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A Data-Driven Extended Producer Responsibility Platform for Plastic Waste Traceability and Recycling Management

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ABSTRACT

Plastic waste management remains a critical challenge in developing countries due to fragmented recycling systems, limited traceability, and insufficient integration of material-flow information. This study proposes a data-driven extended producer responsibility (EPR) platform that integrates transactional records, verification mechanisms, and monitoring functions to improve transparency and accountability in plastic waste recycling. The platform was developed based on sales and purchase data collected from recycling stakeholders in Indonesia and was designed to connect producers, collectors, recyclers, verifiers, and administrators through a unified information system. A comprehensive analysis of plastic waste transactions during 2024 was conducted to characterize material flows and evaluate the applicability of the proposed framework. The results identified 18 categories of plastic waste materials, with nine categories recorded in purchase transactions totaling 27,028,801 kg and seven categories recorded in supply transactions totaling 4,896,392 kg. The developed platform successfully implemented transaction recording, verification, monitoring, and user management functions. Functional evaluation confirmed the reliability of the system components, while usability assessment indicated strong acceptance among stakeholders. The findings demonstrate that transaction-based digital platforms can provide an effective mechanism for improving plastic waste traceability and supporting EPR implementation. This study contributes to the development of digital circular economy infrastructure by providing a scalable information framework for transparent recycling management.

1. INTRODUCTION

The plastic waste problem in Indonesia is becoming increasingly complex due to rising consumption of single-use products and limited capacity for post-consumer waste management. This challenge relates not only to the ever-increasing volume but also to the inherent difficulty of plastic biodegradation, leading to long-term accumulation in the environment. Various global studies indicate that post-consumer plastic is one of the largest contributors to marine and terrestrial pollution, as outlined by Godfrey [1], who emphasized that developing countries with large populations face the highest risk of plastic waste leakage. On the other hand, Horodytska et al. [2] reported that more than 75% of plastic produced since 1950 now ends up in landfills, indicating the limited effectiveness of waste management systems. A similar situation occurs in Indonesia, where recycling infrastructure is still unable to accommodate the entire flow of plastic waste, resulting in a significant imbalance between the amount of plastic produced and that successfully recycled. This situation underscores the urgency of developing approaches to close data gaps, enhance traceability, and ensure more systematic plastic management through multi-actor collaboration.

Studies on plastic waste management indicate that successful recycling depends heavily on consistent material-flow data and clear mechanisms of producer responsibility. Several studies emphasize the importance of policy schemes that shift the burden of waste management from governments to producers, the parties that produce plastic products. Therefore, extended producer responsibility (EPR) has been widely adopted in various countries as a policy strategy to increase plastic collection and recycling for sound waste management [3], as demonstrated in a study by Rubio et al. [4], which outlined the effectiveness of EPR in increasing packaging waste collection rates. Furthermore, Lorang et al. [5] found that implementing EPR in the European plastics sector improved material collection efficiency and reduced environmental leakage. In developing countries, non-standardized management systems impede optimal EPR implementation, particularly when sales, purchasing, and waste-flow data are not integrated. This situation underscores the urgent need for a data-driven approach to EPR schemes to achieve tangible impacts on plastic circularity.

Research on EPR in recent years has highlighted how producer responsibility mechanisms can improve supply chain transparency and encourage sustainable industrial practices. Lindhqvist [6], an early proponent of the EPR concept, emphasized that a rigorous monitoring and reporting system must accompany the shift in responsibility to producers to ensure that the policy is not merely administrative. In another study, Hammoud et al. [7] showed that the effectiveness of EPR is significantly influenced by the availability of information systems capable of validating upstream and downstream material flows, particularly in countries with immature waste management infrastructure. Furthermore, Magrini et al. [8] emphasized that the success of modern EPR hinges on the ability of digital platforms to ensure adequate traceability, enabling real-time monitoring of collection, processing, and recycling activities. These findings underscore the need for technology integration to ensure that recycling claims and producer contributions can be accurately verified.

Recent research shows that digital transformation plays a crucial role in strengthening the implementation of EPR, particularly through the development of data-driven platforms and traceability systems. A study by Arbeláez-Estrada et al. [9] emphasized that the primary challenge of EPR lies in the traceability of post-consumer waste, prompting the development of approaches using computer vision and multimodal data to identify producers accurately. Similarly, Dissanayake et al. [10] demonstrated that the integration of technologies such as blockchain, IoT, and data analytics can improve transparency and accountability in the waste supply chain. Digital platforms such as CleanHub have also demonstrated effectiveness in documenting waste flows in real time through data-driven tracking and visual verification systems [11]. Furthermore, recent studies highlight the synergy between EPR and digital product passports to improve circularity and cross-system data management [12]. These studies emphasize that digitalization is a key element in improving the effectiveness, transparency, and scalability of modern EPR systems.

Recent research shows that integrating digital technologies into the EPR framework is becoming an increasingly important approach to improving transparency and traceability in plastic waste management. A study by Sobanaa et al. [13] emphasized that digitalization enables more accurate product lifecycle monitoring through integrated data-driven systems. Furthermore, Bressanelli et al. [14] identified that digital platforms and the Internet of Things (IoT) play a crucial role in supporting circular economy models, particularly in connecting material and information flows in real time. In the context of EPR, Khetriwal et al. [15] demonstrated that implementing digital systems can improve producer accountability through more transparent reporting and verification mechanisms. Furthermore, Kristoffersen et al. [16] explained that the use of digital platforms in the supply chain allows for increased operational efficiency and reduced data discrepancies. Overall, this literature confirms that data-driven digital platforms are a key component in strengthening the implementation of modern EPR.

