trend Analysis

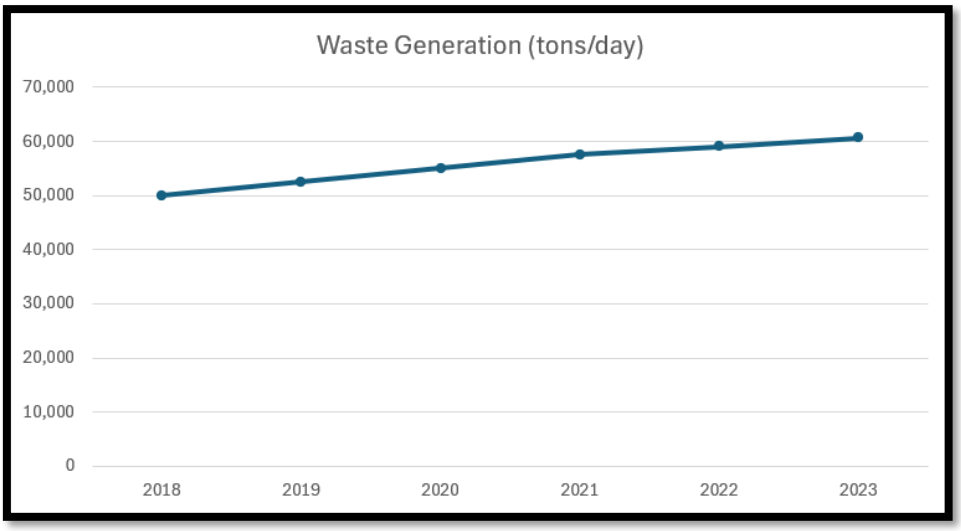

Figure 2. Projected Daily Solid Waste Generation in the Philippines (2018-2023)

The projected daily solid waste generation in the Philippines from 2018 to 2023 shows a marked and continuous increase, reflecting the country's rapid urbanization and economic growth. In 2018, the estimated daily waste generation was approximately 52,500 tons, which steadily rose each year to reach 60,640 tons per day in 2023 shown in **Figure 2** (PSA (2023)& Statista (2024)). This upward trend highlights the mounting pressure on existing waste management infrastructure and the urgent need for innovative solutions.

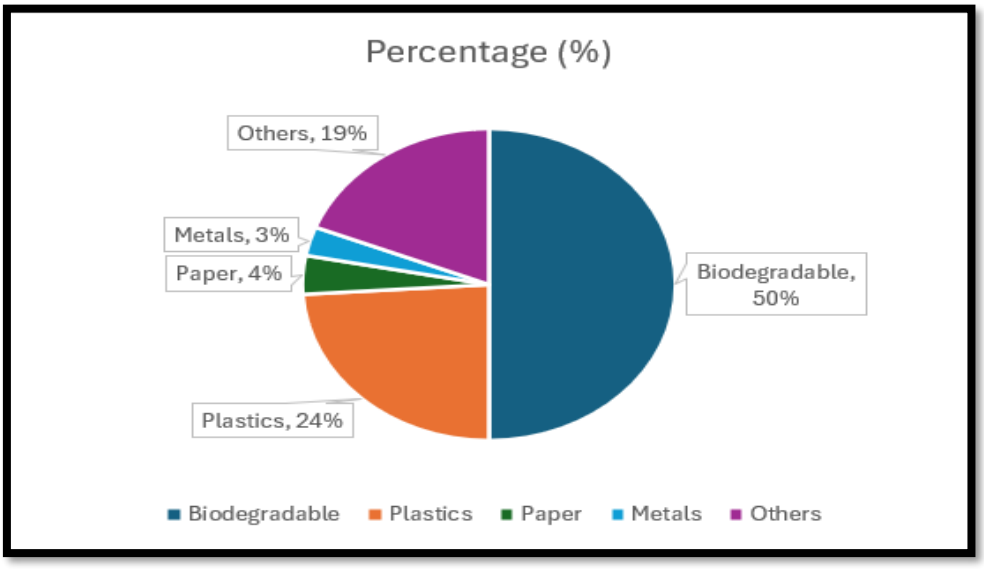

Figure 3. Waste Composition in the Philippines

The composition of waste in the country is dominated by biodegradable materials, primarily food waste, which constitutes about 50% of municipal solid waste shown in Figure 3. Recyclables such as plastics, paper, and metals make up roughly 28%, with plastics alone accounting for nearly 24% of total waste (United Nations Development Programme (2024) &Bueta, et al. (2023)). Alarmingly, only about 28%

