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APPLIED RESEARCH

Blockchain-Based Sustainable Retail Loyalty Program

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ABSTRACT This paper addresses the issue of sustainability in retail sales, where the composition of the products themselves, their production and packaging process, and their transport to the point of sale play an important role. We propose a solution to apply a unified system of environmental product rating in different retail chains where trust is ensured through a distributed ledger. The system allows fair and transparent rewards for customers who purchase eco-friendly products while also maintaining their privacy. The prototype of the decentralized application for the uniform loyalty system based on the Algorand blockchain has shown promising results in terms of throughput and cost efficiency. We believe that the prototype has the potential to revolutionize loyalty systems and promote sustainable practices. This study provides key insights into how to interconnect retailers and customers into a uniform reward program, how to motivate customers to purchase sustainable and eco-friendly goods, and how retailers can manage the amount of reward for the given Eco-score categories.

INDEX TERMS Ecological product rating, sustainability, Algorand, smart contract.

I. INTRODUCTION

The impact of human activity on the environment has been one of the most debated and important issues today. Environmental problems are linked to consumerism and population growth. It is necessary to emphasize the elimination of the negative environmental footprint caused by the production, packaging and transport of various goods and foods [1]. Producers can only influence some of these negative issues. Therefore, for customers, the important aspect is to prioritize purchasing products from local producers or the sustainability of the products. The price of these products is often higher than regular products because of a more difficult production process. It can discourage potential clients. One possible solution to motivate customers to make green purchases is to use existing loyalty programs and adapt them to the environmental rating of individual products. Customers earn loyalty points for each purchase of green products and then can exchange loyalty points for a discount.

The main issue with loyalty programs is that companies spend billions of dollars annually, but most members are inactive, which seems wasteful. Customers belong to an average of 14.8 loyalty programs, but they are active in only 54% of the programs [2]. Moreover, each loyalty program has its plastic loyalty card for customers. It is extremely uncomfortable for customers to carry a wallet with too many cards. The unified loyalty program can improve the spending of loyalty points by customers. It also brings new opportunities, such as the exchange market, where customers can exchange loyalty points with each other. On the other hand, there needs to be more trust among participants, such as retailers and customers. It makes sense to use blockchain technology to ensure fairness in the assignment of loyalty points and the rating of products. It can provide a sufficient level of decentralization and transparency.

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The blockchain is a distributed ledger with cryptographically secure peer-to-peer access. Updating records in the ledger can be done only with the consent of all parties involved. The basic principle of this technology is to store data in a chain of blocks where each block references its predecessor. Changing one of the blocks means modifying all its successors. However, this is computationally extremely difficult as the number of blocks grows. As a result, we can consider these stored data to be immutable [3]. Consensual algorithms, such as Proof of Work (PoW) and Proof of Stake (PoS), are basic approaches to reaching a consensus between participants. Suppose that the members of the loyalty program should be rewarded for purchasing green products. In that case, the system must have a minimal negative environmental impact. Therefore, the use of PoW does not make sense due to the high consumption of miner computers [4]. The consensus algorithm is very important in selecting a blockchain platform for such a system. Another important parameter is the throughput, which should at least chase a value similar to that of traditional payment systems.

Our goal is to design a unified loyalty system architecture in which customers will be rewarded through tokens for purchases in a chain store. However, this reward will not be based only on the total purchase amount. The Eco-score and price of each product will be used as input parameters to calculate the total reward. The product will be represented using the Eco-score expressed in letters from A to E. In order to preserve some freedom for retailers, they will be able to set the percentage of the reward for products in each category as they wish, but they must follow a gradual increase from the worst category E to the best category A. The higher reward for a product with a better Eco-score can instigate customers to buy these products frequently.

The contributions of this paper are as follows:

- We describe the drawbacks of traditional loyalty programs and examine alternatives using blockchain to create a uniform loyalty program to reduce carbon footprint and energy consumption and increase interest in people in sustainable products.
- We design the architecture of a unified loyalty system for retailers and customers where trust is ensured through a distributed ledger.
- Designed architecture targets rewarding customers who buy eco-friendly and sustainable products.
- The decentralized approach of this solution enables user empowerment in loyalty programs. Customers get control over their loyalty rewards and their data.
- We expand the frontier of knowledge and better adaptability among people within the token economy design aiming at sustainable behaviors.
- It is also improving the transparency of eco-rating products. Further, retailers do not need to store private data because loyalty points are bonded to their wallet addresses.
- Based on that architecture, we implement a web application for a unified loyalty system that cooperates with the Algorand distributed ledger.[1] Then, we show its performance results.