Although various studies have outlined the benefits of EPR and the importance of an integrated data system, a clear research gap remains: the lack of a sales and purchase data-based EPR platform capable of comprehensively mapping plastic material flows in the Indonesian context. This gap is crucial because, without transaction-based traceability, recycling claims are challenging to verify, and the risk of data manipulation remains. Therefore, the objective of this research is to develop an EPR platform based on sales and purchase data to ensure transparency and verifiability of the plastic material recycling process in Indonesia. Furthermore, the urgency of this research lies in the need to build a digital system that involves all actors, producers, collectors, recyclers, verifiers, and administrators, to ensure more accountable and measurable plastic waste management. This effort is expected to pave the way for a more robust and credible EPR implementation and support improvements in national plastic waste governance.

2. MATERIAL AND METHOD

This research was conducted through several systematically designed stages to ensure the development of the EPR platform meets user needs and supports accurate traceability of plastic material flows. The first stage was a needs analysis, conducted to identify the platform's functional and non-functional requirements and to map the EPR process in Indonesia. At this stage, the needs of each stakeholder, including producers, collectors, recyclers, administrators, and verifiers, were explored through document reviews, internal discussions, and literature reviews on plastic waste management practices in various countries. The types of Plastic Waste Materials traded and purchased were also identified. This analysis provided the initial foundation for ensuring that the platform's functionality could support comprehensive recording, reporting, verification, and monitoring of the recycling supply chain [17].

The next stage is conceptual design, which includes the development of system architecture, workflow, core features, and user interface design. Conceptual design is carried out by integrating the results of the needs analysis and drawing on relevant design concepts [18], including the design of the EPR information system and associated policies. At this stage, a data flow design is produced that connects each actor in the EPR scheme, enabling all transactional activities, validations, and material movement to be mapped on a single platform. Figure 1 depicts the operational architecture of the EPR application, illustrating how the transaction recording, verification, monitoring, and user management modules interact. The transaction recording feature captures material flow data systematically from each actor in the recycling chain. The verification feature validates recorded transactions through a designated verifier to ensure data accuracy and consistency. The monitoring feature provides real-time visualization of recycling activities to support transparency and traceability. These integrated features reduce data inconsistencies between purchase and supply records within the EPR system.

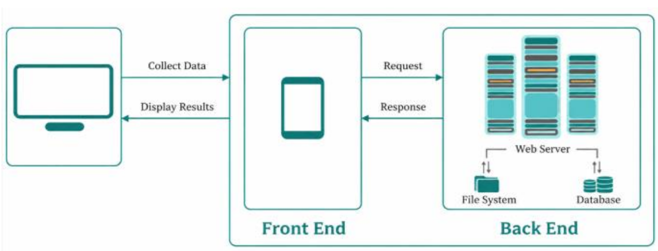

Figure 1. Architecture design of platform design framework

The next stage is the development and implementation of an initial prototype. This process follows the principles of the software development life cycle (SDLC), enabling rapid iteration and responsiveness to changing needs [19]. Development activities include interface and back-end programming, database integration, and feature adjustments in accordance with the conceptual design. After the main modules are completed, initial functional testing is conducted to ensure all components operate as designed. Testing includes validating transaction recording flows, verifying processes by verifiers, real-time monitoring by administrators, and assessing feature compatibility across various user devices.

Functional testing was conducted to ensure each feature operates according to predefined system requirements. Data accuracy was verified through cross-checking mechanisms between recorded transactions and validated outputs. System reliability was evaluated based on consistency, responsiveness, and data integrity during testing scenarios. User feedback was incorporated through usability testing to assess system performance and practical applicability.

The evaluation and validation phase was conducted through simulations and field trials to assess the platform's performance against user needs and established objectives. This evaluation focused on system reliability, data recording accuracy, and the platform's ability to facilitate a transparent verification process [20]. Furthermore, validation tests were conducted to ensure the integrity of the generated data and the functional stability of the system across various usage scenarios. Once the platform was deemed to meet the initial criteria, an external verification phase was conducted, during which the platform was introduced to key stakeholders to obtain feedback and assess readiness for broader adoption. This phase was also used to develop a dissemination strategy and to increase the platform's utilization rate.

The final stage is ongoing maintenance and development, which are carried out continuously to ensure that the platform remains responsive to user needs and to the dynamics of EPR policies. This activity includes routine improvements based on user feedback, feature enhancements that enhance the value of the recycling process, and further research to strengthen validation mechanisms within the supply chain [21]. Furthermore, a workflow diagram of the recycling process, from material collection and transaction recording to recycler processing and third-party verification, is used to ensure that all activities are appropriately monitored by administrators, thus maintaining the transparency and accountability of the EPR scheme.

The EPR platform design framework developed in this study was designed to ensure that all data flows related to the sale and purchase of plastic materials can be recorded, verified, and monitored in a single, integrated system. This framework integrates the basic principles of EPR, information system architecture, and the operational needs of five leading actors: producers, collectors, recyclers, administrators, and verifiers. According to Centobelli et al. [22], each actor must be granted distinct access and functional rights based on their role in the recycling supply chain to ensure data security, operational transparency, and traceability of material flows. During the framework development stage, a mapping of the data entities involved was conducted, including the type of plastic material, transaction volume, verification status, and recycling process track record. This mapping resulted in an architectural structure consisting of four core modules: transaction recording, verification, monitoring, and user management, which are interconnected and serve as the foundation for platform operations.