of plastic waste is recycled, while a significant portion ends up in landfills, dumpsites, or leaks into the environment and oceans, contributing to pollution and resource loss. The economic impact of plastic waste is substantial, with an estimated loss of $790 million to $890 million annually due to inefficient material recovery (Philippine Star (2023)).

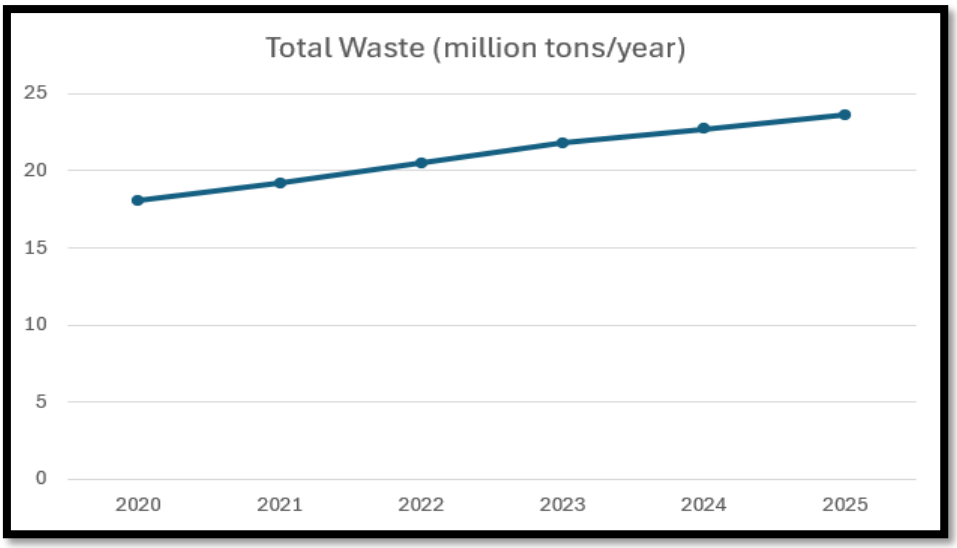

Figure 4. Projected Total Solid Waste Generation in the Philippines (2020-2025)

Looking ahead, projections indicate that total solid waste generation will continue to rise, reaching an estimated 23.6 million tons annyally by 2025 shown in figure 4. This growth is primarily driven by urban and industrial regions, with CALABARZON recently surpassing Metro Manila as the largest waste-generating area. Metro Manila generated approximately 9,200 tons per day in 2016, but CALABARZON's rapid industrialization has led it to overtake Metro Manila in recent years shown in Figure 5 below (Statista (2024) & Philippine Senate Economic Planning Office (2017)).

