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Promoting Sustainable Household Engagement in Recycling via Blockchain-Based Loyalty Program

Kawther Saeedi

Information Systems Department, King Abdulaziz University, Jeddah 21589, Saudi Arabia; ksaeedi@kau.edu.sa

Abstract: Recycling plays a crucial role in impacting national GDP and environmental sustainability. Given the complexities inherent in recycling processes, technology serves as a driving force for advancing and optimizing these practices. In the Kingdom of Saudi Arabia, substantial initiatives are underway to foster a green environment and promote a circular economy. However, at the time of writing this paper, existing regulations mandate recycling primarily for business sectors, with no corresponding requirements for household waste collection or segregation. As a result, a significant portion of recyclable waste remains unprocessed. This paper expands upon earlier studies carried out in Jeddah, analyzing the obstacles and variables impacting sustainable recycling solutions, along with the essential conditions to boost household involvement in recycling. This study explores the potential of blockchain technology to improve household engagement by developing a blockchain-based loyalty program. The proposed system leverages the decentralized, immutable, and transparent features of blockchain technology to reward individuals with tokens for the recycling waste they produce, thereby facilitating token tracking across the recycling value chain and enhancing transparency in the circular economy. This article delves into the technical architecture of the loyalty program, aligning its domain model elements with blockchain design heuristics and integrating it with a mobile application that aims to boost recycling engagement by applying social economy principles. This innovative approach promises to overcome the current regulatory and motivational barriers, as well as promote sustainable recycling habits at the household level.

Keywords: tokenization; DApp; recycling value chain; rewording system; circular economy

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1. Introduction

Recycling is crucial for national GDP and environmental sustainability, yet it remains a complex process requiring significant technological advancements. In the Kingdom of Saudi Arabia (KSA), the government has launched extensive initiatives to promote a green environment and advance a circular economy as part of Vision 2030 [1]. However, current efforts primarily target the commercial sector, with minimal regulations for household waste segregation and collection [2]. The absence of household-level governance has led to the neglect of significant recyclable waste, thereby reducing the efficacy of national recycling initiatives.

This paper builds on previous research in Jeddah, which identified key factors and challenges in promoting sustainable household recycling practices [2] followed by the design and development of a mobile application promoting household engagement in the recycling process [2,3]. This research heightened awareness of recycling's importance, as well as barriers such as inconvenience and task difficulty that hinder participation [2]. Due to inadequate segregation and collection processes, the current practices in Jeddah effectively recycle only 15% of collected waste [2]. This underscores the need to address waste management from its source [3] and highlights the importance of motivating households to engage in recycling [4–6].

Our previous work focused on developing a business model that incorporates social economy principles to recycle waste [3]. This work concentrates on encouraging

waste segregation to boost the volume of recycling. This paper highlights the design of a blockchain-based loyalty program to incentivize household recycling waste segregation and increase its volume. This approach is crucial for sustaining the transportation model established in earlier research [3] and advancing the circular economy. The use of blockchain technology is a novel contribution, as it enables secure, transparent, and immutable tracking of recycled materials. During this phase, we assign a value to recyclable waste based on its volume and type, which we then exchange for reward tokens. By mapping the solution design to blockchain heuristics, we ensure a reliable and transparent value chain for recycling. This paper establishes a business case for adopting blockchain by detailing the conceptual development and technical architecture of the blockchain solution. Depicting conceptual aspects of such complex technology helps to understand and discover the variance of its adaptation.

This paper begins with a literature review of blockchain's transformative capabilities and incentive-based recycling programs, emphasizing blockchain's decentralization, security, and potential applications beyond cryptocurrencies. It then details various global initiatives integrating blockchain with recycling incentives, showcasing different implementations. This paper differs from other works in that it focuses on household recycling in Saudi Arabia, an area that is often overlooked in recycling initiatives. Recycling initiatives are complex in nature and context-specific [7]; therefore, it is important to propose a solution design tailored to this context as well as to contribute to a circular economy vision in Saudi Arabia.

Section 3 provides an overview of the research phases, with a focus on the work conducted in this paper using a design science research methodology to develop a business model that incentivizes household participation through a loyalty program. Section 3.2 reviews common loyalty programs in the Saudi Arabian market, which influenced the decision to tokenize recyclable materials on the blockchain. The value chain of the blockchain-based recycling reward system is also outlined in this section. The technical architecture of the blockchain-based loyalty program is detailed in Section 3.3, aligning domain model elements with blockchain design heuristics. This paper concludes in Section 4 by discussing the implications, strengths, limitations, and future research directions for the proposed system, highlighting its potential to revolutionize the recycling value chain and empower the circular economy in Saudi Arabia. It also explores opportunities to leverage AI-driven insights from the data stored throughout the recycling value chain.

2. Literature Review

The following sections delve into two pivotal aspects of modern technological and environmental advancements: blockchain technology and incentive-based recycling programs. Section 3.1 explores blockchain's transformative potential, detailing its decentralized nature, security features, and its evolution from cryptocurrencies to broader applications like smart contracts and supply chain management. Section 3.2 examines how incentive-based recycling programs, supported by policies and innovative technologies, are being used globally to encourage household recycling with a particular focus on the integration of blockchain technology to enhance transparency, traceability, and rewards in recycling initiatives.