In addition to ensuring that the platform's basic functions operate smoothly, this design framework also addresses interoperability and system sustainability. The architectural design is intended to be flexible to support future feature enhancements, including integration with external databases or government waste-management reporting systems. The design framework also accommodates the need for an automated audit trail, enabling the clear recording of data changes and user activity for transparency and oversight, as reported by Sewpersadh [23]. This platform design framework is intended to support efforts to substantiate recycling claims, minimize the risk of data manipulation, and strengthen the implementation of EPR in the context of plastic waste management in Indonesia.

3. RESULT AND DISCUSSION

3.1 Results of the type of plastic waste materials survey for the platform

The diversity of plastic waste materials in the recycling supply chain is a key basis for understanding the complexity of EPR-based waste management, as shown in Table 1. The table lists 18 types of plastic materials along with their symbols and functional explanations. Table 1 shows that plastic waste does not only originate from single resins such as Polipropilena (PP)-1, High-Density Polyethylene (HDPE), Low-Density Polyethylene (LDPE), or LDPE-1, but also includes multilayer groups with structural variations, namely Multilayer (MLY), MLY-1, MLY-2, Multilayer Non-Metallized (MLY-NM), and Multilayer Metallized (MLY-M), which have different physical characteristics that affect the level of difficulty in the recycling process. In addition, there are categories of materials with energy functions, such as briquettes (BRK), Refuse-Derived Organic Fuel (RDF-OR), inorganic Refuse-Derived Organic (RDF-AO), and RDF-AO-1, which indicate that part of the plastic waste stream is diverted into alternative fuels. The presence of Used Beverage Cartons (UBC) and UBC-1 on the list shows that the waste management system not only focuses on polymer-based plastics but also includes mixed materials such as aluminum, which is commonly used in beverage packaging. The classification structure presented indicates that each material type has distinct characteristics, handling processes, and recycling potential; therefore, the EPR platform must be able to record these variations precisely.

The findings on the variety of plastic waste types in this study align with previous studies emphasizing that material diversity is a significant challenge in modern recycling systems. Research by Achilias et al. [24] showed that single-resin materials such as HDPE and PP are easier to reprocess because of their high thermal stability. In contrast, multilayer resins often do not enter the recycling cycle due to the difficulty of separating the polymer layers. Another study by Ting et al. [25] also underscored that material variations, particularly in the RDF category or organic-inorganic mixtures, require stricter pre-sorting to ensure the quality of recycled products and processing efficiency. The presence of 18 material types in this study reflects the empirical conditions of plastic waste flows in Indonesia. Furthermore, this aligns with previous research indicating that the EPR system requires information technology capable of mapping materials in detail, so that recycling claims can be scientifically and administratively justified.

Table 1. Type of plastic waste materials

Symbol	Type of Waste Material	Explanation
PET-PP	Polietilena tereftalat (PET)-Polipropilena (PP)	Can be recycled into plastic pellets
PET-1	PET-1	PET bottles that have been sorted and are ready to be pressed
PP-1	PP-1	PP that has been ground into chips
HDPE	High density polyethylene	Hard plastics such as shampoo bottles, jerry cans, and buckets
LDPE	Low density polyethylene	Thin plastic, such as plastic bags and vegetable plastic
LDPE-1	LDPE-1	LDPE is shredded into chips
MLY	Multilayer	Multilayer plastic labels on beverage bottles
MLY-1	Multilayer-1	Pre-milled multilayer sachets
MLY-2	Multilayer-2	Full multilayer packaging
MLY-NM	Multilayer non-metallized	Multilayer packaging without metal foil, such as non-foil sachets
MLY-M	Multilayer metallized	Multilayer packaging with metal foil (for example coffee and snack sachets)
BRK	Briket	Compacting waste into an alternative solid fuel
UBC	Used beverage containers	Whole aluminum beverage cans
UBC-1	UBC-1	Ground aluminum beverage cans
RDF	Refuse derived fuel	Fuel from shredded mixed waste
RDF-OR	Organic RDF	RDF from dry organic materials such as paper and wood
RDF-AO	Inorganic RDF	Plastic and rubber-based RDF with high calorific value
RDF-AO-1	Inorganic RDF-1	Variations of inorganic RDF with different compositions

Note: HDPE = High-Density Polyethylene; LDPE = Low-Density Polyethylene; MLY = Multilayer; BRK = Briquettes; UBC = Used Beverage Cartons; RDF = Refuse-Derived.