The rest of this paper is organized into the following sections. An analysis of the distributed ledger Algorand and similar solutions in the field of loyalty systems are given in Section II. Based on the study, we propose a solution for the architecture of the unified loyalty system to reward customers for purchasing eco-friendly and sustainable products in Section III. The next section is Evaluation (IV, which aims to ensure that the solution is correct, and we also perform a variety of tests here. Section V discusses the results and their implications, and we summarize the paper and its novelty in Section VI.

II. STATE OF THE ART

In this section, we first discuss eco-initiatives to purchase sustainable products. Subsequently, we focus on blockchain platforms suitable for loyalty systems with minimum negative effects on the environment. The analysis mainly contains the principles of Algorand, which seems to be the most ecologically oriented blockchain. Finally, we analyze existing loyalty systems based on blockchain and explain the advantages, disadvantages, and possibilities for improvement.

A. ECO-INITIATIVES

Several retail chains and voluntary initiatives are already exploring methods to advance the issue of the sustainability of products and the way they are distributed to end customers. In July 2021, a group of young, environmentally conscious Europeans published a petition to introduce a European Eco-score [5] to rate the environmental impact of products manufactured or sold within the European Union. The purpose is to motivate end consumers to buy environmentally sustainable products based on their standard rating on a scale from A to E.

The French ECO2 Initiative [6] has proposed a solution for the ecological assessment of food products, also requested in the petition mentioned above. They have designed an algorithm to calculate an ecological score based on the life cycle of each food and other related factors. As shown in Figure 1, the calculation considers data about the impact of the production, packaging, and transport process on the environment stored in a database. Other considered factors are packaging size and its potential for recycling, impact on endangered plants or animal species, and the creation of greenhouse gases in cultivation considering the seasonality of food. As a result, a score from 0 to 100 is converted to the rating scale.

Well-known retail chains are already dealing with the issue of product sustainability. An example is the Lidl[2] supermarket chain which labeled approximately 140 products from its range with Eco-Score labels in stores located in Berlin in the first half of 2021. There are five levels in total, from the green level 'A' to the worst level 'E' in red. The methodology

[1] https://www.algorand.com/

[2] https://unternehmen.lidl.de/pdf/show/51552

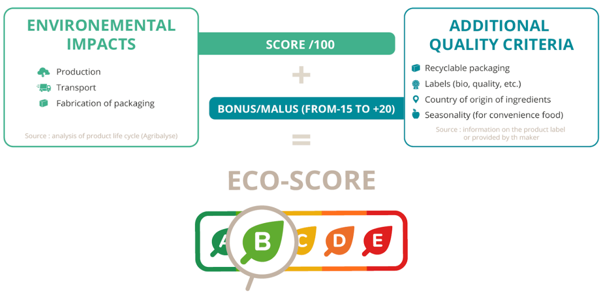

FIGURE 1. **Factors considered in the calculation of the ECO2 Initiative's Eco-Score.**[7]

for calculating the Eco-score consists of two components: the environmental impact of the product based on the Product Environmental Footprint (PEF) and other sustainability criteria for which plus or minus points are awarded, such as the origin of ingredients, packaging, or certificates. They may also introduce this innovation in other stores based on customer feedback. However, there needs to be more transparency because the customer must trust labeling with the ability to verify the product Eco-score independently.

Colruyt,[3] which owns a chain of supermarkets in Western Europe, has introduced an application with the ability to view the Eco-scores of the products it sells. In order to know the full environmental impact of a product, they rely on the information derived from life cycle analyses stored in the Agribalyse database, which keeps average values for the same product category. Then, Eco-scores are calculated based on the PEF method and take various factors into account, as well as Lidl. Customers can save points on the Xtra[4] app when choosing Eco-score A or B products in the store. Once they collect 100 points, they have the opportunity to contribute to an environmental project or participate in a sustainable workshop at the Colruyt Group Academy.