2.1. Blockchain

Blockchain technology is a groundbreaking innovation that serves as a decentralized, distributed ledger, enabling secure, transparent, and traceable transactions without the need for a central authority [8]. Blockchain leverages consensus algorithms to validate groups of transactions across nodes in a peer-to-peer network. Once validated, the blockchain adds these blocks, creating a permanent, time-stamped record that is both immutable and auditable [9]. This fundamental structure replaces intermediaries, inherits high levels of security, and leverages transparency in a decentralized network.

Initially, blockchain was developed as a peer-to-peer electronic cash system by Satoshi Nakamoto in 2008, offering a new form of decentralized payment using digital currency, or

cryptocurrency, known as Bitcoin [10]. Since then, blockchain technology has witnessed a rapid evolution in the cryptocurrency domain until the introduction of smart contracts by the Ethereum blockchain, which marked a significant advancement [10]. The smart contract encodes the terms of transactions and enables self-execution once the conditions are met. This enabled more complex applications beyond simple financial transactions and allowed for automation—trustless exchanges of value across various domains.

Blockchain's potential extends far beyond cryptocurrencies. The technology has catalyzed the development of Decentralized Autonomous Organizations (DAOs) [11], which redistribute authority and control among network participants, challenging traditional centralized business models [12]. Tokenization has also emerged as a significant innovation, enabling the secure representation and exchange of physical assets on blockchain platforms [13]. This has opened new opportunities for industries to rethink and innovate their business models, particularly in sectors such as supply chain management [14,15], healthcare, education, e-government [16,17], and the Internet of Things (IoT) [18].

Blockchain technology is characterized by its distributed nature, automated capabilities via smart contracts, security by design, and interoperability with existing systems [8,19]. As a distributed transactional platform, blockchain enables peer-to-peer exchanges without the need for third-party intermediaries, ensuring the integrity and security of transactions through cryptographic mechanisms [20]. Smart contracts enhance the computational capabilities of blockchain, allowing for the automation of complex business processes and ensuring the consistency and validity of operations across multiple organizations [21].

Security is a core feature of blockchain, and its architecture is designed to be secure by nature. The architectural design of blockchain inherently incorporates security characteristics [8]. The security is empowered by time stamping of transactions, confirming transaction validity by all blockchain participants before adding it to the blockchain and adding a block at the end of the chain after producing a cryptographic hash from both transaction data and the hash address of the previous block. These are some of the techniques that have confirmed that records cannot be altered, ensuring the immutability and integrity of the data [19]. This transparency is further enhanced by public access to the stored data (ledger) by every node in the blockchain, making blockchain an ideal solution for applications that require high levels of trust and accountability.

There are different types of blockchain systems: public, private, and hybrid, offering different levels of access and control. This makes blockchain technology adaptable to addressing a wide range of organizational needs [17]. A public blockchain is open and decentralized and allows nodes to contribute or exit with no constraints. Private blockchain restricts access and participation to specific nodes, typically within a single organization or consortium. Hybrid blockchain combines elements of both types, offering a balance of openness and control [22].

Blockchain is complex, as it inherits the complexity of a range of established technologies to create this secure platform. Furthermore, the operation of blockchain requires significant computational resources and power, particularly for public blockchains. Therefore, identifying a valid example for a blockchain-based system is very important for an organization to justify investment as well as for researchers to facilitate understanding its adaptation [19,22]. Despite its complexity and infancy, it is evolving rapidly and promises to revolutionize traditional business models by enabling trustless transactions, enhancing data security, and fostering automation across industries [10]. Blockchain possesses the capability to offer a secure, transparent, and decentralized platform for managing transactions and data. Therefore, blockchain provides a powerful tool for organizations seeking to innovate automation in the digital interconnected world [23].

2.2. Incentive-Based Recycling Programs

Economic development and urbanization have resulted in a significant increase in household waste production. This encourages governments to allocate resources toward recycling initiatives to reduce environmental pollution and landfill use [7]. Developed

countries have established extensive waste segregation and collection frameworks from their sources as well as a variety of policies and regulations to govern recycling systems. Japan's Basic Law for a Recycling-based Society [24] and Germany's manufacturer responsibility system [25] demonstrate the effective implementation of established policies for waste segregation and collection. Another example is Mid-Devon Council, UK, which introduced fines, resulting in higher recycling rates that exceeded national averages [26]. Therefore, policies and good practices are necessary for long-term recycling success [26].

In contrast, the absence of recycling frameworks, inadequate legislation, and a scattered informal recycling effort in developing countries have resulted in a decrease in recycling rates [2,7]. Despite the lower recycling rate in developing countries, the informal recycling industry is expanding to capitalize on the significant amount of recycled waste that has been neglected [7]. This can be a lucrative business but it necessitates tailored approaches for each environment and the development of sustainable systems [7].

