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# Blockchain Technology and Implementation of Extended Producer Responsibility in Plastic Waste Management in Nairobi City County, Kenya

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## Abstract

Blockchain technology has emerged as a transformative tool in plastic waste management, offering decentralized solutions that enhance transparency, traceability and compliance. Previously, Extended Producer Responsibility (EPR) in Kenya operated on a voluntary basis; however, the enactment of the Sustainable Waste Management (Extended Producer Responsibility) Regulations 2024 (Legal Notice 176/2024) made EPR mandatory for producers of plastic waste. Despite this regulatory shift, implementation has faced challenges including free-riding, non-compliance with EPR fee payments and weak regulatory enforcement. This study examined how decentralization of data fosters transparency in producer accountability, how tracking mechanisms improve plastic traceability, the potential of smart contracts to automate compliance and enforcement and how reward token mechanisms incentivize proper plastic disposal. These elements were analyzed in relation to their influence on payment of EPR fees, reporting of plastic waste volumes and end-to-end tracking of plastic across its lifecycle. A descriptive and exploratory research design was used. The target population comprised 250 stakeholders from NEMA, PROs (KEPRO and PAKPRO), blockchain experts and producers of plastic waste. Purposive and stratified random sampling produced a sample size of 152 respondents, from whom 137 valid responses were obtained, representing a 90.13% response rate. Data were collected using structured questionnaires, coded and analyzed using SPSS version 26. Descriptive statistics were generated, and multiple regression analysis was used to determine the influence of blockchain features on EPR implementation. The correlation was significant at the 0.01 level (2-tailed), while ANOVA results produced a p-value < .001, confirming statistical reliability. The study found that tracking mechanisms significantly strengthen accountability, smart contracts automate compliance and regulatory processes and reward token mechanisms effectively motivate behavioral change among producers, recyclers and consumers. While decentralization of data enhances transparency, it did not show a statistically significant direct influence on EPR outcomes. The study concludes that tracking mechanisms, smart contracts and reward token systems are the strongest predictors of effective EPR implementation and recommends prioritizing their adoption while integrating decentralization as a supportive transparency-enhancing feature.

**Keywords:** *Blockchain Technology, Implementation, Producer Responsibility, Plastic Waste Management, Nairobi City County, Kenya*

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## 1.0 Background of the Study

Plastic waste has become a significant environmental challenge globally, with over 400 million metric tons of plastic produced annually, a figure expected to double by 2050 if current trends continue (UNEP, 2023). Ong'are and Vyalu (2023) highlight that Nairobi produces around 2,400 tons of waste daily, with a per capita generation rate of 0.75 kg per day. The researchers note that 62% of this waste is dumped in illegal sites, while less than 10% is collected and recycled. A report by UNCTAD (2020) highlights that trade is immense, with exports of primary, intermediate and final forms of plastics summing up to more than 1 trillion US dollars in 2018 or 5% of the total value of global trade, almost 40% higher than previous estimates. In Kenya, a major environmental issue is the pollution of water bodies by plastic waste, especially the Nairobi River (see Appendix IV for supporting data), which suffers from severe contamination due to plastic waste and industrial effluents. A report by UNEP (2021) indicates that 60% of the plastic waste in Nairobi is improperly disposed of, leading to clogged drainage systems and increased flooding during the rainy season. Without a structured and innovative plastic waste management system, pollution will continue to threaten ecosystems, water quality and public health. EPR is crucial in plastic waste management as it holds producers of plastic waste accountable for the entire lifecycle of their products, reducing environmental pollution. By mandating sustainable waste management, EPR drives investment in recycling infrastructure, minimizes illegal dumping and promotes a circular economy. This approach helps mitigate plastic pollution in cities such as Nairobi, protecting ecosystems, water quality and public health.

Globally, blockchain, according to Oracle, is a securely shared ledger of decentralized data. Because data in a blockchain system cannot be changed without the consent of a quorum of the participants, fraud and data tampering are avoided. Although a blockchain ledger cannot be changed, it may be shared. All participants will be informed if someone attempts to change the data, and they will all know who attempted it. This constitutes the blockchain technology's consensus mechanism (Oracle, 2021). The two main uses of blockchain technology in waste management are to improve traceability and provide payments or rewards. The Plastic Bank uses blockchain technology to create digital tokens that encourage the collecting of plastic garbage and can be redeemed for products or cash in nations like Peru, Haiti, the Philippines and Colombia. The SmartWaste initiative, created by Ecoembes in La Rioja, tracks waste during the collection and sorting procedures using sensors and GPS devices. A blockchain-based solution created by consulting firm Heura guarantees the traceability and optimization of agricultural packaging, supporting effective circular economy models and environmental preservation. Nestlé has also implemented a project to track its Dolce Gusto coffee capsules using blockchain, encouraging consumers to recycle by awarding prizes and discounts when they return capsules to collection points (Laia, 2024). France has committed to achieving 100% plastic waste efficiency by 2025, and the Ellen MacArthur Foundation's New Plastics Economy initiative has brought together over 350 organizations to create a circular economy for plastics.

Blockchain technology is steadily gaining traction across Africa, with applications spanning multiple sectors, including finance, agriculture and supply chain management. Several studies highlight the increasing role of blockchain in promoting economic and environmental sustainability across the continent. According to Labaran and Masood (2025), blockchain has facilitated the monitoring of energy supply chains, improving efficiency and sustainability in Africa's renewable energy sector. A growing interest in waste management solutions has also emerged, as seen in the

plastic credit system proposed in South Africa, Egypt and Algeria, which leverages blockchain to enhance waste tracking and incentivize responsible disposal (Arshad, 2024). This aligns with Kagisho and Joao's (2024) findings that blockchain fosters resilience in industries by addressing environmental and economic challenges in hospitality and related sectors. Siwawa (2025) highlights blockchain's contribution to optimizing waste diversion practices in smart cities which strengthens accountability in waste management. Despite its potential, challenges such as infrastructure deficits, limited regulatory frameworks and low adoption rates continue to hinder widespread blockchain implementation in Africa. These challenges underscore the need for policy support and investment in digital infrastructure to harness blockchain's full potential in Africa's sustainability efforts.

Kisoso (2023) investigated the impact of blockchain technology on the operational performance of financial institutions in Nairobi, Kenya, which revealed significant insights into its adoption and effects. The study found that financial institutions in Nairobi are actively leveraging blockchain technology, particularly for decentralized data functions, driven by the need for transparency, security and efficiency. However, challenges such as financial constraints and regulatory uncertainties were identified as barriers to broader adoption. Key dimensions of blockchain technology, including decentralization of data, immutability and interoperability, were shown to positively influence operational performance, contributing to improved efficiency, quality assurance and customer loyalty. While blockchain adoption in plastic waste management remains in its infancy, studies indicate that blockchain could significantly improve waste traceability, producer accountability and incentive mechanisms under the Extended Producer Responsibility (EPR) framework (Kolade *et al.*, 2023). However, despite Kenya's advancements in fintech applications such as mobile money interoperability, blockchain-driven circular economy solutions are yet to reach full-scale implementation. Blockchain's potential in enhancing transparency, decentralizing compliance tracking and automating reward token mechanisms presents a promising avenue for future research and policy development in Kenya's plastic waste management sector.