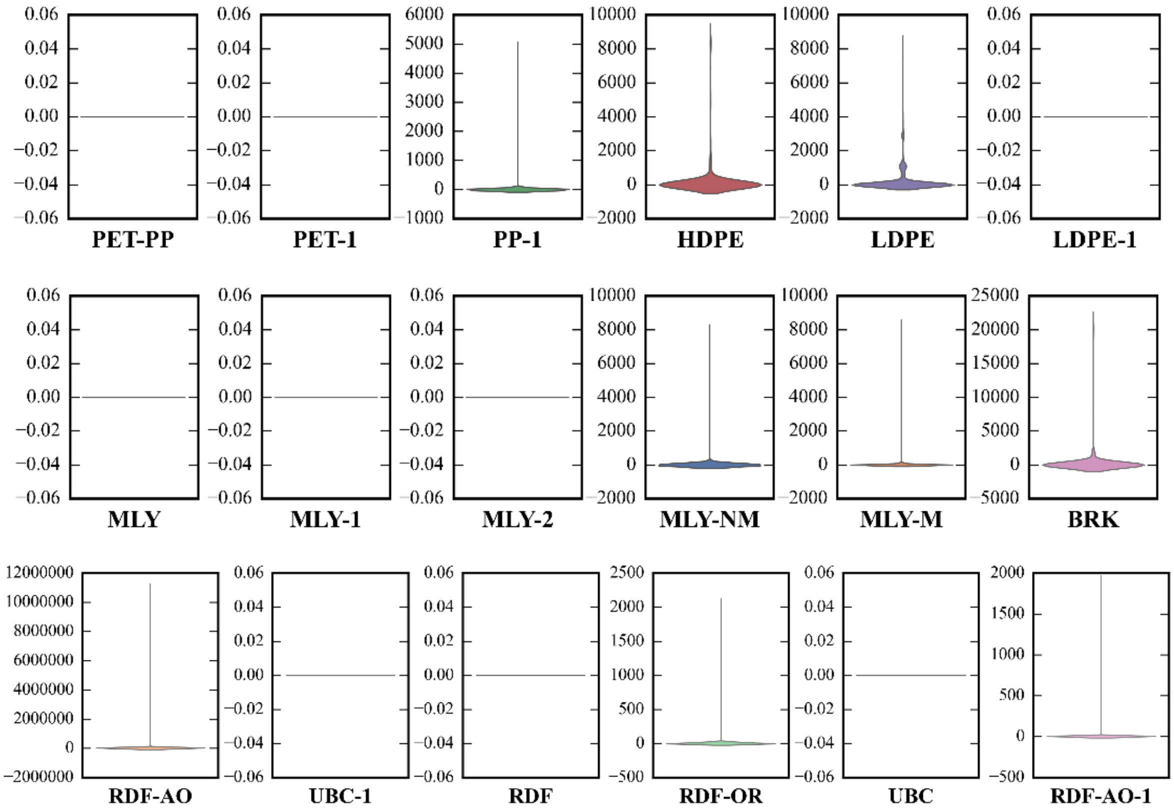

Figure 2. Violin plot distribution of plastic waste materials sales data for the 2024 period

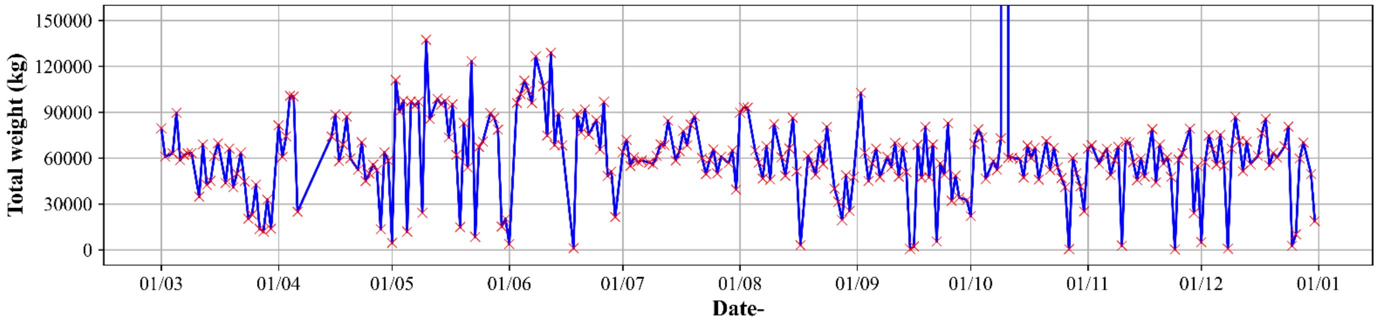

Figure 3. Total daily sales for all types of plastic waste materials in the 2024 period