Rewards are a powerful tool to enhance waste collection services, increase recycling participation, boost the volume of recyclables collected, and reduce residual waste [2,5,27]. The success of incentive schemes, particularly those implemented by the UK government, highlights the potential of such strategies to motivate citizens to engage more actively and effectively in recycling efforts [28]. Additionally, raising awareness and offering rewards and incentives are crucial instruments for promoting recycling. In the UK, incentive programs have demonstrated that financial rewards can significantly elevate recycling awareness and increase collection rates. However, the effectiveness of these programs depends on the careful design of reward schemes, ensuring they are substantial, well-communicated, and supported by efficient service delivery [29].

Other regions have explored incentive-based recycling programs with varying degrees of success. For instance, Hong Kong's GREEN$ smart card initiative encourages recycling by offering rewards for bringing recyclables to community facilities [30]. Research from Finland supports the idea that financial incentives can significantly impact recycling behavior, although each locality must tailor its approach to its specific barriers and conditions [31]. Nigeria and the US have reported similar findings, recognizing the crucial role of financial incentives in encouraging recycling [32,33].

Several innovative recycling initiatives have emerged globally, providing tools to educate and motivate citizens to recycle as well as utilizing blockchain technology, including RECICLOS in Spain [34], Circularise in the Netherlands [35], RecycleGO in the US and Najera [36], PlasticBank in Canada [37], Empower in Norway [38], and the BanQu partnership with Coca-Cola in South Africa [39]. Each initiative has unique features and focuses on contributing to the recycling process in different ways. In Saudi Arabia, EcoRewardsSaudi connects recycling machines to a mobile app loyalty program for the Saudi market [40], rewarding each plastic or metal container with bonus points, which can then be exchanged for partner promotions and discount offers. A social responsibility agreement and a free marking platform encourage partners to participate and sell their goods. This advanced technological solution is only effective in collaboration with various partners, including local authorities, NGOs, and the public, with mobile technologies playing a key role in enhancing communication and engagement [41]. Table 1 highlights the incentive mechanisms empowered by the blockchain.

In the city of Jeddah, the enforcement of fines and penalties for waste management is constrained by the absence of a legal framework and the lack of coordinated participation from various stakeholders in the waste management process. This limitation can render recycling a less efficient method of waste management. Consequently, this paper focuses on exploring incentives and motivational strategies to encourage household participation in waste segregation and collection, as well as fostering sustainable recycling habits at home.

Table 1. Incentive mechanisms empowered by the blockchain.

Initiative	Blockchain Empowered Incentive
RECICLOS in Spain [34]	RECICLOS uses blockchain to tokenize recycled plastic in exchange for different reward schemes such as a lottery. The blockchain is used to trace the transactions of the application [5,34].
Circularise in the Netherlands [35]	Provides Digital Product Passports to unlock supply chain data and provide end-to-end traceability without sharing sensitive data. Circularise also traces plastic with the digital passport and conducts plastic life cycle assessment [35].
RecycleGO in the US and Najera [36]	Utilizes a public blockchain ledger to enhance the visibility of the supply chain and provide benefits to recycling stakeholders. The system provides digital tokens as incentives, which can be distributed in exchange for different roles in recycling [36].
PlasticBank in Canada [37]	Adopts fintech as a platform for exchanging plastic transactions across borders. Member accounts are accessed by a digital wallet to provide a traceable circular economy [37] (Estee Lutte Engao, July 2024, "Plastic Bank Sustainability Report 2023" https://plasticbank.com/blog/plastic-bank-sustainability-report-2023/) (accessed on 17 August 2024).
Empower in Norway [38]	Empowers and encourages plastic waste collection in exchange for tokens secured in the blockchain. The tokens can be exchanged with securely traced money [38].
BanQu in South Africa [39]	Blockchain enables recycling collectors to prove their earnings, enhances buyback centers' transaction tracking, and allows Coca-Cola Africa to trace recycled materials throughout the value chain.

3. Material and Methods

This paper is part of a research project focused on enhancing household recycling engagement, particularly in the context of insufficient regulations and a significant informal recycling sector, with the aim of exploring the potential for a value chain circular economy through technological innovation. The research has progressed through multiple phases shown in Figure 1, where arrows depict the sequential order of these phases. Phase 1 begins with an exploration study to understand the dynamics of household recycling in Jeddah, identifying key challenges through interviews and questionnaires. A design science research approach was employed to address these challenges using design thinking and ideation techniques, followed by an empirical study involving an eight-week experiment to evaluate household participation in waste segregation and collection [2]. Building on these findings, the project conceptualized a business model for household recycling that incorporates social economy principles to facilitate waste transportation, supported by the development of a mobile application to enhance the solution's visibility [3]. The current phase, which is the focus of this paper, involves further design science research to develop a business model that incentivizes household participation through a loyalty program, with blockchain technology integrated into the technical architecture to support this initiative by aligning domain model elements with blockchain design heuristics. Future phases will involve the development of a blockchain-based solution, followed by an assessment of its usability and suitability, and, eventually, the exploration of AI-driven traceable data storage to optimize decision-making and uncover new opportunities for advancing the circular economy.