The success of Extended Producer Responsibility (EPR) and the adoption of blockchain technology in plastic waste management in Nairobi City County relies on the active participation of key stakeholders. These include government regulatory agencies, producer responsibility organizations (PROs) and producers of plastic waste. These are relevant institutions in Kenya's plastic waste management ecosystem. National Environment Management Authority (NEMA) is Kenya's principal government agency responsible for coordinating environmental protection efforts. Established under the Environmental Management and Coordination Act (EMCA) of 1999, NEMA operates under the Ministry of Environment, Climate Change and Forestry, ensuring compliance with environmental laws and policies. Among the Producer Responsibility Organizations (PROs) is Kenya Extended Producer Responsibility Organization (KEPRO). KEPRO helps manufacturers, brand owners and importers comply with Kenya's Extended Producer Responsibility (EPR) Regulations 2024 (and any other similar regulations). The organization focuses on ensuring that producers of plastic waste take responsibility for the collection, recycling and disposal of their plastic packaging waste. Another player is Packaging Producer Responsibility Organization (PAKPRO). PAKPRO is a non-profit organization dedicated to promoting sustainable waste management practices in Kenya, focusing on packaging materials. PAKPRO provides guidance, tools and reporting frameworks to ensure compliance with Kenya's EPR requirements, making it easier for businesses to meet their obligations.

### 1.1 Statement of the Problem

The UN Habitat defines Extended Producer Responsibility (EPR) as a policy approach that places the responsibility for the end-of-life management of a product on the producer rather than the consumer or local government in accordance with the “Polluter Pays Principle” (FBRA, 2024). One of the major concerns hampering effective plastic waste management in Kenya is significant data gaps related to plastic waste volumes and flows. Abdellatif et al. (2021) note a significant lack of reliable and comprehensive data related to plastic waste, describing this scarcity as a reflection of the country's underdeveloped waste management infrastructure. In 2017, the country consumed approximately 1.02 million tons of polymers and imported 4.2 million tons of plastic, while a 2014 report estimated that 24 million plastic bags were used monthly, nearly half discarded in open environments. UNIDO (2021) similarly points out that Kenya lacks adequate data on solid waste generation, collection and recovery rates, with existing estimates relying on pre-consumer product analyses rather than systematic post-consumer tracking. Consequently, incomplete and indirect data continue to undermine waste management planning, limit the ability to assign producer responsibility and reduce the effectiveness of EPR mechanisms (WWF Kenya, 2022; Ong’are & Vyalu, 2023). The problem is further compounded by high rates of mismanaged plastic waste, with IUCN (2020) estimating that 73% of plastic waste is uncollected—equivalent to approximately 903,974 tonnes annually—of which 35,000 to 63,000 tonnes leak into waterways and marine ecosystems.

WWF Kenya (2022) emphasizes that mandatory EPR systems require proper identification and monitoring of producers and waste operators, alongside strict enforcement to prevent free-riding, fraud and misallocation of financial resources. Yet Kenya’s enforcement capacity remains limited, with NEMA bearing the entire responsibility for tracing non-compliant actors, monitoring obligated companies and conducting audits without a sustainable financing mechanism. The introduction of EPR regulations increased NEMA’s responsibilities, but the absence of independent third-party auditing and producer-financed verification mechanisms has led to persistent compliance gaps across Producer Responsibility Organizations (PROs), recyclers and material flows. The reviewed studies and reports indicate that ineffective implementation of EPR continues to undermine plastic waste management in Nairobi City County and nationally. Its reward token mechanisms offer automated incentives for collectors, and its smart contract functionalities enable automated verification, fee collection and audit processes—capabilities essential for effective EPR enforcement. Blockchain’s capacity to provide trustless verification in environments prone to corruption makes it particularly suited to Kenya’s implementation challenges and highlights its potential as a transformative tool for strengthening EPR compliance and improving overall plastic waste governance.

### 1.2 Objectives of the Study

- i. To establish the influence of decentralization of data on the implementation of extended producer responsibility in plastic waste management in Nairobi City County, Kenya.
- ii. To evaluate the influence of tracking mechanism on the implementation of extended producer responsibility in plastic waste management in Nairobi City County, Kenya.
- iii. To examine the influence of smart contracts on the implementation of extended producer responsibility in plastic waste management in Nairobi City County, Kenya.
- iv. To examine the influence of reward token mechanism on the implementation of extended producer responsibility in plastic waste management in Nairobi City County, Kenya.

## 2.0 Literature Review

This section outlines the theoretical foundations on which the study was based, presents the conceptual framework and reviews empirical studies.

### 2.1 Theoretical Review

This study was guided by four theories namely Socio-Technical Systems Theory, Systems Theory, Game Theory and Technology Acceptance Model.

#### 2.1.1 Socio-Technical Systems Theory (STS)

Socio-Technical Systems Theory was developed by Eric Trist and Ken Bamforth in the 1950s after their study of work redesign in British coal mines (Trist & Bamforth, 1951). The theory states that organizations perform best when social elements and technical components are jointly optimized, assuming that technology and human behavior shape each other in work systems (Emery & Trist, 1960; Cherns, 1976). It further assumes that decentralization, participation and collaborative decision-making enhance system effectiveness (Trist, 1981; Mumford, 2006). The theory also recognizes that any technological change must be compatible with human values, informal networks and workflow practices. It stresses that technology should enable users to coordinate better rather than impose rigid structures that undermine participation. STS additionally argues that systems improve when users have autonomy and direct access to information.

#### 2.1.2 Systems Theory

Systems Theory, developed by Ludwig von Bertalanffy, proposes that systems can only be understood holistically because components are interdependent and connected through information flows and feedback mechanisms (Becvar et al., 2023). The theory assumes that systems adapt, self-regulate and function through continuous interaction rather than isolated activities. It also assumes that efficiency improves when communication channels and feedback loops are aligned across interacting units (Khan et al., 2023). Systems Theory maintains that any weakness in one component can destabilize the entire system, creating inefficiencies or failures. It emphasizes that transparency, timely information and coordination help systems respond effectively to disruptions. The theory also suggests that well-structured systems reduce duplication of effort and enhance accountability. Systems Theory informed the tracking mechanism objective because blockchain creates a unified, transparent and self-regulating flow of information across producers, PROs and regulators.

#### 2.1.3 Game Theory

Game Theory, introduced by John von Neumann and Oskar Morgenstern in 1944, analyzes strategic behavior among rational actors facing interdependent choices. The theory assumes that individuals act according to expected payoffs, anticipate competitor or partner behavior and adjust strategies to maximize benefits. It also assumes that cooperation or competition is shaped by incentive structures and enforcement rules within a system. Studies by Udokwu (2024) and Nicolas et al. (2022) show how game-theoretic principles influence blockchain incentives, consensus and multi-agent coordination. The theory highlights that when incentives are aligned, actors naturally choose cooperative strategies instead of opportunistic ones. It further emphasizes that predictable rules reduce uncertainty, encourage trust and minimize conflict among stakeholders. Game Theory also stresses that self-enforcing agreements reduce monitoring costs and improve compliance. This theory informed the smart contracts objective by explaining how incentive-aligned rules can strengthen producer compliance, waste collector cooperation and regulatory oversight.