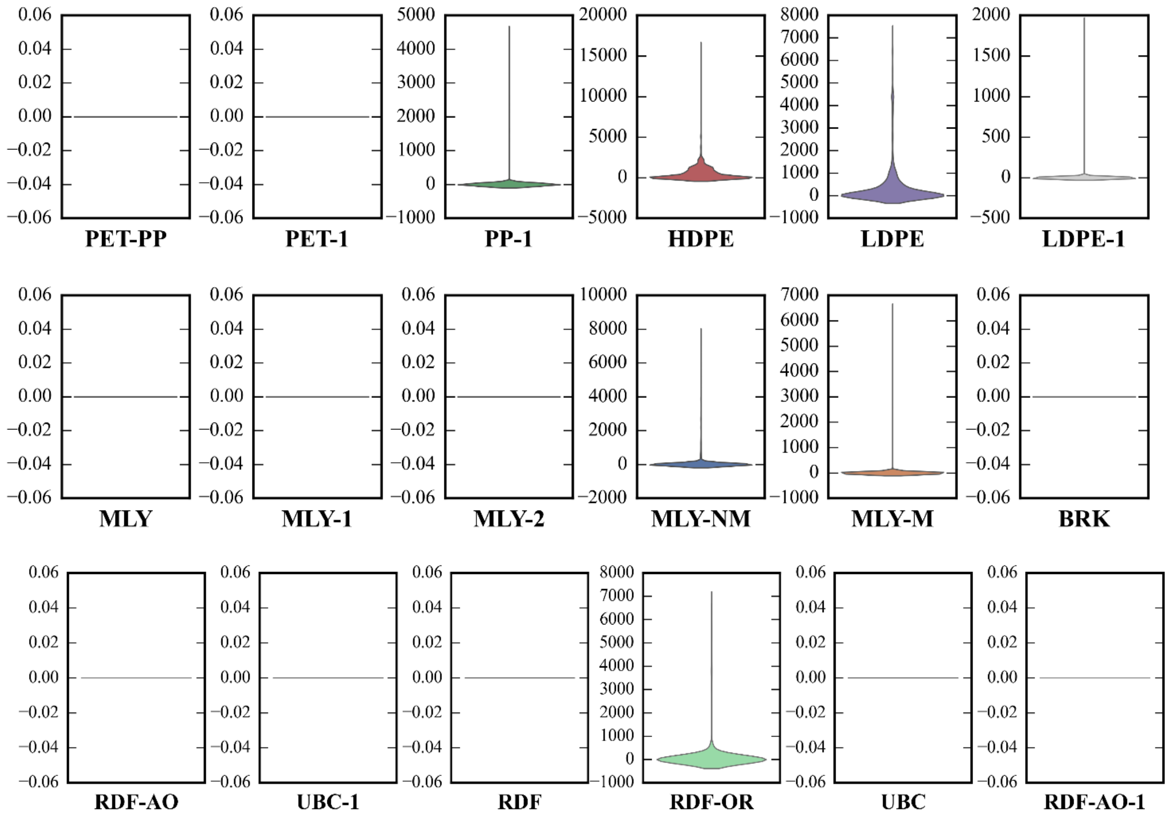

Figure 4. Violin plot distribution of plastic waste materials purchase data for the 2024 period

3.2 Analysis of the amount of plastic waste materials

Variations in the distribution of plastic waste sales throughout 2024 illustrate significant differences in the frequency and volume of trade for each material type, as shown in Figure 2. The data show that nine of the 18 plastic waste types were most frequently purchased by consumers and retailers: PP-1, HDPE, LDPE, MLY-NM, MLY-M, BRK, RDF-OR, RDF-AO, and RDF-AO-1. The dominance of these nine types aligns with the findings of Tratzi et al. [26], who reported that polyethylene- and polypropylene-based plastics constitute the most significant fractions of global consumption and waste collection. Furthermore, a study by Hashemnejad and Doshi [27] aligns with this study, showing that single-resin materials such as HDPE and PP are commonly observed in the collection flow due to their widespread use in both domestic and industrial packaging.

Fluctuations in daily plastic waste sales throughout 2024 provide an overview of the dynamics of material flows within the recycling supply chain, as shown in Figure 3. Based on the analysis, the total volume of the nine types of plastic waste materials most frequently purchased by consumers and retailers in 2024 reached 27,028,801 kg, with a daily average of 9,444 ± 209,626 kg. This value reflects the intensity of collection and transaction activities on a commercial scale. This trend is consistent with the findings of Beylot et al. [28], who reported that variations strongly influence daily waste volume across consumption, economic activity, and industrial production cycles. Furthermore, these results align with the findings of Octaviani et al. [29], who emphasized that plastic waste flows exhibit dynamic patterns due to changes in market demand and uncertainty in the collection chain. The patterns displayed demonstrate the importance of an EPR platform-based recording system for accurately capturing these dynamics, thereby enabling more reliable verification and traceability of material flows.

The distribution of plastic waste supply throughout 2024 shows pronounced variation across material types, as visualized in Figure 4 using a violin plot. Based on the analysis, 7 types of 18 plastic waste materials are most frequently supplied, namely PP-1, HDPE, LDPE, LDPE-1, MLY-NM, MLY-M, and RDF-OR. The presence of single-resin groups such as PP-1, HDPE, and LDPE at high frequency is consistent with the report by Ncube et al. [30], which shows that polyethylene and polypropylene constitute the largest fraction of the global waste stream due to their widespread use in the packaging industry. Meanwhile, the dominance of MLY-NM and MLY-M and RDF-OR reinforces the findings of Krauklis et al. [31], which emphasize that composite materials and waste-based fuels are beginning to make a significant contribution to the circular system due to the increasing number of flexible and blended products on the market. The depicted pattern reflects the statistical distribution of material consumption and the structure of Indonesia's packaging market, which exhibits a pattern similar to global dynamics.

Fluctuations in the daily supply of plastic waste throughout 2024 illustrate the dynamics of material flow at the operational level, as shown in Figure 5. Overall, the total of the seven types of plastic waste materials most frequently supplied during 2024 was 4,896,392 kg, with an average daily supply of 1,260 ± 1,775 kg. This value reflects the intensity of material movement in both informal and formal supply chains. The fluctuating supply pattern shown in the graph aligns with the findings of Kamran et al. [32], who reported that instability in daily waste volume is common in large cities due to changes in economic activity, seasonal variation, and production fluctuations in the household industry sector. Furthermore, Octaviani et al. [29] noted that the flow of plastic waste supply often exhibits high volatility due to uncertainty in supply from collectors and dependence on fluctuations in material selling prices. An EPR platform-based recording mechanism that monitors supply changes in real time is essential for more accurate verification and reporting.