Fashion chain H&M has expanded its loyalty program to reward customers for shopping with an emphasis on their ecological footprint [7]. In particular, they consider goods made from sustainable materials, using personal shopping bags, or choosing a more eco-friendly way of delivery. After a successful pilot in 2019-20, they expanded collaboration with TextileGenesis.[5] It is a textile traceability platform based on blockchain to track sustainable fibers through six levels of the supply chain [8]. However, all of these platforms are not very interoperable with each other.

The ECO coin [9] platform proposed a solution to reward consumers for eco-friendly behavior during a typical day using its cryptocurrency, with the possibility of subsequent redemption, especially for eco-conscious services and experiences. Examples could be reducing meat consumption or car travel, using a green energy supplier, etc. On the one hand, such factors are difficult to assess objectively, but on the other hand, this solution is the only one that uses blockchain technology to ensure transparent rewards. However, the available digital sensors, human verifiers, and certified dealers limit that way of reward. Each ECO coin is backed by a tree, and tree owners can exchange their trees for ECO coins. For every ten trees, one ECO coin will be paid out to the owner. The trees are held in escrow, preserving the ownership with the original owner while under the custody of the ECO coin foundation. A small verification fee is paid periodically to check tree validity and ownership. ECO coins can also be obtained by engaging in sustainable actions or purchasing them with fiat currency. Suppose the average tree lifespan is 100 years. In that case, the lifespan of an ECO coin gradually decreases by 1% annually to match the average lifespan of the backing tree. It is similar to traditional inflation in currencies. The currency is governed by a Decentralized Autonomous Charity, giving a voice to all users in its development. The goal is to establish a sustainable economy and marketplace that connects earning and spending opportunities for ECO coins.

B. BLOCKCHAIN TECHNIQUES

Blockchain is generally popular for its features, such as decentralization, security, transparency, immutability, and audibility. On the other hand, when we choose a blockchain platform or type of blockchain, we always face a problem called "The Scalability Trilemma" [10]. It means that we have to make a trade-off between the three key characteristics of blockchain technology: scalability, security, and decentralization. It is difficult to achieve all three of these attributes simultaneously. Therefore there have been developed different approaches to resolve this problem. They optimize one aspect, and this often comes at the expense of the others. There are the following blockchain techniques:

- **Permissionless ledger** - allows anyone to participate in the network, validate transactions, and contribute to the consensus process without requiring explicit permission or approval. The benefit is the high level of decentralization, but the main problem is scalability. Examples are Bitcoin [11] and Ethereum [12].
- **Permissioned ledger** - requires explicit permission or invitation to join and participate in the network. Benefits are enhanced privacy and better scalability if there are optimal numbers of nodes. Drawbacks are lower transparency, and decentralization can only be useful if nodes are hosted by several providers. Hyperledger Fabric [13] is one such ledger.
- **Sidechain** - operates in parallel with the main chain and enables the transfer of assets or data between the two chains. It aims to enhance the scalability of public blockchains and reduce transaction fees. There are sidechains such as Polygon and Liquid Network [14].

[3]https://www.colruytgroup.com/en/conscious-consuming/eco-score
[4]https://www.colruytgroup.com/en/conscious-consuming/save-points
[5]https://textilegenesis.com/

[7]https://docs.score-environnemental.com/v/en/

- **Ledger database** - combines aspects of traditional databases with the advantages of blockchain technology. A centralized ledger database (CLD) provides universal audit and verification for applications involving parties that may not trust each other. It offers robust auditability through the use of time notary anchors generated by a two-way peg protocol, which enhances the reliability and integrity of the system. The main distinctions between blockchain and CLD are the involvement of a trusted third party for system maintenance and the absence of a requirement for a consensus mechanism. LedgerDB is a well-known CLD that is recognized for its exceptional system performance [15]. Decentralized ledger databases are designed to store and manage large amounts of data while maintaining blockchain technology's security, decentralization, and immutability features. Data consistency is reached through a consensus algorithm based on the variant of the Byzantine Fault Tolerant. BigchainDB [16] presents this solution. The papers [17], [18] introduced more detailed comparisons of both approaches.