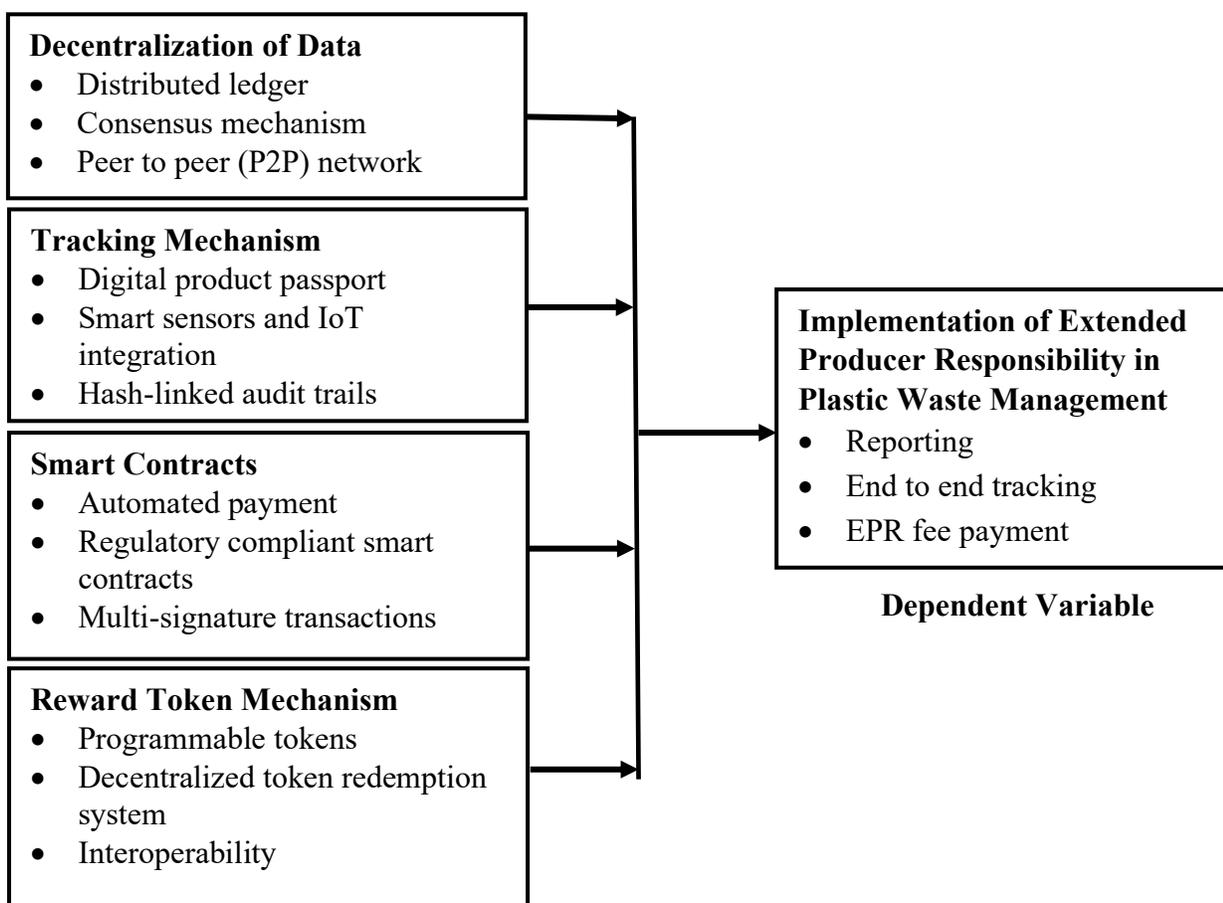
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### 2.1.4 Technology Acceptance Model (TAM)

The Technology Acceptance Model was developed by Fred Davis (1989) to explain how individuals adopt and use new technologies. The model states that perceived usefulness and perceived ease of use determine behavioral intention, assuming that technology adoption is driven by user attitudes shaped by perceived value and simplicity. The model also assumes that external variables such as trust and facilitating conditions influence acceptance (Venkatesh & Bala, 2008). TAM research shows that technologies with low complexity and clear benefits enjoy faster adoption across stakeholder groups (Shrestha et al., 2021; Kolade et al., 2024; Oyinlola & Schröder, 2023). The model emphasizes that motivation increases when users believe a system improves efficiency or provides tangible rewards. It also highlights that digital literacy and system accessibility determine whether adoption will be widespread or limited. TAM further notes that supportive infrastructure and intuitive design strengthen user confidence. This theory informed the reward token objective by explaining how perceived benefits and usability shape willingness to adopt blockchain incentives in Nairobi’s EPR framework.

## 2.2 Conceptual Framework

The conceptual framework for this study is shown in Figure 1.



**Independent Variables**

**Figure 1: Conceptual Framework**

### 2.3 Empirical Review

Empirical studies on blockchain and Extended Producer Responsibility (EPR) show that decentralization, tracking, smart contracts and reward tokens can significantly improve waste management, but they also point to cost, regulatory and scalability challenges. Zhang (2019), Kamath (2018) and Ping et al. (2024) focus on decentralization and tracking in waste and food systems, while Ongena et al. (2018), Steenmans et al. (2021), Peters and Panayi (2016) and Beck et al. (2016) explore smart contract applications in environmental governance. Reward token mechanisms are examined by Gibovic and Bikfalvi (2021), Pulsfort et al. (2021) and Gong et al. (2022), highlighting how incentives can drive behaviour change. Collectively, these studies provide a strong foundation but remain limited by short timeframes, pilot scopes, and limited application in African EPR frameworks.

Zhang (2019) examined the Yitong rural waste-to-energy system in Changzhi County, China, using a mixed-methods design combining site visits, questionnaires and technical assessments. The study showed that integrating distributed ledgers, smart contracts, IoT smart bins and cryptocurrency rewards (E/F coins) enabled processing of 255 tons of waste per day for 25,000–40,000 farmers and increased internal rate of return from 11% to 30%. Farmers earned 25 Energy coins and 75 Fertilizer coins per 100 kg of segregated waste, with 100% using WeChat Pay or Alipay, indicating high digital readiness. Nonetheless, Zhang (2019) highlighted high infrastructure costs, need for mobile applications, route optimisation demands and lack of longitudinal and comparative analysis. These findings show how decentralised data and multi-feature blockchain systems can support EPR-like accountability, but scalability and regulatory issues remain unresolved.

Kamath (2018) analysed Walmart–IBM blockchain pilots in the pork supply chain in China and mango supply chain in the Americas using case study methods based on pilot reports, executive interviews and industry documentation. The study found that blockchain reduced traceability time from seven days to 2.2 seconds, improved food safety response, enhanced trust and reduced information asymmetry, though regulatory uncertainty, high implementation costs and interoperability problems limited wider use. Building on this, Ping et al. (2024) implemented a blockchain-based reverse logistics tracking system for e-waste in Metropolis using IoT sensors at 500 points, 100 collection sites, 10 recycling facilities, 20 blockchain nodes and 100,000 consumers over 12 months. Their system processed 50,000 transactions daily, increased recycling rates by 27%, improved material recovery by 18% and doubled participation, but faced privacy concerns, sensor reliability issues and high capital costs. Both studies confirm that blockchain tracking strengthens transparency and producer accountability, but they also call for multi-city, cross-border and longer-term EPR evaluations.

Ongena et al. (2018) and Steenmans et al. (2021) identified fraud, information loss, manual verification and limited monitoring as major weaknesses in EPR and waste governance. Drawing on Peters and Panayi’s (2016) definition of smart contracts as self-executing coded agreements and Beck et al.’s (2016) concept of “trust-free cryptographic transactions,” they explored blockchain initiatives using stakeholder interviews, BPMN mapping, scoping reviews of 21 projects and semi-structured interviews. Their findings showed that smart contracts and related blockchain tools can

automate compliance, streamline payments and support models such as Plastic Bank, which uses cryptocurrency rewards for plastic collection. Nonetheless, they reported data-input integrity risks, stakeholder resistance, regulatory uncertainty and early-stage pilot status, mainly in developed countries, with limited quantitative metrics and weak integration into formal EPR regulations. These studies highlight blockchain's potential governance benefits while underscoring the need for longitudinal, mixed-method evidence in diverse contexts.