3.3 The integrated prototype design

The integrated prototype design of the EPR platform developed in this study represents a functional implementation of the transaction-data-based EPR concept, as shown in Figure 6, which displays a dashboard interface, transaction-recording modules, collection and sales visualizations, and statistical summaries of key actors within a single integrated system. The design results of the EPR platform are available at https://platform.epr-indonesia.net/admin. The EPR platform demonstrates how purchase and sales data can be tracked over time through time-based graphs and material categories, enabling administrators, collectors, producers, and verifiers to monitor plastic waste management performance in real time. This design approach aligns with the concept of digital traceability platforms discussed by Čuš-Babič et al. [33], which emphasizes the importance of integrating visual dashboards to increase transparency in the material supply chain. Furthermore, the interface structure and user-role separation are similar to those of the waste tracking system developed by Reike et al. [34], in which transaction data visualization serves as an operational decision-making tool. This prototype demonstrates the technical readiness of the developed EPR platform and demonstrates its conformity with global best practices in information system-based recycling data management.

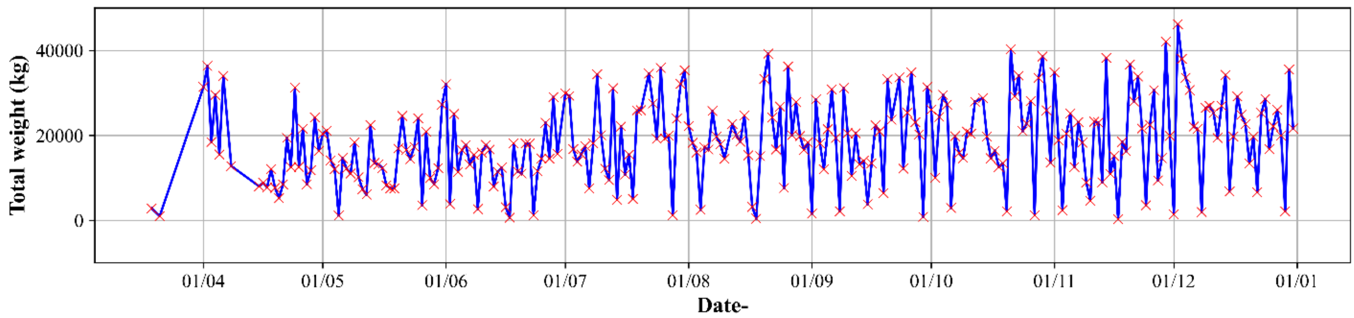

Figure 5. Total daily purchase for all types of plastic waste materials in the 2024 period