C. ALGORAND

To preserve the idea of this project, it is necessary to choose an eco-friendly platform to implement the solution. We have chosen the category of permissionless ledger with a high level of decentralization, transparency, and trustlessness. Currently, most blockchain platforms run on the Proof of Work consensus algorithm. The miners must first resolve a complex mathematical problem to verify the transactions. Due to the limited amount of given cryptocurrency in a network, the difficulty of this problem increases after mining one coin. The miners compete to get the right to add a new block. During mining, they consume considerable electricity because this process requires powerful GPUs and processors [19]. Therefore, some blockchain platforms shifted from PoW to PoS consensus mechanisms, such as Ethereum last year. On the other hand, there is different annualized electricity consumption between blockchain platforms running on PoS, as shown in Figure 2.

Algorand blockchain [20] aims to be carbon-negative and partners with ClimateTrade in 2021 to offset its carbon footprint with a portion of transaction fees. The basic premise of the Algorand platform for environmental sustainability is its consensus algorithm, called Pure Proof of Stake (PPoS). It is a modified version of Proof of Stake (PoS), one of the two main consensus algorithms used within blockchain networks. The main principle of the PoS algorithm is that only nodes that stake (lock) at least a minimum specified amount of tokens of a given currency in the network as collateral can participate in transaction validation. From these stakeholders, the creator of a new network block is then randomly selected with consideration of the number of held tokens. In the case of cheating detection, a given node risks losing its staked tokens. Contrary to apprehensions about the risk of token loss, PPoS sets forth favorable conditions for verifiers, rendering cheating illogical for them. Consensus is reached when a supermajority of the total amount of staked tokens is in the hands of non-malicious verifiers. The minority is thus prevented from cheating, and for the majority, cheating would mean depreciating the value of their own resources to their detriment. This consensus algorithm achieves high efficiency and speed. However, it requires minimal computing power, resulting in a low environmental impact during runtime. Algorand states that a single transaction has an energy consumption of approximately 0.000008 kWh [21].

Another significant parameter is the maximum throughput of the blockchain platforms [22] because each payment can be rewarded through loyalty points in a chain store. The comparison of throughput among PoS blockchains can be seen in Table 1.

TABLE 1. Throughput comparison of PoS blockchains.

	Throughput (TPS)
Ethereum	30
Cardano	250
Avalanche	4500
Polkadot	1000
Solana	65000
Tezos	1000
Algorand	6000
Polygon	65000
TRON	2000

D. ALGORAND SMART CONTRACTS

Application development on the blockchain is made possible by digital contracts called smart contracts. They are safe and unstoppable programs that execute automatically only if precisely defined conditions are met. They replace unreliable intermediaries in transactions involving multiple parties, introducing novel forms of interaction among participants in various industries where there is a demand for enhanced security, transparency, and fairness. This applies to the transfer of financial value, information, or mediation of other contractual relationships where certain business logic needs to be respected [23]. One of the main shortcomings of smart contracts is that they can only directly access data stored in the blockchain. However, when developing applications, it is often necessary to work with real-world data that are not on the blockchain. Access to such data is provided by services called blockchain oracles [24], and, in turn, they allow the transfer of data from external repositories to smart contracts.

Algorand Smart Contracts are small programs on the Algorand blockchain that function on layer 1 and are categorized as stateful or stateless contracts. The type of contract written determines how the program logic is evaluated. Contracts are written in Transaction Execution Approval Language (TEAL), an assembly-like language interpreted by the Algorand Virtual Machine (AVM) in an Algorand node. TEAL