Gibovic and Bikfalvi (2021) evaluated blockchain-based incentives in the RECICLOS project in Catalonia through a six-week experimental pilot with 1,053 households using QR-coded bags and a web app. Data from mobile tracking, surveys, blockchain logs and waste quality checks at the TIRGI plant showed that correct separation increased from 66.6% to 85.8%, with 6,749 bags registered and 13,060 tokens issued. Raffles were preferred by 59.5% of participants, far surpassing tax discounts, lotteries and donations, demonstrating the power of gamified incentives for recycling. The authors concluded that blockchain-based rewards improve trust, transparency and automated allocation, but noted short duration, QR usability issues for about 10% of users and limited geographic scope. They recommended larger, longer studies and stronger integration of blockchain incentives into municipal EPR and waste management policies.

At supply chain and organisational level, Pulsfort et al. (2021) used expert interviews and focus groups with senior executives to explore blockchain-enabled tokenization for plastic bottle recycling in a large beverage company. They found that tokenizing plastic as a traceable digital asset with assigned ownership creates a digital material passport that enhances transparency, combats greenwashing and can replace traditional deposit–refund schemes. Gong et al. (2022) applied a multiple case study design across six blockchain recycling initiatives using secondary data from reports, corporate documents and project records. Their findings highlighted Plastic Bank, which engaged over 17,000 collectors and recycled 28.8 million kilograms of plastic by 2021 through token rewards. Both studies stressed that token systems can drive participation and circularity but face technological complexity, regulatory gaps and low public awareness. They called for quantitative impact studies, regulatory alignment and national-level integration of token-based incentives into EPR frameworks.

### **3.0 Research Methodology**

The study adopted a descriptive and exploratory research design to examine how blockchain technology can strengthen Extended Producer Responsibility (EPR) in Nairobi City County. The descriptive approach enabled the researcher to assess current compliance practices among producers of plastic waste, stakeholder awareness, and existing inefficiencies within the EPR system. The exploratory component was essential because blockchain use in Kenya's waste sector is still new, making it necessary to assess feasibility and emerging opportunities. The unit of analysis included NEMA, PAKPRO, KEPRO, producers of plastic waste and blockchain organizations, while the unit of observation comprised individual officers involved in technology, environmental regulation and recycling operations. The target population consisted of 250 stakeholders, and a sample of 152 respondents was selected using Fisher, Laing and Stoeckel's formula. Purposive sampling was applied to NEMA, PROs and blockchain experts, while stratified random sampling was used for

producers of plastic waste. Data was collected through structured questionnaires, key informant interviews and secondary document reviews. After obtaining institutional approvals, questionnaires were distributed online and interviews conducted with key officers. Data was coded, cleaned and analyzed using SPSS version 26, employing descriptive statistics and multiple regression to assess how blockchain features influence EPR implementation.

#### 4.0 Discussion of Results and Findings

The discussion of results and findings are presented in sections.

##### 4.1 Response Rate

An online questionnaire was shared with all the selected respondents to gather data. The required sample size was 152 participants; 137 valid responses were obtained, yielding a 90.13% response rate. According to Mugenda & Mugenda (2003), a response rate of 50% or above is considered good for analysis and reporting, 60% is considered adequate and 70% or higher is considered exceptional. The 90.13% response rate obtained in this survey was regarded as extraordinary since it exceeded 70% and was utilized for further reporting, analysis and recommendations. Table 1 shows the responses recorded.

**Table 1: Response Rate**

Participants Sampled	Frequency	%
Returned	137	90.13
Unreturned	15	9.87
<b>Total</b>	<b>152</b>	<b>100</b>

##### 4.2 Descriptive Statistics

The study utilized a Likert Scale to evaluate the collected data so as to ensure the accuracy and validity of the findings. The self-administered questionnaire was systematically divided into five sections, each designed to measure specific aspects of the study using a standardized Likert-type scale. Following the recommendation by Joshi, *et al.* (2015), the scale was structured with five response categories: 1 (Strongly Disagree), 2 (Disagree), 3 (Neutral), 4 (Agree), and 5 (Strongly Agree). The statements within the questionnaire were formulated in an affirmative manner to enhance clarity and consistency in responses. Each of the five sections contained five distinct items aimed at capturing relevant insights. The responses were then analyzed using statistical methods, specifically mean and standard deviation, to facilitate a comprehensive interpretation and generalization of the results. These statistical measures helped to summarize the central tendencies of the responses and provided a clear understanding of the participants' perspective.

###### 4.2.1 Decentralization of Data

The first objective of the study sought to establish the influence of decentralization of data on the implementation of EPR in plastic waste management in Nairobi City County, Kenya. To achieve this, the respondents were required to give their rating on a five-point Likert scale. Table 2 presents the findings obtained.

**Table 2: Descriptive Statistics for Decentralization of Data**

Statement	Mean	Std. Dev
Using a shared digital record system helps keep accurate and unchangeable records of how producers follow EPR rules.	4.33	0.608
The way blockchain confirms shared information helps build trust and cooperation among those involved in plastic waste management.	4.39	0.678
A peer-to-peer (P2P) system like blockchain allows producers, recyclers and regulators to interact directly without needing a central authority, helping improve how EPR is carried out.	4.39	0.721
A decentralized system reduces the need to depend on one central authority, making plastic waste handling more open and efficient.	4.44	0.629
When everyone can access the same trusted data, it helps avoid disagreements in plastic waste reports.	4.61	0.585

Respondents generally acknowledged that using a shared digital record system helps keep accurate and unchangeable records of how producers follow EPR rules ( $M = 4.33$ ,  $SD = 0.608$ ) which indicates a strong support for blockchain’s ability to provide transparent compliance monitoring. This finding is consistent with research by Huang *et al.* (2025) who highlighted that decentralization of data prevents falsification of records by allowing only verifiable transactions to be recorded. Similarly, respondents agreed that the way blockchain confirms shared information helps build trust and cooperation among those involved in plastic waste management ( $M = 4.39$ ,  $SD = 0.678$ ), which reflects the perceived role of blockchain’s consensus mechanism in enhancing collaboration. The study further revealed that a peer-to-peer (P2P) system like blockchain allows producers, recyclers and regulators to interact directly without needing a central authority thereby improving how EPR is carried out ( $M = 4.39$ ,  $SD = 0.721$ ). In addition, participants agreed that a decentralized system reduces the need to depend on one central authority which makes plastic waste handling more open and efficient ( $M = 4.44$ ,  $SD = 0.629$ ). This finding resonates with research by Chen *et al.* (2024) who reported that the decentralized structure of blockchain technology ensures that no single party has full control over the data which promotes transparency and removes the possibility of data tampering. Finally, when everyone can access the same trusted data, respondents strongly indicated that it helps avoid disagreements in plastic waste reports ( $M = 4.61$ ,  $SD = 0.585$ ), underscoring blockchain’s role in minimizing conflicts and discrepancies. These findings show that respondents strongly support decentralization as an essential driver of trust, transparency and efficiency in implementing Extended Producer Responsibility for plastic waste management in Nairobi City County.

#### 4.2.2 Tracking Mechanism

The second objective of the study sought to evaluate the influence of tracking mechanism on the implementation of EPR in plastic waste management in Nairobi City County, Kenya. To achieve this, the respondents were required to give their rating on a five-point Likert scale. Table 3 presents the findings obtained.