The requirements of encouraging household participation in the recycling process via a loyalty program and reminders are outlined in the first phase of this research to overcome the drop in recycling waste collection amount over time [2]. To design a business model that incentivizes household participation through a loyalty program tailored to the Saudi market, a detailed analysis of a business model for the top seven loyalty programs in Saudi Arabia [42] is depicted in Section 4.2. Conceptualization of technical architecture empowering the proposed loyalty program employing blockchain is performed via mapping domain model elements to blockchain design heuristics detailed in Section 4.3.

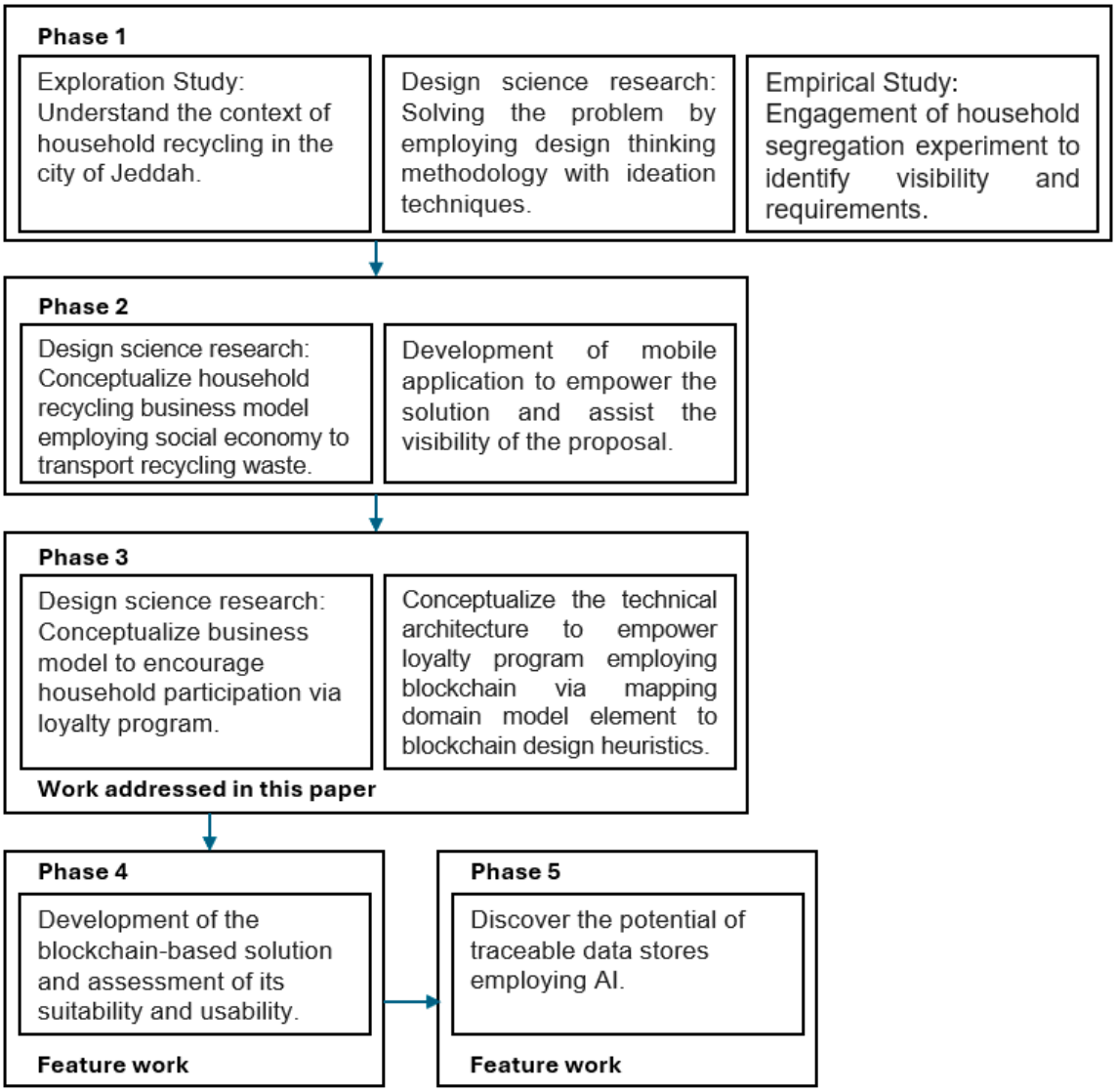


Figure 1. Research phases.

3.1. Description of the Project

This project addresses the early-stage recycling challenges in Saudi Arabia, particularly the absence of a household recycling system, leading to substantial neglect of recyclable waste. Building on prior research in Jeddah, this project involves developing a mobile application designed to enhance household engagement in recycling through a social economy approach [3]. The solution facilitates connections between individuals donating recyclable materials and recycling outlets via a self-funded transportation system, encouraging participation. The application has been developed, tested, and evaluated, demonstrating high perceived usefulness and ease of use [2]. An eight-week experiment revealed that a significant percentage of participants were willing to separate waste when provided with convenient collection options. The findings also indicate the economic feasibility of the initiative, contingent on sufficient household participation [3]. The work presented in this paper aims to further enhance the application by integrating a loyalty program, introducing virtual reward tokens to motivate families to recycle, and offering loyalty points as incentives. The project leverages blockchain technology to tokenize collected recycling waste with reward tokens, facilitating their exchange with a range of incentives provided by participating partners. This represents a paradigm shift in personal rewards for recycling, offering transparent, efficient, and automatic monitoring and control of reward tokens. This is in addition to the provision of transparently and efficiently monitoring the flow of

recycled materials from homes to treatment plants, ensuring accuracy and reliability in the process.