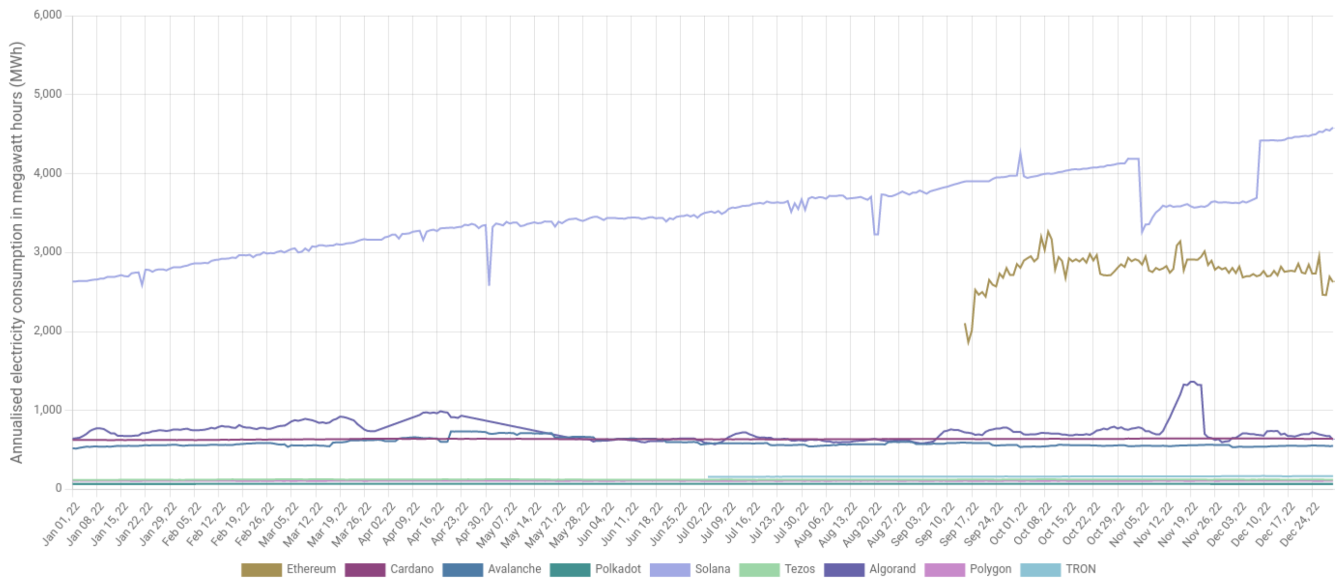

FIGURE 2. **Comparison of annualized electricity consumption of PoS blockchains.**[9]

programs can be written manually or using the PyTEAL compiler in Python.

E. RELATED LOYALTY SYSTEMS

In this section, we analyze the principle of operation of individual blockchain-based loyalty systems and describe the architecture on which they are based. The unified loyalty program can offer customers advantages and encourage them to spend more loyalty points. If the loyalty program is also aimed at supporting sustainable products, it can attract people with an environmental mindset.

One of the most popular commercial projects is Qiibee [25], which introduces a standardized plug & play solution. Brands can create their own tokens with the LoyaltyToken protocol. To issue loyalty tokens, brands stake QBX on the public Ethereum chain. The QBX tokens are frozen and locked in the vault by the cross-chain bridge. Then, the bridge issues the loyalty tokens for the loyalty blockchain and sends them to the brand account. The brand can now reward customers, who can redeem their loyalty tokens or exchange them for QBX.

Another project in this domain is BitRewards [26], built on the Ethereum chain. Retailers can connect to the platform by installing an extension or integrating it into their own loyalty system. Customers are rewarded with BIT tokens for purchases and can redeem them for their next purchases as a discount. There is a special smart contract as middleware between the store and the customer, holding the customer's tokens until full payment in fiat currency is received. Afterward, the tokens will be transferred to the store account.

The last commercial project is Loyyal,[10] utilizing private channels on the Hyperledger Fabric network. Smart contracts create an asset definition for loyalty coins. At least one bank must be present on the network to convert fiat currencies to loyalty points and vice versa, but this results in restricted loyalty points usage. The platform is offered as Blockchain-as-a-Service (BaaS), and clients have to pay monthly license fees according to the number of processed transactions.

Several academic papers focus on resolving some drawbacks of the platforms mentioned above. The first paper [27] aims to make payments without any bank's involvement in the Loyyal platform using the integration of Stellar blockchain and Hyperledger. Another paper [28] designs the approach to extend existing off-chain organization management systems and optimize blockchain database size. It is achieved through Hyperledger Fabric and Hyperldeger Composer, which ensure data synchronization between on-chain and off-chain applications. Tu et al. [29] propose a Hyperldeger-based loyalty system with a call auction method of the stock exchange market to implement many-to-many matching. The last paper [30] presents TECH TOKEN, which is produced on the Ethereum chain following the token standard ERC20.[11] The main difference with other platforms is that a manufacturer is the creator and distributor of tokens to suppliers, and then suppliers give them to a customer for purchasing.