**Table 3: Descriptive Statistics for Tracking Mechanism**

Statement	Mean	Std. Dev
A digital record on blockchain helps clearly track plastic waste from production to disposal.	4.46	0.664
Smart sensors and IoT devices make it easier to track plastic waste in real time and meet EPR goals.	4.45	0.641
Blockchain systems that securely link records help keep plastic waste tracking data reliable and unchanged.	4.53	0.607
The ability to track plastic waste at each lifecycle stage increases accountability among producers of plastic waste and recyclers.	4.53	0.543
Using blockchain for tracking makes it harder for people to give false reports about plastic waste handling.	4.52	0.665

Respondents strongly agreed that a digital record on blockchain helps clearly track plastic waste from production to disposal ( $M = 4.46$ ,  $SD = 0.664$ ). This finding is consistent with research by Ping *et al.* (2024) who reported that tracking mechanism feature of blockchain technology enhances the implementation of EPR through transparent product lifecycle monitoring, automated compliance reporting and verifiable material recovery documentation that eliminates information asymmetries between producers and regulators. Respondents also indicated agreement that smart sensors and IoT devices make it easier to track plastic waste in real time and meet EPR goals ( $M = 4.45$ ,  $SD = 0.641$ ). In addition, respondents agreed that blockchain systems that securely link records help keep plastic waste tracking data reliable and unchanged ( $M = 4.53$ ,  $SD = 0.607$ ). The ability to track plastic waste at each lifecycle stage was also perceived as increasing accountability among producers of plastic waste and recyclers ( $M = 4.53$ ,  $SD = 0.543$ ). Finally, participants agreed that using blockchain for tracking makes it harder for people to give false reports about plastic waste handling ( $M = 4.52$ ,  $SD = 0.665$ ). All five items under tracking mechanism received very high mean values (between 4.45 and 4.53) with low standard deviations (between 0.543 and 0.665). This shows strong consensus among respondents that blockchain-enabled tracking mechanisms are highly effective in strengthening accountability, transparency and reliability in plastic waste management under EPR frameworks in Nairobi City County. These findings support research by Ajala (2023) who reported that enforcement of EPR is often hindered by the absence of transparent waste tracking systems, leading to unverified recycling claims, low compliance rates and regulatory loopholes.

#### 4.2.3 Smart Contracts

The third objective of the study sought to examine the influence of smart contracts on the implementation of EPR in plastic waste management in Nairobi City County, Kenya. To achieve this, the respondents were required to give their rating on a five-point Likert scale. Table 4 presents the findings obtained.

**Table 4: Descriptive Statistics for Smart Contracts**

Statement	Mean	Std. Dev
Automatic payments using blockchain make money transfers between EPR partners faster and easier.	4.49	0.620
Smart contracts that follow predefined rules help producers meet EPR obligations by automatically enforcing the set conditions.	4.50	0.654
Requiring several people to approve blockchain transactions makes EPR-related processes more open and trustworthy.	4.56	0.651
Smart contracts can help pay recyclers automatically after their work is confirmed, which makes collection more efficient.	4.57	0.592
Using smart contracts helps reduce delays and unnecessary steps when applying EPR rules.	4.50	0.654

Respondents strongly agreed that automatic payments using blockchain make money transfers between EPR partners faster and easier ( $M = 4.49$ ,  $SD = 0.620$ ). They also agreed that smart contracts that follow predefined rules help producers meet EPR obligations by automatically enforcing the set conditions ( $M = 4.50$ ,  $SD = 0.654$ ). Similarly, requiring several people to approve blockchain transactions was seen as making EPR-related processes more open and trustworthy ( $M = 4.56$ ,  $SD = 0.651$ ). Respondents further agreed that smart contracts can help pay recyclers automatically after their work is confirmed, thereby making collection more efficient ( $M = 4.57$ ,  $SD = 0.592$ ). Finally, they indicated that using smart contracts helps reduce delays and unnecessary steps when applying EPR rules ( $M = 4.50$ ,  $SD = 0.654$ ). The consistently high means (4.49 - 4.57) with relatively low standard deviations (0.592 - 0.654) suggest that respondents overwhelmingly supported the role of smart contracts in enhancing efficiency, trust and automation in the implementation of EPR in plastic waste management in Nairobi City County, Kenya. This implies that smart contracts are perceived as a critical blockchain feature for streamlining EPR processes in Nairobi City County. These findings support research by Bułkowska *et al.* (2023) who reported that smart contracts enable secure legally compliant transactions between two parties by using digital signatures within a peer-to-peer network which ensures transparency and data security through encryption.

#### 4.2.4 Reward Token Mechanism

The fourth objective of the study sought to examine the influence of reward token mechanism on the implementation of EPR in plastic waste management in Nairobi City County, Kenya. To achieve this, the respondents were required to give their rating on a five-point Likert scale. Table 5 presents the findings obtained.

**Table 5: Descriptive Statistics for Reward Token Mechanism**

Statement	Mean	Std. Dev
Special monetary digital tokens can motivate people to take part in collecting and recycling plastic waste.	4.56	0.651
A system where people can exchange tokens fairly and openly helps ensure rewards are given for abiding by EPR regulations.	4.58	0.602
Reward tokens that work across different systems make it easier for all parties to exchange them in plastic waste programs.	4.61	0.621
Giving tokens as rewards encourages people to return plastic waste for recycling.	4.62	0.632
Using reward tokens helps keep everyone involved and committed to better plastic waste management.	4.53	0.654

Respondents strongly agreed that special monetary digital tokens can motivate people to take part in collecting and recycling plastic waste ( $M = 4.56$ ,  $SD = 0.651$ ). This finding is consistent with research by Kolade *et al.* (2024) who reported that the perceived economic benefit of token incentives strongly influences adoption among waste collectors and recyclers in African urban centres. Respondents also supported the idea that a system where people can exchange tokens fairly and openly helps ensure rewards are given for abiding by EPR regulations ( $M = 4.58$ ,  $SD = 0.602$ ). In addition, respondents agreed that reward tokens that work across different systems make it easier for all parties to exchange them in plastic waste programs ( $M = 4.61$ ,  $SD = 0.621$ ). Similarly, giving tokens as rewards was seen as encouraging people to return plastic waste for recycling ( $M = 4.62$ ,  $SD = 0.632$ ). Finally, participants agreed that using reward tokens helps keep everyone involved and committed to better plastic waste management ( $M = 4.53$ ,  $SD = 0.654$ ). This finding supports research by Gibovic and Bikfalvi (2021) who reported that blockchain-based incentive mechanisms significantly improve recycling behaviors by increasing trust, transparency and automated reward allocation. The consistently high mean values (4.53 - 4.62) and low standard deviations (0.602 - 0.654) suggest a very strong consensus among respondents that reward tokens can effectively motivate participation, increase accountability and sustain commitment in the implementation of EPR. This highlights reward token mechanism as a powerful blockchain feature for driving behavioral change and engagement in plastic waste management in Nairobi City County.

#### 4.2.5 Implementation of EPR in Plastic Waste Management

The general objective of the study was to examine the influence of blockchain technology on the implementation of extended producer responsibility in plastic waste management in Nairobi City County, Kenya as shown in Table 6 below.