3.2. Business Model Analysis

The Saudi Arabian market features a variety of loyalty programs tailored to different industries, including retail, telecommunications, travel, and banking. These programs, which range from points-based and tiered systems to coalition and subscription-based models, are designed to incentivize customer retention and engagement [43]. Companies like Al Rajhi Bank, STC, and Saudi Airlines utilize these strategies to offer tangible rewards such as discounts, free products, and exclusive services, fostering a loyal customer base. Additionally, programs like WalaPlus target corporate clients, providing employee-centric benefits that extend to families, thereby enhancing both customer and employee loyalty [42].

Table 2 outlines various loyalty program types in the Saudi market, highlighting how these strategies are implemented across different sectors and detailing their reward exchange schemes and involved stakeholders. Points-based programs, such as those offered by Al Rajhi Bank and STC, allow customers to redeem points for discounts or products. Tiered programs, like Saudi Airlines' Alfursan, provide escalating rewards as customers advance through levels. Coalition programs, exemplified by Centrepoint's Shukran, enable point redemption across multiple brands. Subscription-based models, like Saudi Aramco's program, offer exclusive rewards in exchange for a recurring fee, primarily benefiting employees. Lastly, gamified programs, such as Almarai's, engage customers through challenges and tasks, offering points and rewards as incentives. These models reflect how businesses in Saudi Arabia engage customers and employees, enhancing loyalty and retention. By adopting the appropriate model, businesses can effectively increase customer retention, drive sales, and gather valuable consumer insights [42].

Table 2. Common loyalty program types and their exchange schemas in Saudi Arabia.

Loyalty Program Type	Description	Example in Saudi Arabia	Reward Exchange Scheme	Stakeholders Involved
Points-Based	Earn points for purchases, redeemable for rewards	Al Rajhi Bank Mokafaa, STC Qitaf	Points exchanged for discounts, vouchers, or products	Consumers, Retailers, Banks, Telecom Providers
Tiered	Progress through levels with increasing rewards	Saudi Airlines Alfursan	Higher tiers offer exclusive services and larger discounts	Consumers, Airlines, Partners (Hotels, Car Rentals)
Coalition	Multiple brands offer a shared loyalty program	Centrepoint Shukran	Points redeemed across partner brands	Consumers, Retailers, Partner Brands
Subscription-Based	Recurring fee for exclusive benefits	Aramco Life Rewards	Subscription grants access to exclusive rewards	Employees, Employers, Program Providers
Gamified	Engages customers through challenges and rewards	Almarai Rewards SIRC Rewards	Points and rewards for completing specific tasks	Consumers, Retailers, Technology Providers, Recycling

Businesses in Saudi Arabia leverage loyalty programs to build long-term relationships with households and individuals by designing programs that align with local consumer preferences, emphasizing ease of use, value, and personalization. The Saudi Investment Recycling Company (SIRC) [40] employs a gamified reward system to encourage the recycling of plastic bottles and cans, offering discounts from retail partners as incentives. In addition to rewards, consumers are motivated by a competitive dashboard that showcases their participation levels. Retail partners participate not only as part of their corporate social responsibility efforts but also to tap into new marketing channels to promote their products and services.

Based on an analysis of loyalty programs in prominent Saudi Arabian markets, focusing on functional aspects, revenue models, stakeholders, and exchange schemes, a tailored value chain for a blockchain-empowered recycling reward system has been designed. Figure 2 illustrates the conceptual model of this value chain, highlighting the

workflow among systems and stakeholders involved in the process. This is followed by a detailed illustration of the stakeholders and their roles, as shown in Table 3. The figure also demonstrates the trigger validation and traceability mechanisms facilitated by blockchain technology. The process begins when a driver collects recyclable waste from a household doorstep. Using a mobile application, the driver inputs details of the recyclable waste, including weight, type, location, and collection time. These details are then confirmed by the household before the recyclable waste is tokenized on the blockchain. This step ensures that genuine data are accurately recorded on the blockchain.