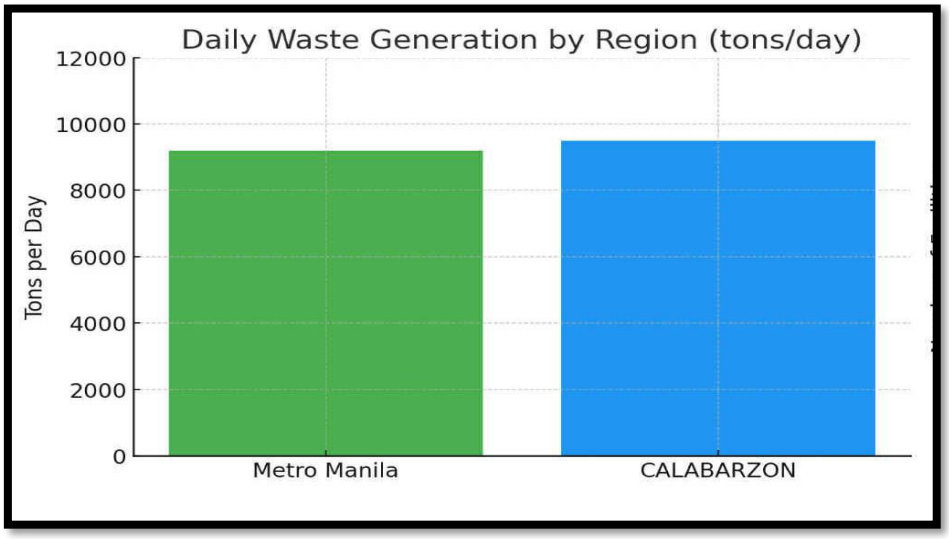

Figure 5. Waste Generation by Region (Metro Manila and CALABARZON)

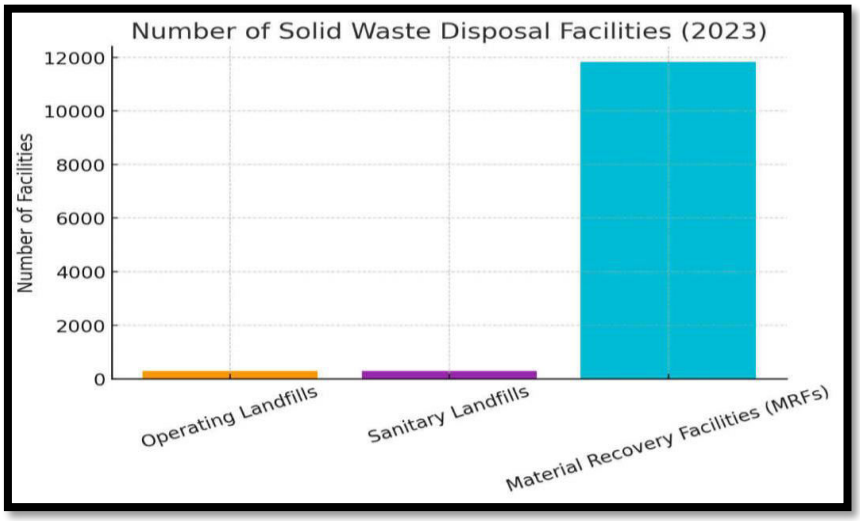

Figure 6. Number of Solid Waste Disposal Facilities (2023)

The country's waste management infrastructure currently includes 299 operational sanitary landfills servicing 675 local government units (LGUs), alongside 11,823 Material Recovery Facilities (MRFs) servicing over 18,000 barangays shown in Figure 6. However, these facilities are insufficient to cope with the increasing waste volumes, leading to challenges such as illegal dumping, reduced landfill lifespan, and inefficient waste segregation (Environmental Management Bureau, Department of Environment and Natural Resources. (2023)).

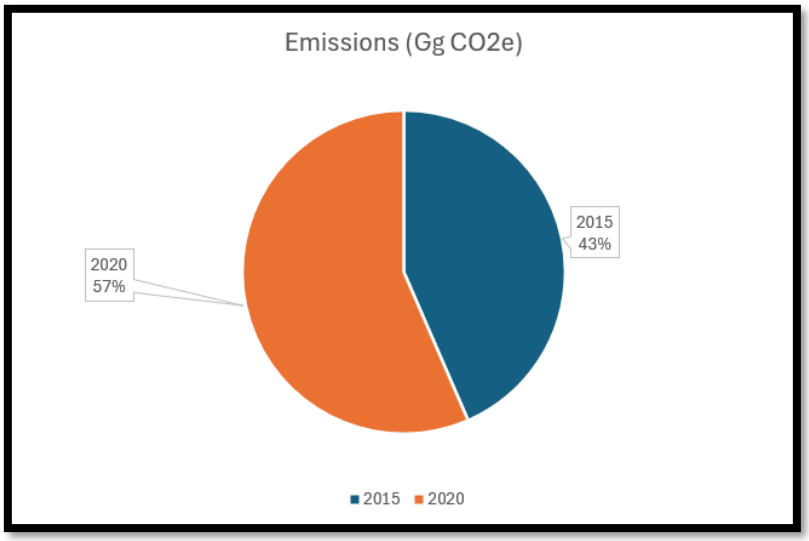

Figure 7. Greenhouse Gas Emissions from Waste Sector in the Philippines (2015 vs. 2020)