**Table 6: Descriptive Statistics for Implementation of EPR in Plastic Waste Management**

Statement	Mean	Std. Dev
Blockchain helps reduce false environmental claims by showing clear proof of what has been done.	4.55	0.581
The fact that blockchain records cannot be changed ensures transparency and accountability in plastic waste data	4.64	0.578
Tracking plastic waste on blockchain makes it easier to hold producers accountable towards their EPR obligations.	4.67	0.570
Smart contracts can help ensure that producers pay EPR fees on time and accurately.	4.57	0.604
Verifying actions through blockchain builds trust and helps stakeholders follow EPR regulations better.	4.58	0.590

Respondents strongly agreed that blockchain helps reduce false environmental claims by showing clear proof of what has been done ( $M = 4.55$ ,  $SD = 0.581$ ). This finding resonates with research by Huang *et al.* (2025) who reported that distributed ledgers make it harder for non-compliant producers of plastic waste to falsify recycling data or avoid their legal obligations under EPR laws since there will be real-time data sharing between producers of plastic waste, waste collectors and regulatory bodies. Respondents also agreed that, the fact that blockchain records cannot be changed ensures transparency and accountability in plastic waste data ( $M = 4.64$ ,  $SD = 0.578$ ). Similarly, tracking plastic waste on blockchain was seen as making it easier to hold producers accountable towards their EPR obligations ( $M = 4.67$ ,  $SD = 0.570$ ). This finding supports the research of Ping *et al.* (2024) who reported that the tracking feature of blockchain technology eliminates traditional opacity, enables real-time regulatory reporting and creates verifiable producer responsibility metrics. Respondents further indicated that smart contracts can help ensure that producers pay EPR fees on time and accurately ( $M = 4.57$ ,  $SD = 0.604$ ). Finally, participants agreed that verifying actions through blockchain builds trust and helps stakeholders follow EPR regulations better ( $M = 4.58$ ,  $SD = 0.590$ ). The consistently high mean values (4.55 - 4.67) with very low standard deviations (0.570 - 0.604) demonstrate a strong consensus among respondents that blockchain technology significantly enhances the implementation of Extended Producer Responsibility in plastic waste management.

### 4.3 Inferential Statistics

Inferential statistics is a branch of statistics that makes use of various analytical tools to draw inferences about the population data from sample data.

#### 4.3.1 Correlation Analysis

Pearson moment correlation analysis was used to find the correlation coefficient. The study tested whether interdependency existed between the independent variables and whether there was any relationship between the dependent variable and independent variables and the direction of their relationship. The study computed correlation to test the strength and direction of the relationship that exists between blockchain technology and the implementation of EPR in plastic waste management in Nairobi City County, Kenya. The correlation values range from 0 to 1; if  $\pm 0.1 < r < \pm 0.29$ , then the relationship between the two variables is small, if  $\pm 0.3 < r < \pm 0.49$ , then the

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relationship is medium, and if  $r > \pm 0.5$  then there is a strong relationship between the two variables under consideration. Table 7 presents the correlation analysis findings for this study.

**Table 7: Correlations**

		Decentralization of data	Tracking Mechanism	Smart Contracts	Reward Token Mechanism	Implementation of EPR in plastic waste management
Decentralization of data	Pearson Correlation	1.000				
	Sig. (2-tailed)					
	N	137				
Tracking Mechanism	Pearson Correlation	.605**	1.000			
	Sig. (2-tailed)	0.000				
	N	137	137			
Smart Contracts	Pearson Correlation	.620**	.582**	1.000		
	Sig. (2-tailed)	0.000	0.000			
	N	137	137	137		
Reward Token Mechanism	Pearson Correlation	.459**	.508**	.584**	1.000	
	Sig. (2-tailed)	0.000	0.000	0.000		
	N	137	137	137	137	
Implementation of EPR in plastic waste management	Pearson Correlation	.525**	.622**	.709**	.659**	1.000
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	
	N	137	137	137	137	137

\*\* . Correlation is significant at the 0.01 level (2-tailed).

The correlation analysis reveals a strong positive correlation between decentralization of data and the implementation of Extended Producer Responsibility (EPR) in plastic waste management, with a coefficient of  $r(135) = .525$ ,  $p < .001$ . This suggests that when data is decentralized through blockchain systems, transparency and openness are enhanced thereby supporting the effectiveness of EPR practices. This finding supports the research by Tapscott and Tapscott (2017) who reported that a blockchain-based system is capable of safely recording important data about operations along

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an entire value chain and that the adoption of such a system is useful as it provides compliance, transparency, tracking, tracing, error reduction, payment processing among many other advantages. A strong positive correlation was also found between tracking mechanisms and implementation of EPR,  $r(135) = .622, p < .001$ . This implies that accurate tracking of plastic waste across its lifecycle using blockchain increases accountability and strengthens compliance with EPR obligations. This finding is consistent with research by Nandi *et al.* (2021) who noted that blockchain technology provides transparency, traceability and security to transactions, real-time data and smart contracts, to suit specific needs of its users and that it may integrate with other emerging technologies such as Big Data, Artificial Intelligence (AI), IoT and cloud computing. Da Cruz and Cruz (2020) also mention that traceability is perceived as synonymous of transparency across value chains.

The analysis further indicates a very strong positive correlation between smart contracts and implementation of EPR,  $r(135) = .709, p < .001$ . This suggests that the use of automated, self-executing agreements ensures efficiency and compliance in enforcing EPR regulations which makes smart contracts a powerful enabler. This finding is consistent with research by Sigalov *et al.* (2021) who noted that smart contracts enable automatic payments once predefined conditions are fulfilled and can efficiently manage deposit-based incentive schemes that reward proper waste disposal and recycling efforts. Finally, a strong positive correlation was observed between reward token mechanisms and EPR implementation,  $r(135) = .659, p < .001$ . This implies that incentive structures embedded in blockchain systems motivate stakeholders to actively participate in plastic waste collection and recycling thereby reinforcing the success of EPR programs. This finding resonates with research by Gong *et al.* (2022) who noted that a blockchain-based token system strengthens consumer commitment to recycling by rewarding eco-friendly behaviors and minimizing landfill waste, thereby encouraging sustainable consumption and lower carbon emissions. Overall, these results demonstrate that all four blockchain features are positively and significantly associated with the implementation of EPR confirming that blockchain technology offers essential support for plastic waste management initiatives in Nairobi City County, Kenya.

### 4.3.2 Regression Analysis

Multiple regression analysis was used to assess the relationship between blockchain technology and implementation of EPR in plastic waste management in Nairobi City County, Kenya. Three tables presenting the results of the regression analysis were examined in the subsections that follows.

#### 4.3.2.1 Model Summary

Model summary was used to examine the amount of variation in the implementation of EPR in plastic waste management in Nairobi City County, Kenya, as a result of changes in decentralization of data, tracking mechanism, smart contracts and reward token mechanism. The results are shown on Table 8.

**Table 8: Model Summary**

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.793 <sup>a</sup>	.629	.617	.25722

a. Predictors: (Constant), Reward Token Mechanism, Decentralization of Data, Tracking Mechanism, Smart Contracts

The regression model demonstrates a strong overall fit, as indicated by an *R*-squared value of 0.629, suggesting that approximately 62.9% of the variance in the dependent variable, implementation of Extended Producer Responsibility (EPR) in plastic waste management, can be explained by the independent variables included in the model, namely decentralization of data, tracking mechanism, smart contracts and reward token mechanism. The remaining 37.1% of the variation in the implementation of EPR is attributable to other factors not captured within the scope of this study which implies the existence of additional variables that may also influence the implementation of EPR.