As mentioned above, eco-initiatives have introduced ideas with great potential to support purchasing ecological and sustainable products. However, they need more rules unification, and customers' motivation level needs to be higher. Similarly, the large number of loyalty programs is limited for the customer. In other words, customers have accumulated many

[9] https://indices.carbon-ratings.com/

[10] https://loyyal.com/

[11] https://ethereum.org/en/developers/docs/standards/tokens/erc-20/

loyalty points, but they cannot exchange the points of one company with the points issued by another. Consequently, they cannot apply discounts to products they need now. Each participant can benefit if we fuse eco-initiatives and loyalty programs into the unified loyalty system. Customers will be able to exchange points and will be more motivated to buy ecological and sustainable products if they know that they will get more points. Similarly, retailers can gain several advantages, including reducing expired loyalty points, eliminating the need to manage customer information, and increasing attractiveness to potential new customers. Using blockchain, we can achieve a unified loyalty system with aspects of consistency and security. Several stakeholders will have to agree on adding and modifying these data, which will prevent possible unfair behavior and ensure the required fairness. The product ratings will be the same for each retail chain, but they will still be able to set their own policy on the level of rewards for each category within the product rating range.

III. SOLUTION DESIGN

This section provides a detailed overview of the system design. We will explore each critical component, giving a full description of the architecture, its specifications, and the functions it offers. All design decisions and their justifications will be discussed. Finally, we will outline the goals we want to achieve with the design.

A. HIGH-LEVEL ARCHITECTURE

Figure 3 shows individual parts of the architecture of our proposed solution. The core of the architecture consists of the Algorand smart contract to create tokens and distribute tokens to customers for purchases of ecological and sustainable products. The other part is the backend server which provides REST API to communicate with the smart contract. Similarly, the Oracle blockchain plays an important role in calculating the reward because it collects the Eco-rating of products from data in the real world for the smart contract. Because it is a permissionless blockchain, anyone can join the network and become a validator of transactions. It means that the logic of a smart contract has to ensure who can call the given function of the smart contract. The overall architecture contains the following components:

- *Single-page web application*: The application provides a web interface to interact with our system for various roles. The following section will describe roles and their functions in more detail. However, the application is mainly used to demonstrate our proposed system and may be replaced by a plugin or a module to integrate with existing store chain systems in the future.
- *Backend server*: The server includes communication with the smart contract deployed on the Algorand network. As an output, it provides API calls for user interfaces, namely, with the interface for systems of the individual chain stores, as well as with the interface of the mobile application intended for customers. The backend is an OPTIONAL system part used only to demonstrate communication with the smart contract. The module or plugin can replace the backend to integrate with existing retail systems in the future. The smart contract still holds account balances even if the backend server is down. Its functions can be further called by participants if they have permission for the given function.
- *Smart contract*: The smart contract is a set of instructions automatically executed when predetermined conditions are met. It ensures the management of our token and a fair way of rewarding customers. Similarly, it defines and enforces rules for participants based on their defined roles. Moreover, it keeps the balance of our generated tokens in the ecosystem. No one can create their token applied as a discount for purchasing because our token is mapped to the unique address of the original smart contract. Participants can call the following contract functions:
  - *opt_in()*: During the registration process of new retailers, it is called to allocate local storage for each of them, where information of a new retailer, such as type account, is saved. Algorand uses three types of storage global, local, and box.[12]
  - *create_asa()*: The smart contract owner can mine new EcoRetail tokens using this function and subsequently distribute them to chain stores. Our EcoRetail token is described in more detail in the following subsection.
  - *exchange_asa()*: This function is available only for the registered chain stores and allows purchasing EcoRetail coins for Algo coins from your wallet. It is executed as an atomic transfer, which means that one call can contain more transactions, and all transactions in the batch either pass or fail.
  - *send_reward()*: Similar to the previous case, the function is executed as an atomic transfer and can only be called by the registered chain stores to redeem rewards to customers through EcoRetail coins for purchasing in their store.
- *Algorand blockchain*: Using blockchain in combination with the Oracle blockchain ensures a transparent system of rewarding and authenticity of operations in the system. Algorand blockchain maintains public records of all participants' balances and transaction history. The Oracle blockchain supplies eco-ratings for goods to the smart contract, ensuring consistency of ratings across all chain stores.
- *Blockchain oracle*: It acts as a bridge between the blockchain and data from the real world. It consists of multiple nodes that collect data from several trusted resources. Subsequently, the blockchain oracle feeds data to smart contracts from the outside world because they run in their isolated environment. In our

[12] https://developer.algorand.org/docs/get-details/dapps/smart-contracts/apps/#smart-contract-storage

case, it should get and provide information about Eco-rating products. The reliability and accuracy of the blockchain oracle are critical for decentralized applications because incorrect or malicious information can even lead to financial loss. Because of that, producers, chain stores, and eco-initiatives should cooperate in the Oracle blockchain to ensure a uniform and fair eco-rating of each product [31].