The environmental impact of the growing waste stream is evident in the increasing greenhouse gas emissions from the waste sector. Emissions rose from 23,176 Gg CO2e in 2015 to 30,122 Gg CO2e in 2020, with methane emissions from solid waste decomposition being a significant contributor as shown in Figure 7. This trend underscores the urgent need for sustainable waste management strategies that can

mitigate environmental harm (Environmental Management Bureau, Department of Environment and Natural Resources. (2023)).

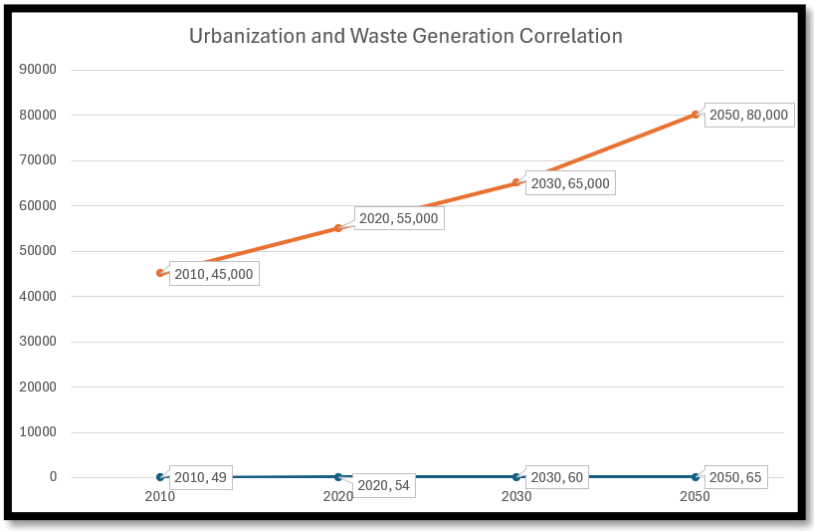

Figure 8. Urbanization and Waste Generation Correlation

Urbanization plays a pivotal role in driving waste generation, with the urban population increasing from 49% in 2010 to over 54% in 2020, and projected to reach nearly 65% by 2025 as shown in figure 8. This demographic shift, coupled with rising consumption patterns and a transition to an industrial and service-based economy, has led to increased generation of non-biodegradable waste such as plastics and metals (United Nations Development Programme. (2024, August 11)).

In summary, the waste trend analysis highlights a growing and complex waste management challenge in the Philippines. Increasing waste volumes, changing waste composition, insufficient infrastructure, and environmental impacts all point to the need for innovative solutions. These findings establish a critical foundation for exploring blockchain technology as a tool to enhance waste source tracking, improve data transparency, and strengthen governance in the Philippine waste management system.

3.2. Gap Analysis of Current Systems

The comparative analysis of waste data systems used by Local Government Units (LGUs) and national agencies in the Philippines features distinct weaknesses in data accuracy, transparency, reporting frequency, and system integration, which collectively impede effective waste management.

3.2.1. Data Accuracy

Waste data collection at the LGU level is often manual or semi-digital, relying heavily on physical surveys and reports from waste collectors or barangay officials. This process is prone to human error, inconsistent data recording, and underreporting, especially in informal sectors. Common example is that, many LGUs lack the technical capacity and resources to implement automated or sensor-based data capture systems, resulting in inaccuracies and delays in waste

volume and source data based on the Senate Economic Planning Office on November, 2017.