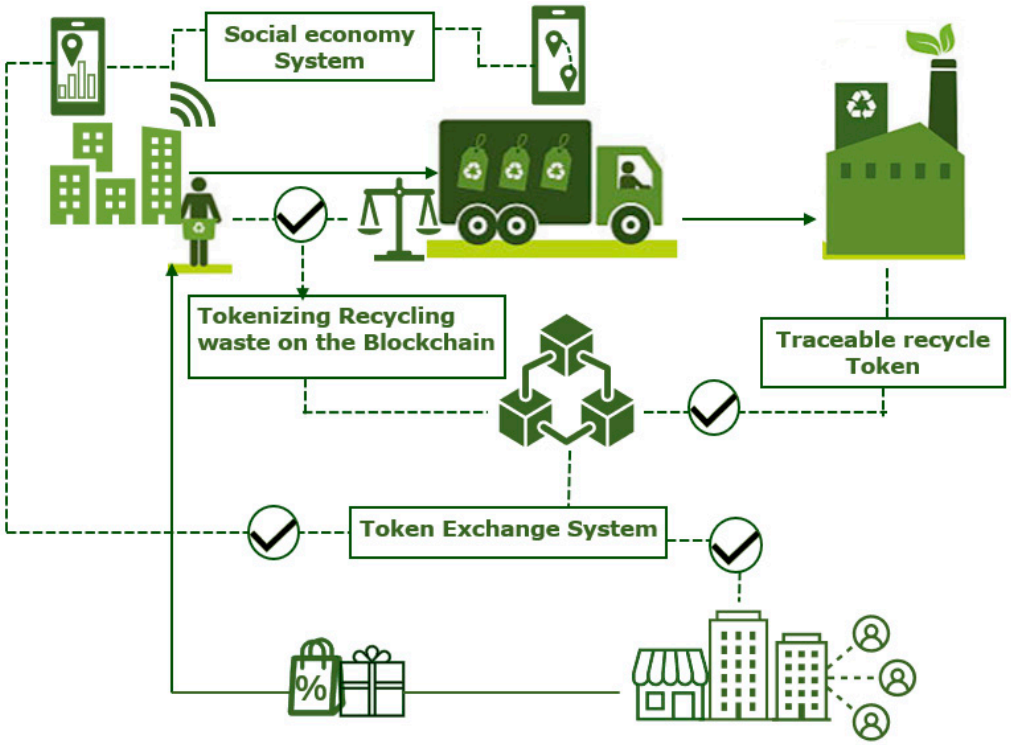


Figure 2. Value chain of recycling reward system empowered by blockchain.

Table 3. Reward system key stakeholders and their roles.

Stakeholder	Role
Households (Users)	Participate by sorting and providing recyclable materials. Use the mobile application to schedule pickups for their recyclables. Receive benefits from rewards and incentives.
Transportation Providers	Collects recyclable materials from households, weighs the received waste, and delivers them to recycling outlets. Use the mobile application to get directions of the recycling waste collection journey, log the recycling waste weight, and log the driver's waste in the system.
Recycling Outlet	Receive the recycled waste and process the collected materials, contributing to environmental sustainability efforts. Use the mobile application to log the received amount of recycling waste and the paid value.
Participating Partners	Supply rewards and incentives, promoting sustainable practices and engaging with the community. Use the mobile application to promote offers and reward values.
Government Agencies	Regulate and govern the recycling process, issue licenses and permissions, support recycling initiatives, and provide funding or policy frameworks.

The second point of traceability occurs at the recycling outlets, where the delivery of recyclable waste is tracked. A smart contract automates the distribution of rewards based on predefined rules, minimizing the need for manual intervention. This ensures that the collection, redemption, and exchange of rewards are handled accurately and efficiently. Householder access data are stored in the blockchain through a DApp-secured digital wallet for reward tracking, redeeming, and exchanging.

3.3. Conceptualizing the Technical Architecture for the Proposed Loyalty Program

The proposed loyalty program aims to integrate blockchain technology to revolutionize the recycling reward system by ensuring transparency, traceability, and automation. This section conceptualizes the technical architecture by mapping the domain model elements to blockchain design heuristics, ensuring that each aspect of the program is empowered by the strengths of blockchain technology [20].

The blockchain-based system enhances traceability and transparency in the recycling process by leveraging key domain model elements and blockchain heuristics. Households, as users, initiate the process by sorting recyclables, which are then collected by transportation providers. These providers log each collection event on the blockchain, ensuring that every step is recorded in an immutable ledger. As recycling waste is transported to a recycling facility, the system stores updates, creating a transparent and unalterable audit trail. This approach not only provides the precise tracking of materials from the point of collection to recycling facilities but also ensures complete visibility and accountability throughout the entire recycling journey.

A decentralized application (DApp) empowered by a smart contract and digital wallet provides a user-friendly interface facilitating complex interactions with the blockchain. In addition, it enhances security and privacy, safeguarding personal information and transaction details by securely storing them on the blockchain [10]. The digital wallet provides a means to identify the users securely with a pair of public and private keys. The DApp provides a means to easily track recycling rewards with tokens and then exchange and redeem tokens with participating partners based on a predefined contract for token exchange.

Tokenizing the weight and type of recycling waste on the blockchain is based on a predefined formula. The target is to incentivize households to actively participate in segregating and collecting recycled waste. The recycled waste is weighed at the time of collection and at the pickup location, and then the weight and token conversion are shared with the household on the blockchain. This step is the first verification point between stakeholders in the household and the drivers of collected recycling waste, regarding the amount and type as well as the first tracking station of the transparency value chain. Thereby, it maintains data integrity and further enhances trust in the system.