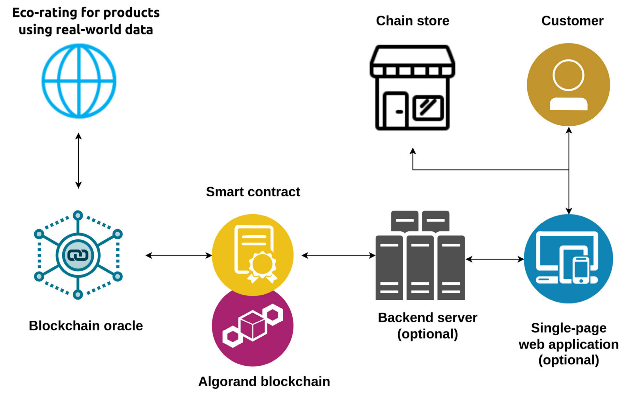

FIGURE 3. **High-level architecture design.**

B. KEY FUNCTIONS

The main goal of our design is to provide a unified loyalty system that rewards customers for purchasing ecological and sustainable products. There are three defined roles for interacting with the system: a customer, a chain store, and a producer. During the login process, users are asked to log in using their crypto wallet through MyAlgo Wallet[13] which allows connecting websites and users of a decentralized application to interact with the Algorand blockchain. Users can manage their accounts and sign all transactions outside of the web application. Figure 4 shows the login page and how to manage wallet accounts during the login process. Each new user is assigned a role that is recorded along with the public address of the user's wallet in the smart contract. There are two types of roles:

1) CUSTOMER

The interface for this kind of role provides only a few details shown in Figure 4. It mainly displays basic account data by calling *api/get-account-balance/*, such as the wallet address and the balance of Algo and EcoRetail coins. In future work, it may be extended to include the functionality of the exchange market where customers can exchange their EcoRetail tokens for another type of asset.

2) CHAIN STORE

Besides account information, additional functionality is available only for chain stores. The call *api/buy-eco-coins-get-txn/* enables buying EcoRetail coins per Algo coins at the exchange rate at the time. By calling *api/update-rewards-policy/*, chain stores set up their own reward policy for products in each category. The web interface for both functions is shown in Figure 5. Finally, call *api/process-purchase/* and *api/send-txn/* to ensure the processing of the purchase list and the redemption of the reward. The first call calculates the rewards and creates a batch of transactions. The second call then sends the transactions to execute into the Algorand network. To add a product, we need to insert the product ID, amount of sold product, and price per unit. We enter the customer's wallet address when the purchase list is complete, as can be seen in Figure 6