On the other hand, National Bodies such as the Department of Environment and Natural Resources (DENR) and the National Solid Waste Management Commission (NSWMC) aggregate data reported by LGUs but face challenges in verifying and standardizing this data. The lack of a unified data validation mechanism leads to discrepancies and gaps in national waste statistics.

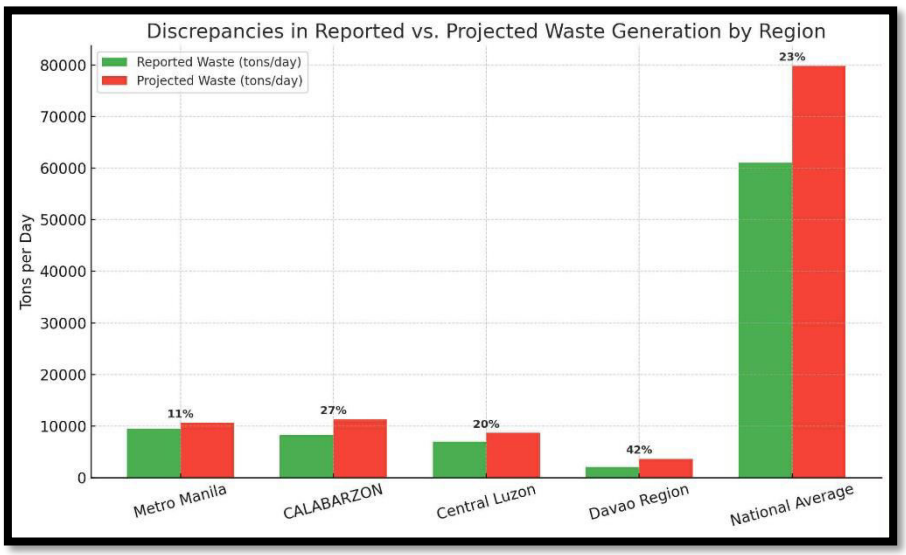

Figure 9. Discrepancy in Reported vs. Projected Waste Generation

Figure 9 shows the analysis of reported versus projected waste generation across major regions in the Philippines reveals significant discrepancies that highlight deep-rooted issues in data accuracy and waste monitoring systems. According to the NSWMC (2022) and PSA (2023), Metro Manila reported approximately 9,499 tons/day of solid waste generation. However, using the World Bank's per capita benchmark of 0.7 kg/person/day (Kasa et al., 2018), the projected waste for its estimated 13.8 million population in 2022 should be closer to 10,660 tons/day, showing a discrepancy of around 11%. This suggests that at least 1,161 tons/day of waste may be unaccounted for such as waste that is likely being managed informally, illegally dumped, or simply not reported due to flawed local monitoring systems.

The situation is more concerning in regions like CALABARZON and Davao Region, where discrepancies reached 27% and 42%, respectively. For instance, Davao, with a population of over 5.2 million, reported only 2,118 tons/day of waste, whereas the projected figure is around 3,670 tons/day. This large gap implies that nearly 1552 tons/day of waste may be missing from formal records.

Nationally, the total reported waste is approximately 61,000 tons/day, whereas the projected volume based on population and per capita waste generation should be 79,800 tons/day, indicating a nationwide underreporting of 23%. This discrepancy translates to a daily shortfall of about 18,800 tons of unreported

waste, which has major implications for environmental management, public health, and infrastructure planning.

Several factors contribute to these discrepancies. Primarily, the LGUs' manual or inconsistent reporting and the lack of standardized digital data systems to consolidate and verify submissions. Underestimation of informal sector contributions, such as street sweepers, junk shops, and unauthorized disposal. Also, inaccurate population estimates in some jurisdictions and the absend of real-time tracking and monitoring tools. Below is the Figure 10 showing the Audit Report of NSWMC in Data Submission Accuracy.