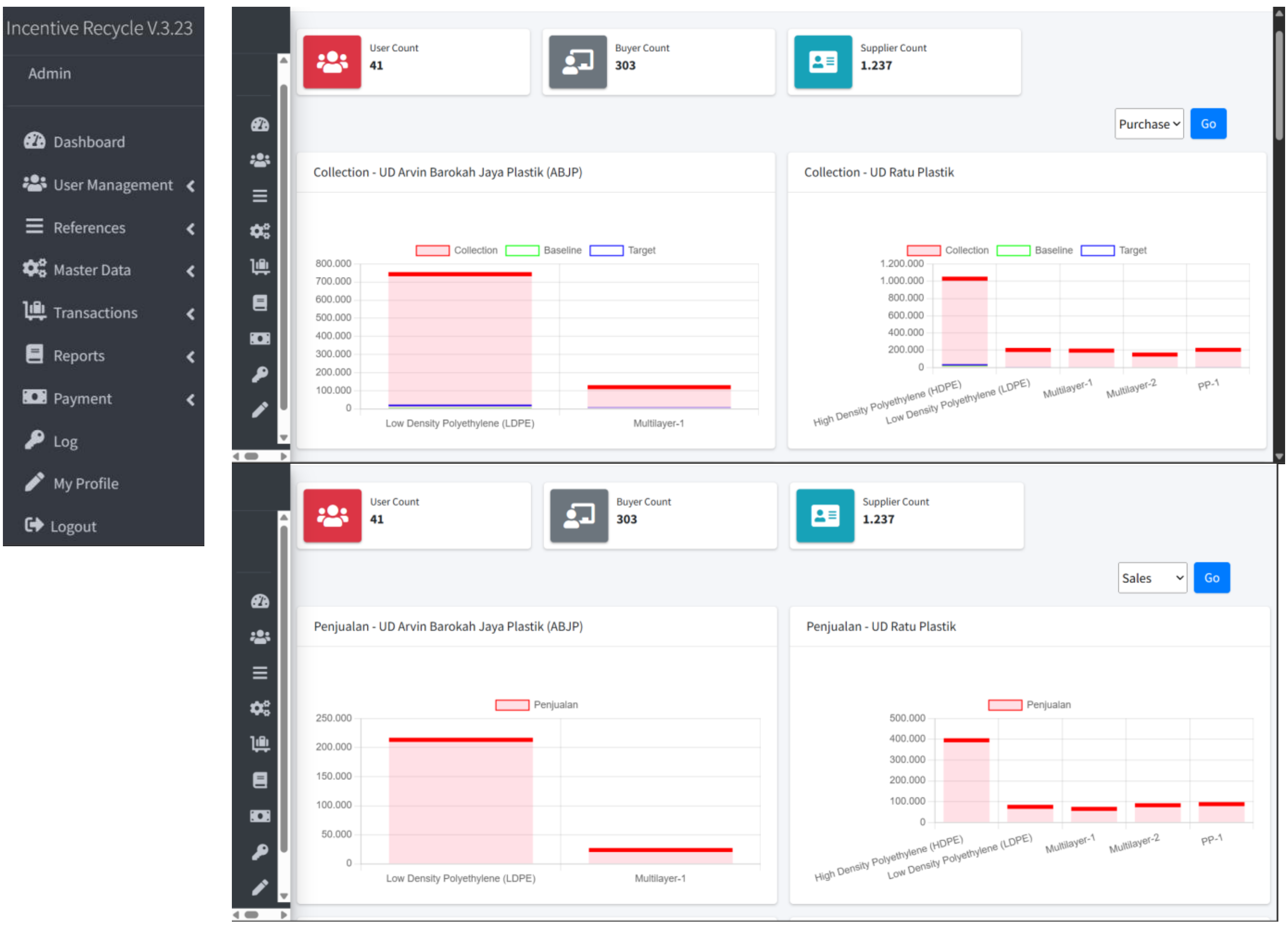

Figure 6. Integrated prototype design extended producer responsibility (EPR) platform

Table 2. Functionality testing of the platform

Feature	Input	Expected Output	Test Result	Status
Transaction Recording	Collector inputs transactions	Transactions successfully recorded	Transactions recorded	Success
Verification	Verifier verifies transactions	Transaction status updated	Status verified	Success
Monitoring	Administrator accesses reports	Reports displayed with graphs	Reports visible	Success
User Management	Administrator adds a new user	New user successfully added	User added successfully	Success

Table 3. System validation

Question	Answer		
	Poor	Good	Excellent
How would you rate the user-friendliness of the platform interface?	-	-	65
Are the presented concepts understandable?	-	-	65
How well does the platform provide the necessary tools and features for managing your responsibilities?	-	10	55
How effective is the platform in enhancing visibility and traceability across the waste management process?	-	8	57
How well does the platform support communication and coordination among stakeholders?	-	10	55
How would you rate the platform's impact on improving operational efficiency (e.g., faster reporting, optimized routes)?	-	10	55
How effectively does the platform promote sustainable waste management practices?	-	10	55
How reliable is the platform in terms of uptime, responsiveness, and data security?	-	15	45

3.4 Functionality testing

Functional testing was conducted to ensure that each key feature of the EPR platform functioned as designed and supported the operational needs of actors in the recycling supply chain, as summarized in Table 2. Testing included transaction recording, verification, monitoring, and user management. Overall, the key features of the EPR platform performed well, with no significant issues. The transaction recording feature demonstrated that collectors accurately recorded data and that it was immediately displayed in the system. The verification feature also delivered the expected response, with transaction statuses successfully updated by the verifier. Meanwhile, the monitoring feature allowed administrators to access graphical reports in real time, and user management ensured smooth user additions. The success of these tests confirmed that the platform prototype had achieved sufficient functional reliability for the initial implementation phase.

The functional testing results reported in this study demonstrate stable, consistent platform performance, and these findings align with several prior studies on the development of digital systems for supply chain management and data verification. For example, research by Cheung et al. [35] demonstrated that the success of a web-based waste management system depends on the smooth functioning of the recording and verification features, as these two components are central to the material tracking process. Furthermore, this aligns with the findings of Benlhabib and Berrado [36], who showed that user management and monitoring dashboard features are crucial for maintaining transparency and accountability in a digital platform-based tracking system. The alignment between the results of this study and those of the comparative study strengthens the belief that the developed EPR platform has been designed and tested in accordance with the functional principles recommended for the development of environmentally based information systems.

3.5 Usability testing

The usability test results provide a comprehensive overview of the level of comfort, ease of use, and effectiveness of the EPR platform in supporting user activities, as summarized in Table 3. Overall, the majority of respondents rated almost all aspects highly, particularly the user-friendliness and concept-understandability indicators, each with a score of 65. In addition, features directly related to operations, such as the provision of work tools, the effectiveness of enhanced traceability, and the platform's ability to support coordination among actors, accounted for a high proportion in the excellent category, namely 55–57. However, several aspects, such as system reliability (including uptime, responsiveness, and data security), showed slight variation, with 45 respondents giving excellent scores and 15 giving good scores. This indicates that the platform is not only easy to use but also well-received by stakeholders and provides a strong foundation for future technical improvements.

The usability findings in this study align with numerous prior studies that emphasize the importance of user experience in the successful implementation of environmentally based digital systems. Research by Alsyouf et al. [37] in the Technology Acceptance Model (TAM) indicates that perceived ease of use is a key predictor of user intention to adopt a new system, reflected in high user-friendliness scores. Furthermore, a study by Benlian et al. [38] confirmed that platforms that enhance conceptual understanding and provide relevant operational features tend to achieve higher levels of acceptance, consistent with high excellence scores on concept understandability and tool readiness indicators. Furthermore, the results regarding platform reliability align with those of Petter et al. [39], who emphasized that system quality, including security and responsiveness, is a critical component of information system success models. A comparison with the literature indicates that the usability performance of the developed EPR platform is on track and meets the criteria for system adoption in the context of sustainable waste management.