The adjusted *R*-squared value of 0.617 accounts for the number of predictors in the model and adjusts the *R*-squared value accordingly thus providing a more accurate representation of the model’s explanatory power. The multiple correlation coefficient of  $R = 0.793$  indicates a strong positive relationship between the predictors and the dependent variable. The standard error of the estimate of 0.25722 demonstrates that the model predicts the dependent variable with relatively small average errors. Therefore, the model’s high *R*-squared value, strong correlation coefficient, and low standard error suggest that the included predictors collectively contribute significantly to explaining variations in the implementation of EPR. Consequently, the model appears to be a robust predictor of the implementation of EPR within the context of blockchain-enabled plastic waste management in Nairobi City County, Kenya.

#### 4.3.2.2 Analysis of Variance

The ANOVA table provides information about the overall fit of the regression model and whether the predictors included in the model significantly contribute to explaining the variance in the dependent variable. In this study, the significance of the model was tested at 95% confidence interval (significance level of 5% ( $\alpha = 0.05$ )). If the *p*-value was less than the chosen significance level of 0.05, the data was deemed eligible for investigation. This was the chosen level of significance. The results are displayed in Table 9.

**Table 9: ANOVA<sup>a</sup>**

Model		Sum of Squares	Df	Mean Square	F	Sig.
1	Regression	14.785	4	3.696	55.869	<.001 <sup>b</sup>
	Residual	8.733	132	.066		
	Total	23.519	136			

a. Dependent Variable: Implementation of EPR in plastic waste management

b. Predictors:(Constant), Reward Token Mechanism, Decentralization of data, Tracking Mechanism, Smart Contracts

A multiple regression analysis was conducted to examine whether blockchain technology features significantly predicted the implementation of extended producer responsibility (EPR) in plastic waste management in Nairobi City County. Composite variables for decentralization of data, tracking mechanisms, smart contracts, reward token mechanisms and implementation of EPR were computed as mean scores of their respective Likert-scale items to ensure comparability across constructs on a standardized 1 - 5 scale. The analysis of variance (ANOVA) results indicated that the regression model was statistically significant,  $F(4, 132) = 55.869, p < .001$ . The regression sum of squares was 14.785 with a mean square of 3.696, while the residual sum of squares was 8.733

with a mean square of 0.066. The total sum of squares was 23.519, demonstrating that the predictors collectively explained a substantial portion of the variance in the dependent variable. This finding suggests that the variation in the implementation of EPR in plastic waste management was not due to random chance but was significantly explained by the combined influence of blockchain features. Specifically, the significant *F*-statistic confirms that at least one of the predictors; decentralization of data, tracking mechanisms, smart contracts or reward token mechanisms, had a non-zero effect on the implementation of EPR. Therefore, the results provide strong evidence that blockchain technology features, when considered together, significantly influence the implementation of EPR in plastic waste management within Nairobi City County.

#### 4.3.2.3 Beta Coefficients of the Study Variables

Multiple linear regression model was used to establish the influence among predictor variables and explain magnitude and course of relationship amongst the variables of the study utilizing coefficient of determination and the level of significance. The beta coefficients were used to illustrate the association between the variables using a model of the structure:  $Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \epsilon$  Where; *Y* = Implementation of Extended Producer Responsibility (dependent variable);  $\beta_0$  = *Y* Intercept; *X*<sub>1</sub> = Decentralization of Data; *X*<sub>2</sub> = Tracking Mechanism; *X*<sub>3</sub> = Smart Contracts; *X*<sub>4</sub> = Reward Token Mechanism;  $\beta_1, \beta_2, \beta_3, \beta_4$  = Regression coefficients measuring the impact of each independent variable;  $\epsilon$  = Error term representing unexplained variations. Table 10 below shows the beta coefficients of the study variables.

**Table 10: Beta Coefficients**

Model	Unstandardized Coefficients		Standardized Coefficients		
	B	Std. Error	Beta	T	Sig.
1 (Constant)	.701	.276		2.542	.012
Decentralization of data	-.005	.069	-.005	-.070	.945
Tracking Mechanism	.243	.074	.238	3.299	.001
Smart Contracts	.355	.070	.391	5.091	<.001
Reward Token Mechanism	.267	.058	.312	4.617	<.001

a. Dependent Variable: Implementation of EPR in plastic waste management

The regression equation is shown as:

$$Y = 0.701 - 0.005 X_1 + 0.243 X_2 + 0.355 X_3 + 0.267 X_4$$

A multiple regression analysis was conducted to examine the predictive role of blockchain technology's features on the implementation of extended producer responsibility (EPR) in plastic waste management in Nairobi City County. Composite variables were computed as mean scores of their respective Likert-scale items. The unstandardized coefficients indicate the weight of each predictor in the regression equation. The constant ( $\beta_0$ ) was 0.701, with a p-value of .012 suggesting that when all predictors are held constant, the baseline level of implementation of EPR is statistically significant. The beta coefficient for decentralization of data was - 0.005 with a p-value of .945 which suggests that decentralization of data does not have a statistically significant effect on the implementation of EPR in plastic waste management. While this was the finding from this particular

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research study, Rejeb *et al.* (2023) highlights that blockchain's decentralized and tamper-proof architecture significantly improves transparency within supply chains while minimizing administrative costs and reducing reliance on intermediaries. Sousa and de Brito (2024) also report that blockchain enhances a peer-to-peer network by ensuring secure, transparent and immutable data verification while simultaneously reducing costs and removing intermediaries.

The beta coefficient for tracking mechanism was 0.243, with a p-value of .001 suggesting a statistically significant positive effect of tracking mechanisms on the implementation of EPR in plastic waste management. This finding resonates with research by Tang (2025) who reported that blockchain technology enables complete transparency and traceability within the plastic supply chain by digitally recording every stage of a product's lifecycle which promotes accountability, ensures compliance with Extended Producer Responsibility (EPR) regulations and incentivizes the use of post-consumer recycled (PCR) plastics, thereby minimizing environmental leakage. The beta coefficient for smart contracts was 0.355, with a p-value of <.001, suggesting a highly significant positive effect of smart contracts on the implementation of EPR in plastic waste management. The beta coefficient for reward token mechanism was 0.267, with a p-value of <.001 suggesting a highly significant positive effect of reward token mechanisms on the implementation of EPR in plastic waste management. This finding resonates with research by Ahmad *et al.* (2021) who reports that the digital tokens issued through blockchain can be redeemed for discounts, services or charitable donations and this blockchain-based reward system promotes a culture of recycling and supports the circular economy. All in all, these findings indicate that tracking mechanisms, smart contracts and reward token mechanisms significantly contribute to explaining the variation in the implementation of EPR, while decentralization of data does not significantly predict EPR outcomes in this context.

#### 4.4 Qualitative Analysis

The study gathered qualitative insights on the potential application of blockchain technology to enhance the implementation of Extended Producer Responsibility (EPR) in plastic waste management in Nairobi City County. The responses provided a deeper understanding of how decentralization of data, tracking mechanism, smart contracts and reward token mechanism could influence the implementation of EPR. Several themes emerged from participant feedback, revealing both opportunities and challenges for blockchain-enabled EPR systems. Some respondents emphasized that Kenya is still at an early stage in leveraging blockchain for waste management, with one respondent remarking: *"We still have a long way to go for Kenya to implement EPR through blockchain technology."* This illustrates the perceived readiness gap between current practices and digital innovation in environmental governance.

A recurring theme in the responses was the need for inclusive stakeholder engagement. Producers were frequently mentioned as key actors in the success of EPR initiatives. One respondent highlighted: *"Producers should be involved before, during and after the rollout of such a system because they know best how they can contribute to proper waste collection."* This perspective underscores that blockchain technology alone is not sufficient; effective collaboration among producers, government and communities is critical for sustainable outcomes.