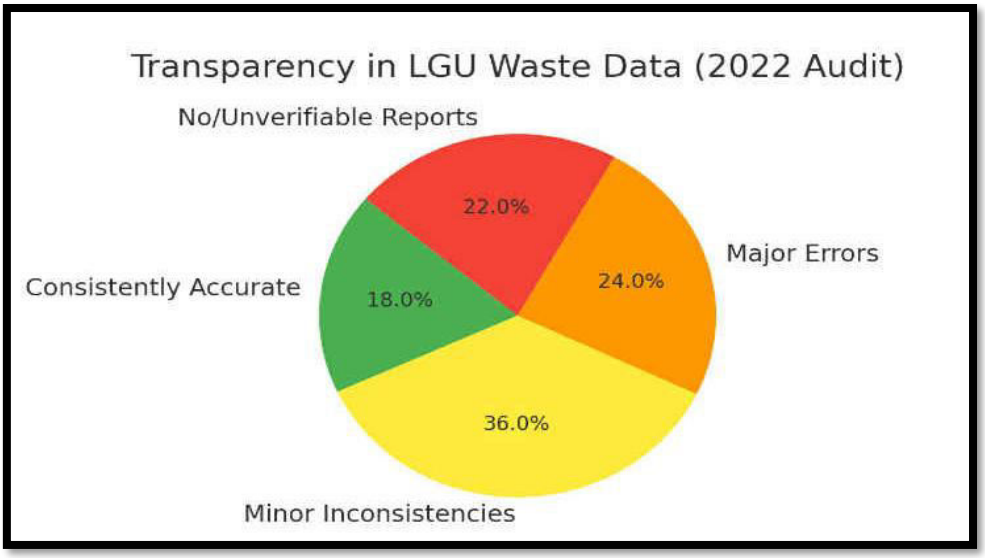

Figure 10. Data Submission Accuracy (Audit Reports by NSWMC)

The significance of the Data Submission Accuracy based on audit reports by the National Solid Waste Management Commission (NSWMC) lies in its direct impact on the reliability of national waste management planning and policy-making. With only 18% of LGUs consistently submitting accurate and verifiable data, and a combined 60% of reports containing minor to major errors or being unverifiable, the Philippine solid waste data ecosystem faces serious credibility issues. These inaccuracies hinder the government's ability to assess actual waste volumes, identify high-risk areas, and design responsive programs. Moreover, without a standardized, transparent reporting mechanism, resource allocation, environmental compliance, and strategic interventions remain inefficient and misinformed. The data gaps underscore the urgency of adopting technology-driven systems, such as blockchain, to improve accuracy, accountability, and real-time monitoring of waste data at all administrative levels.

3.2.2. Transparency

According to the Open Government Partnership 2024, Transparency in waste data dissemination varies widely among LGUs. While some urban LGUs have begun deploying digital platforms such as Baguio City's household waste tracking app launched in 2024, to enhance data transparency and incentivize waste

reduction, many still maintain opaque systems with limited public access to waste data. This restricts community engagement and accountability.

Meanwhile, according to the World Bank & NSWMC 2024, National agencies publish periodic reports and roadmaps, for example the PH Plastic Roadmap by the Solid Waste Management Division, but these often rely on aggregated LGU data that may lack granularity and timeliness. Public access to detailed, real-time waste data remains limited, constraining transparency and stakeholder participation.

3.2.3. Reporting Frequency

According to the Senate Economic Planning Office on November, 2017 reporting intervals at the LGU level are inconsistent, ranging from quarterly to annual submissions, with some areas experiencing delays or missing reports altogether. This irregularity hinders timely decision-making and responsiveness to waste management issues, particularly in rapidly urbanizing regions like Metro Manila and CALABARZON.

While National agencies typically compile and release waste data annually or biannually, depending on the program. The time lag between data collection and reporting reduces the effectiveness of policy interventions and monitoring of waste management progress.

3.2.4. System Integration and Interoperability

According to the Metro Manila Solid Waste Management Information System, Waste data systems at the LGU level fragmented, with many operating in silos without standardized data formats or interoperable platforms. This fragmentation complicates data consolidation and cross-sector collaboration. Metro Manila's Solid Waste Management Information System (SWMIS) integrates data from 17 LGUs but is still limited in scope and real-time capabilities.