Producers reported that the platform interface is intuitive and supports efficient transaction recording. Recyclers indicated that verification features improve clarity and reduce ambiguity in material tracking. Administrators highlighted that monitoring dashboards enhance visibility and decision-making. Most stakeholders agreed that the platform is easy to use and supports their operational needs. These findings confirm that the platform meets usability expectations across different user roles.

3.6 Discussions

This study uses data from a single source, which may limit the generalizability of the findings. Future studies should incorporate multi-center data to improve robustness across different regions. Different regulatory and operational contexts may influence data patterns and system performance. The platform architecture is adaptable to diverse datasets with appropriate calibration. This limitation highlights the need for broader validation in future implementations.

The platform implements role-based access control to restrict data access based on user responsibilities. Sensitive data is protected using encryption during storage and transmission. The system design considers compliance with GDPR principles, including data minimization and user consent. Secure authentication mechanisms are applied to prevent unauthorized access to the platform. These measures ensure data privacy, security, and trust among stakeholders.

The current platform is designed as a standalone system without integration with external databases. Future development may include API-based integration with government and waste management systems. Interoperability would improve data consistency, reduce redundancy, and enhance traceability across systems. Standardized data exchange protocols can support seamless communication between different platforms. This approach enables scalability and broader implementation of EPR systems.

The platform can be scaled to include additional waste types, such as hazardous and electronic waste. Its modular architecture allows flexible integration of new data structures and processing modules. Future integration with IoT devices can enhance real-time tracking and data accuracy. Advanced analytics and automation can improve decision-making and verification processes. These developments support the platform's long-term scalability and adaptability.

The platform applies role-based access control to define responsibilities for each stakeholder. Producers, collectors, recyclers, and verifiers interact through structured transaction workflows. Each transaction follows a sequential process from recording to verification and monitoring. Centralized data storage ensures consistency and prevents duplication across stakeholders. Real-time access enables synchronized collaboration among all actors in the system. Verification steps ensure data accuracy before information is shared across roles. Monitoring dashboards provide visibility of activities for all authorized stakeholders. This architecture supports smooth data flow and coordinated operations within the EPR system.

Each transaction must pass a verification stage before being finalized in the system. An independent verifier validates data to reduce the risk of manipulation. The platform records audit trails for all user activities and data changes. Role-based access control restricts unauthorized data modification. Cross-checking mechanisms compare recorded and verified transaction data. Centralized storage ensures data consistency across all stakeholders. Blockchain is not used, but controlled logging ensures transparency. These mechanisms guarantee data integrity and traceability within the platform.

This study does not evaluate system performance under high-volume data conditions, unlike Mustafovski et al. [40], who reviewed developments in deep learning and IoT-based sensors for smart waste management. Performance metrics such as response time and processing speed are not analyzed. The current evaluation focuses on the platform's functionality and usability. This limitation may affect the assessment of system scalability. Future work should include stress testing under real operational conditions. Large-scale data scenarios are needed to evaluate system responsiveness. Performance optimization will be addressed in subsequent studies. This limitation highlights the need for further validation in practical environments.

The platform applies a structured data flow from recording to verification and monitoring stages. Each transaction is assigned a unique identifier for tracking across the system. Data points are linked between actors to maintain workflow continuity. Validation checkpoints ensure data consistency at each processing stage. Audit trails record all changes and user interactions within the platform. Different waste types are handled using standardized data structures. These mechanisms ensure accurate tracking of all data points. The system supports transparent and reliable data flow across stakeholders.

The platform is designed to align with the principles of EPR. Data recording and reporting follow standardized formats to support regulatory compliance. The system enables traceability required by national waste management regulations. Verification mechanisms support accountability in recycling processes. The platform can be adapted to different regulatory frameworks across regions. Modular architecture allows integration with policy-specific reporting requirements. This design supports compliance with both national and international guidelines. The platform enhances the transparency required for regulatory monitoring.

The platform uses a modular architecture that supports adaptation to different national regulations. Data structures can be customized to match country-specific waste classification systems. New waste types can be added through extensible data schemas and classification modules. Standardized data exchange protocols enable interoperability across regions. The system can be integrated with local databases and regulatory reporting systems. Global deployment can be supported through configurable workflows and user roles. Future development includes support for hazardous and electronic waste categories. This approach ensures scalability and adaptability in diverse operational contexts.

4. CONCLUSIONS

The results of this study indicate that developing an EPR platform based on sales and purchase data can provide a more structured, transparent, and measurable mechanism for recording, verifying, and monitoring the flow of plastic waste. Key findings indicate that only a subset of material types were actively transacted during 2024, and this variation was successfully mapped through visualization and quantitative analysis, supporting a better understanding of the dynamics of the recycling supply chain. Theoretically, this study enriches the study of environmental information systems by demonstrating how digitization can enhance the reliability of EPR data. Practically, this platform provides operational solutions for producers, collectors, recyclers, and verifiers to ensure traceability of the recycling process. Limitations of this study include a small user base and the absence of integrated, broader-scale performance testing. Therefore, further research is needed to evaluate system interoperability and strengthen data validation algorithms. This research makes a significant contribution to enhancing plastic waste governance in

Indonesia and is a first step towards implementing a more accountable and sustainable EPR.

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