Concerns regarding the credibility and validation of records also surfaced. Respondents expressed skepticism about how blockchain validators would address false or misleading entries in the system. As one participant noted: *"I agree with the use of blockchain in EPR but my concern is how will the validators be able to prove wrong/false records from all those involved."* This indicates a need for

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robust mechanisms within blockchain frameworks to ensure data authenticity and accountability in waste tracking.

Capacity building and piloting were identified as essential prerequisites to large-scale implementation. One respondent stated: *“A lot of pilots and capacity building to all stakeholders is required before full implementation.”* Similarly, another emphasized the value of incremental adoption, suggesting: *“Nairobi County should consider pilot programs with local startups to test how it works.”* These perspectives reinforce that experimentation and learning are vital steps before full-scale integration of blockchain in waste management systems.

Respondents also recognized blockchain’s potential to improve transparency, fairness and efficiency in EPR. For example, one participant remarked: *“Blockchain can help make EPR more transparent, fair, and reliable.”* Another added: *“If parties can leverage on blockchain technology it can really help with the issue of waste management and keep all stakeholders on check with so much mistrust and brokers it will be a game changer.”* Such feedback demonstrates that blockchain is viewed as a trust-enhancing technology capable of strengthening accountability in the recycling value chain.

Despite these perceived benefits, respondents pointed to broader institutional and policy challenges. Some highlighted the lack of county government support in recycling ecosystems, double licensing issues and inconsistent enforcement of plastic control regulations. One participant noted: *“Less county support in collection and recycling ecosystems. CESS fees for intercounty transfer of recyclable plastic.”* Others stressed regulatory uncertainty, particularly around emerging technologies, with one respondent observing: *“Kenya lacks clear regulations and policies governing the use of blockchain. This creates uncertainty for investors and developers, especially in areas like cryptocurrency, smart contracts, and digital identity.”*

The qualitative findings reveal stakeholder perspectives on blockchain technology's potential to enhance the implementation of EPR in plastic waste management in Nairobi City County. Respondents identified significant opportunities for blockchain's decentralization of data, tracking mechanism, smart contracts and reward token mechanism to address existing challenges in transparency, accountability and stakeholder coordination. However, participants also highlighted substantial implementation barriers related to capacity building, regulatory frameworks, technical integration and economic considerations. The feedback emphasizes that successful implementation of blockchain technology in the implementation of EPR requires comprehensive preparation, inclusive stakeholder engagement, robust validation mechanisms, meaningful economic incentives, supportive regulatory frameworks and careful attention to technical integration requirements. Addressing these challenges would enable Nairobi City County to develop more effective, transparent and blockchain-enabled EPR systems for plastic waste management.

## 5.0 Conclusion

This study concludes that these three blockchain technology features; tracking mechanism, smart contracts and reward token mechanism positively influence the implementation of Extended Producer Responsibility (EPR) in plastic waste management in Nairobi City County. While decentralization of data was perceived as valuable for transparency and trust, the regression analysis established that it does not have a statistically significant direct influence on EPR outcomes in this context. This suggests that decentralization alone is insufficient to drive meaningful improvements unless it is integrated with the other blockchain features that have demonstrated stronger predictive

power. The study established that tracking mechanism plays a vital role in strengthening accountability and reliability across the plastic waste lifecycle. Digital product passports, integration of smart sensors and IoT and hash-linked audit trails enhance traceability which ensures that producers and recyclers are held accountable. This finding underscores the need for county policymakers and waste actors to invest in digital infrastructure that supports traceability as a foundation for more transparent plastic waste management practices.

The study found that smart contracts have a significant influence on the implementation of EPR by automating payments, enforcing compliance and streamlining regulatory processes. Smart contracts' ability to reduce delays and limit opportunities for manipulation demonstrates their potential as a key driver of efficiency. These findings highlight the necessity of integrating smart contracts into plastic waste management frameworks supported by regulatory alignment and capacity building among stakeholders. The study further revealed that reward token mechanism has a significant influence in motivating behavioral change. Reward token mechanism encourages participation, increases the transparency of token monetary value and sustains commitment among producers, recyclers and consumers. This suggests that reward token mechanism should be central to Nairobi's EPR rollout in order to ensure that participation in plastic waste collection and recycling is both meaningful and rewarding. Although decentralization of data was viewed by respondents as an important enabler of trust and transparency, its lack of statistical significance indicates that it is more supportive than decisive in shaping EPR outcomes. For decentralization of data to play a stronger role, it needs to be applied in conjunction with tracking mechanism, smart contracts and reward token mechanism.

In conclusion, the findings from this study demonstrate that blockchain technology holds considerable promise in advancing the implementation of EPR in plastic waste management in Nairobi City County. However, its success requires a holistic approach that prioritizes tracking, automation through smart contracts and incentive-driven participation through reward token mechanism, while complementing these with decentralization of data. This approach if properly executed would greatly advance Nairobi City County's efforts toward streamlining the implementation of EPR and building more transparent, accountable and sustainable plastic waste management systems.

## **6.0 Recommendations**

The study recommends that blockchain-enabled tracking mechanisms should be prioritized to strengthen accountability and transparency in the implementation of EPR in plastic waste management in Nairobi City County. Policymakers and waste managers in Nairobi City County should consider adopting digital product passports to improve traceability of plastic waste across its lifecycle. At the same time, integrating smart sensors and Internet of Things devices would allow for real-time monitoring, while hash-linked audit trails can safeguard the integrity and reliability of records. These measures would ensure that data on plastic waste generation, collection and recycling remains accurate, tamper-proof and accessible to all stakeholders. Smart contracts should also be integrated into the implementation of EPR in plastic waste management as a means of enhancing efficiency and automating compliance. Smart contracts can enforce regulatory obligations, streamline payments to recyclers and reduce delays therefore are a powerful tool for building trust in the plastic waste management system. It will be essential to align smart contracts with existing legal frameworks and regulatory procedures to ensure their smooth adoption. Capacity-building

programs for stakeholders can greatly support the use of smart contracts and prevent resistance to new automated processes.

Reward token mechanism presents another strong avenue for motivating active participation in plastic waste management. By designing reward token-based incentives, Producer Responsibility Organizations and county authorities can encourage producers, consumers and recyclers to take part in EPR initiatives. A decentralized token redemption system that allows rewards to be exchanged fairly and transparently would help ensure inclusivity, while interoperability with widely used platforms such as M-Pesa would make participation both accessible and sustainable. Reward tokens therefore have the potential to anchor long-term behavioral change in plastic waste management practices. Although decentralization of data did not emerge as a statistically significant predictor in the implementation of EPR, it remains an important enabling factor for trust and transparency. A distributed ledger system can provide shared records that are tamper-proof, while consensus mechanism can help build cooperation among producers, recyclers and regulators. Peer-to-peer networks can reduce reliance on centralized authorities which may promote openness and efficiency. When integrated with other blockchain features such as tracking mechanism, smart contracts and reward token mechanism, decentralization of data can provide the supportive framework needed to strengthen transparency in the implementation of EPR in plastic waste management in Nairobi City County.

In conclusion, the study recommends that Nairobi City County should focus on tracking mechanism, smart contracts and reward token mechanism as immediate priorities, while also integrating the decentralization of data as a supportive feature to foster transparency and trust. A holistic approach that combines these features with supportive policies, awareness programs and stakeholder engagement will help establish a more transparent, efficient and sustainable framework for implementing Extended Producer Responsibility in plastic waste management in Nairobi City County.

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