On the other hand, National agencies face challenges integrating data from diverse LGU systems and informal waste sectors. Efforts such as the integration of informal sector data into LGU systems are ongoing but not yet widespread or fully operational.

Table 1. Summary of the Comparative Weaknesses in Waste Data Systems

Aspect	LGUs	National Agencies
Data Accuracy	Manual/semi-digital collection prone to errors; limited automation and validation	Aggregates LGU data; lacks unified validation; discrepancies persist
Transparency	Variable; some digital initiatives exist but limited public access overall	Periodic aggregated reports; limited real-time public data access
Reporting Frequency	Inconsistent; quarterly to annual; delays common	Annual or biannual; time lag reduces responsiveness

System Integration	Fragmented, siloed systems; limited interoperability	Challenges integrating diverse LGU data; informal sector data largely excluded

As shown in Table 1, both LGUs and national agencies face significant challenges in waste data accuracy, transparency, reporting frequency, and system integration. LGUs struggle with manual data collection, inconsistent reporting, and fragmented systems, while national agencies contend with aggregating and validating disparate data sources. These weaknesses highlight the urgent need for an interoperable, real-time, and transparent data system like potentially enabled by blockchain and digital technologies to improve waste source tracking and management efficiency in the Philippines.

3.3. Systematic Literature Review

The systematic literature review focused on global and local studies exploring the integration of blockchain technology into waste management systems, with particular emphasis on waste source tracking and data transparency. The reviewed literature consistently supports the potential of blockchain to revolutionize environmental monitoring by offering a secure, immutable, and transparent system for recording and verifying waste-related data.

One of the most relevant studies, Mollah et al. (2021), emphasizes how blockchain can streamlin waste data management by decentralizing control, reducing the risk of data manipulation, and improving traceability from source to disposal. Similar research from Zhang et al. (2020) highlights blockchain's role in enhancing trust among multiple stakeholders, including local governments, private waste handlers, and the general public through real-time data accessibility and automated compliance via smart contracts.

Findings also indicate that blockchain systems have been successfully piloted in countries like India, the Netherlands, and South Korea, where digital ledgers were used to track industrial, plastic, and electronic waste. These systems provided improved accountability and reduced cases of illegal dumping and unreported waste generation.

For the Philippines context, where data fragmentation, poor integration between agencies, and limited community participation persist, the reviewed literature suggests that blockchain could fill critical gaps in data transparency. However, implementation challenges such as infrastructure cost, low digital literacy, and lack of clear policy frameworks must be addressed. Overall, the literature supports the feasibility and relevance of blockchain-based applications as a long-term solution to improve waste source tracking and build a transparent, data-driven environmental governance system in the Philippines.

4. Conclusions

This review paper examined the feasibility of using blockchain technology to improve waste source tracking and data transparency in the Philippines, a country

currently facing substantial challenges in its solid waste management systems. Through an analysis of national waste trends, data system gaps, and a comprehensive review of relevant literature, the study identified critical weaknesses in the current approaches used by local government units and national agencies, specifically in terms of data accuracy, reporting frequency, transparency, and system integration. These limitations hinder the development of effective policies and the efficient allocation of resources, ultimately undermining environmental governance and public health. Blockchain technology, with its core features of decentralization, immutability, and real-time access, presents a transformative opportunity to modernize the waste management ecosystem. The study's proposed conceptual framework illustrates how blockchain, in conjunction with IoT and mobile technologies, can enable secure, traceable, and automated waste monitoring systems. Moreover, the findings highlight that beyond offering technical solutions, blockchain can strengthen stakeholder accountability and support the Philippines' alignment with Sustainable Development Goals. As such, this review recommends the piloting of blockchain-based waste tracking applications in high-waste urban regions, along with capacity-building initiatives and policy development to support their adoption. Ultimately, this research contributes a localized, context-aware perspective to the global discourse on digital innovation in environmental sustainability, providing a foundation for future empirical studies and system implementations in developing country settings.

5. Acknowledgements

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