Tokens represent the value that can be exchanged with merchant rewards and can potentially encourage households to segregate and collect more recycled waste and promote sustainable practices [10]. This process not only simplifies tracking but also establishes an integrated system facilitating direct exchange with rewards offered by participating partners. This leverages reward tokens and exchanges on the blockchain through the motivation of successful monetary practices in the blockchain such as cryptocurrency and decentralized finance (DeFi). The integration of smart contracts streamlines operations and boosts efficiency by automating the reward value chain for recycling. This automation reduces the need for manual oversight, ensuring both accuracy and efficiency in reward distribution. Additionally, smart contracts automatically verify the authenticity of data at each stage of the recycling process.

The blockchain system is engineered to integrate seamlessly with existing waste management and transportation infrastructures, ensuring smooth data exchange and real-time updates. This interoperability allows all stakeholders, including government agencies and participating partners, to effectively access and utilize the data. Additionally, the system's scalable architecture can accommodate the growing number of transactions as

more households, transportation providers, and recycling outlets participate, maintaining efficiency and responsiveness as the program expands [44].

The blockchain system offers real-time monitoring through a transparent ledger, allowing stakeholders to track recycling activities, assess progress, and identify areas for improvement. The comprehensive data stored on the blockchain can be analyzed to generate insights into recycling patterns, user behavior, and system performance. These data-driven insights are valuable for informing policy decisions, optimizing logistics, and enhancing the overall effectiveness of the recycling program [16,17].

The conceptualization of the technical architecture of the proposed loyalty program is depicted with technical components of a full stack blockchain application and arrow depicting the information flow among these components as illustrated in Figure 3. This conceptualization leverages the core strengths of blockchain technology to create a robust and scalable system that promotes sustainable recycling practices. This architecture not only aligns with the functional requirements of the program but also positions it for future growth and innovation in the circular economy.

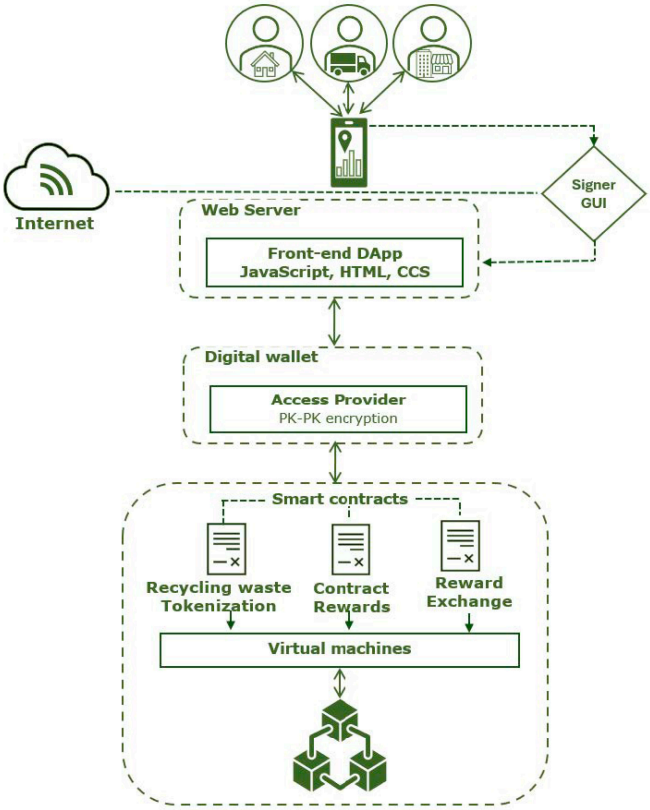


Figure 3. Technical architecture: conceptualization of blockchain-based loyalty program.

4. Discussion

This paper highlights the conceptual design of a blockchain-based loyalty program to promote recycling. This proposal aims to revolutionize the value chain of household recycling in Jeddah, Saudi Arabia, by tokenizing the amount and type of recycling waste with reward tokens in the blockchain. This addresses the challenges of inadequate waste segregation and low recycling rates. The proposed blockchain-based loyalty program offers a novel solution to incentivize and track household recycling activities in a transparent, traceable, secure, and automated fashion. The solution is designed to address requirements for recycling captured in previous research and aligned with common loyalty programs in the Saudi Arabian market. This section discusses research implications for waste management, the strengths and limitations of the proposed solution, and potential future research directions.

4.1. Implications for Waste Management and Recycling

Adopting blockchain technology in the recycling value chain provides several significant advantages. Firstly, the design inherits the characteristics of blockading, such as immutability, transparency, traceability, and security. Recording all transactions of the recycling value chain from households and throughout the journey to the recycling facilities is crucial, especially for tracing recycling waste that has monetary value. Traceability is an important vehicle to promote a circular economy, especially when expensive or dangerous recycling material is transported. Furthermore, waste collection and reward distribution are securely recorded and easily traceable. This transparency is crucial for building trust among households, recycling companies, and government agencies, as it ensures that all stakeholders can verify the accuracy of the recycling process.

Secondly, the use of a blockchain-based loyalty program to encourage households to effectively participate in recycling value chains. Effective participation implies segregating recycling waste to produce a higher volume and different types of recycling waste, tokenizing recycled waste by weight and type with predefined reward tokens that can be exchanged for various merchants' services. Offering tangible rewards encourages consistent household participation to collect more rewards, which can help to establish recycling as a regular household activity. Leveraging award tokens and their exchange for services on the blockchain is driven by the success of blockchain-based financial systems like cryptocurrency and decentralized finance (DeFi). By automating the benefits of the value chain for recycling, smart contracts make processes run more smoothly and more efficiently. This technology reduces the need for human control, ensuring the correct and timely distribution of rewards. Furthermore, utilizing smart contracts and digital wallets offers a user-friendly interface that enables interactions with the blockchain. The digital wallet enables secure user identification using a pair of public and private keys. The DApp facilitates the tracking of recycling benefits via tokens, which can then be exchanged and redeemed with collaborating partners according to a predetermined contract for token exchange.

The third significant implication of this study is the provision of a design value chain tailored to local contexts in alignment with the recycling requirements of households, recycling context, and loyalty programs in Saudi Arabia. Understanding the local context and household behavior can increase the likelihood of successful and sustainable recycling habits.

4.2. Strengths and Limitations

The work presented in this article is part of a continuous research project, which has been cited in this article. Phase 1 of this involved research wherein two questionnaires were sent, with +450 and +40 responses, respectively. Additionally, an 8-week experiment was conducted involving 52 participants. Phase 2 of this research showcases the development of a mobile application that incorporates a social economy for the transportation of recycled waste. In this paper, we demonstrate phase 3 by introducing a blockchain-based loyalty program encouraging waste segregation to produce more recycling waste. This requirement is important to sustain the transportation of recycled waste as well as to foster a circular economy.

The use of blockchain technology in the recycling value chain guarantees immutability, transparency, traceability, and security. Facilitating the tracing of all transactions from the household to recycling facilities improves the precision of monitoring recyclable items, particularly those with financial value or hazardous properties. This traceability cultivates confidence among stakeholders, such as homes, recycling firms, and governmental bodies.

Furthermore, the implementation of a blockchain-based loyalty program encourages families to recycle by providing tokenized prizes based on the type and weight of sorted garbage. The ability to exchange tokens for services incentivizes households to participate in regular recycling, making it a habitual practice. This system utilizes the efficacy of blockchain financial systems, such as Bitcoin and decentralized finance (DeFi), to guarantee seamless reward distribution via automated smart contracts.

Moreover, the blockchain recycling value chain is customized to meet the distinct recycling needs and domestic practices in Saudi Arabia. Comprehending local settings and aligning the loyalty program with these elements enhances the probability of cultivating sustainable recycling practices and fostering enduring success in waste management.

On the other hand, the main limitation of this research stems from the inherent complexity of blockchain technology. Blockchain integrates multiple advanced technologies, making it difficult to implement and understand, especially for organizations unfamiliar with its operation. Additionally, the high computational power and energy consumption required, particularly in public blockchain systems, pose challenges in terms of sustainability and cost. Identifying a valid blockchain is crucial for justifying its investment and understanding its practical application. Despite these limitations, blockchain's rapid evolution and potential to revolutionize industries remain promising.

Another potential challenge is ensuring the participation of all stakeholders, including households, local authorities, recycling companies, and business partners. The success of the program relies on the active engagement of these stakeholders, and therefore, coordination efforts need to be prioritized.

4.3. Future Research Directions

The development and testing of the solution will be in phase 5 of this project, focusing on implementing the designed solution and further refining and testing the blockchain-based loyalty program in real-world settings. The system could be tested in a pilot study conducted in Jeddah, which could provide valuable insights into the program's effectiveness and identify any areas for improvement.

Additionally, we could explore the potential for integrating other emerging technologies, such as artificial intelligence (AI) and the Internet of Things (IoT), into the recycling process. For example, AI could use the stored data to predict recycling trends and optimize waste collection routes. IoT devices could enable real-time monitoring, the measurement of waste volume, and trace recycling participation.

Finally, long-term studies are needed to assess the sustainability and scalability of the value chain and its contribution to a circular economy. These studies should examine the environmental impact of increased recycling as well as social and economic long-term effects, such as changes in household behavior and the development of acts governing household recycling.

4.4. Conclusions

This paper is part of ongoing research promoting household recycling and aligns with the recycling context in the city of Jeddah. The study in phase 1 depicts that the low recycling rate in Jeddah is due to inadequate waste segregation and collection processes. Phase 1 identified challenges in promoting sustainable household recycling practices and phase 2 depicted the development of a mobile application for transporting recycling waste. This study focuses on fostering waste segregation to increase recycling volumes by introducing a blockchain-based loyalty program where rewards are exchanged for tokens for recycling participation. This innovative approach aims to sustain earlier waste transportation models and advance the circular economy by securely tracking recycled materials through blockchain technology.

This paper begins with a literature review on blockchain's potential in recycling initiatives and details various global examples. It emphasizes the unique context of household recycling in Saudi Arabia, which has been largely overlooked. This research employs a design science methodology to develop a business model that encourages household participation through a loyalty program. It reviews existing loyalty programs in Saudi Arabia that influenced the decision to tokenize recyclable materials on the blockchain. The technical architecture of the proposed blockchain-based loyalty program is outlined, ensuring alignment with blockchain design principles.

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