[13] https://connect.myalgo.com/

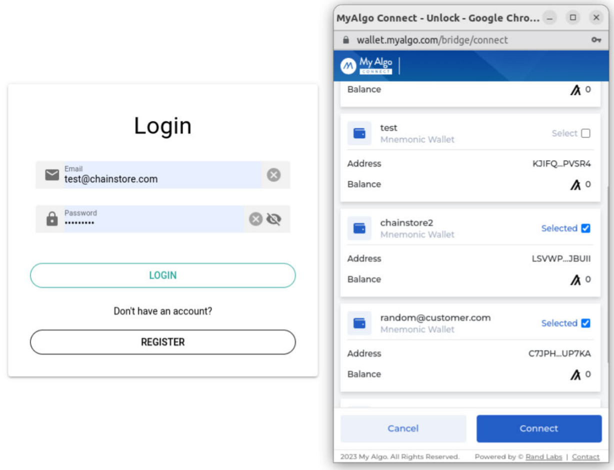

FIGURE 4. **Login page and managing of the wallet accounts.**

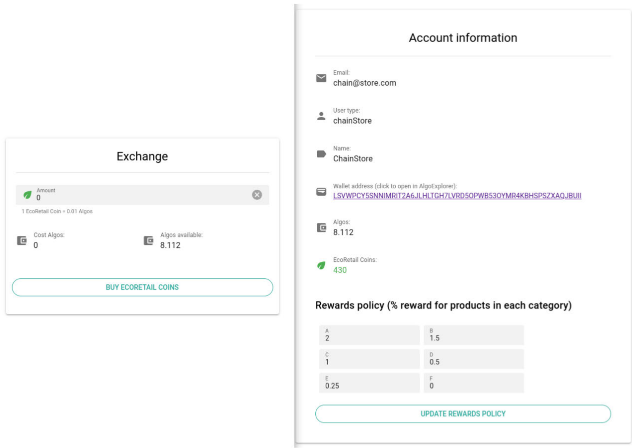

FIGURE 5. **Buying of EcoRetail coins and setting of reward policy.**

C. TOKEN EcoRetail COIN

As a medium of value exchange within our proposed ecosystem, we have chosen a fungible token that can be implemented on the Algorand platform as a so-called Algorand Standard Asset (ASA).[14] Units of this token will represent

[14] https://developer.algorand.org/docs/get-details/asa/

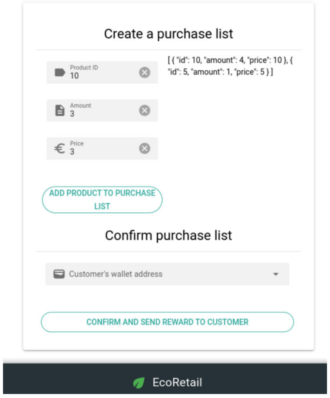

FIGURE 6. Purchase list creation.

```
@Subroutine(TealType.none)
def send_reward():
    return Seq(
        program.check_self(group_size=Int(2), group_index=Int(0)),
        program.check_rekey_zero(2),
        Assert(
            And(
                Gtxn[1].type_enum() == TxnType.AssetTransfer,
                App.optedIn(Int(0), Int(0)),
                App.optedIn(Int(1), Int(0)),
                App.localGet(Int(0), local_user_type) == chain_store,
                App.localGet(Int(1), local_user_type) == customer,
                Txn.sender() == Gtxn[1].sender(),
                # Txn.accounts[1] == Gtxn[1].receiver(),
                Txn.application_args.length() == Int(2),
                App.globalGet(global_asset_id) == Gtxn[1].xfer_asset(),
                Btoi(Txn.application_args[1]) == Gtxn[1].asset_amount()
            )
        ),
        Approve()
    )
```

FIGURE 7. Function *send_reward* in PyTeal.

loyalty points with the same value for each store chain. The token is linked to an implemented smart contract and distributed to individual retail chains based on its set value. They then transfer the computed number of tokens to customers' wallets when they make product purchases, taking into account the environmental rating of the products. This rating remains the same for all retailers, but they can design their own policy in determining the percentage reward to customers for products belonging to each rating group, marked from A to E. Customers can use the collected tokens to redeem discounts and other benefits on subsequent purchases, thus closing the token cycle. Our created token is called EcoRetail coin.

IV. EVALUATION

We evaluated our design by implementing the functional prototype as a proof of concept to make our proposed specifications and functions achievable. Our experiments were carried out on virtual servers with 16GB RAM and 16-vCPU running a Ubuntu 22.04.2 LTS operating system that were hosted on the Xen server with Intel(R) Xeon(R) CPUs E5620 with 4 cores at 2.4 GHz.

Our smart contract logic was written in Python using the Pyteal library, which offers high-level abstractions in a functional programming style for TEAL. It is a stack-based language used for writing smart contracts on the Algorand blockchain, and Pyteal simplifies the process by compiling TEAL contracts into bytecode format for execution. We can see a piece of smart contract in Figure 7 that shows a function to send rewards. The code is available on public GitHub repository.[15]

During our testing, we need to consider the scalability of the proposed solution, that is, how many transactions can be processed per time unit. In the real world, using our system in many retails could result in a high load, which needs to be considered in our testing. Therefore, we divided the testing into two scenarios, testing our application and testing the smart contract. In both cases, our aim was to evaluate the throughput. As mentioned above, the web application is an optional component of our architecture and can be replaced by other components in the future.

A. EVALUATION OF APPLICATION PERFORMANCE

For testing our decentralized application, we selected two types of test scenarios. The first scenario involved sending 100 requests ten times in a row. This test was performed using the Locust tool, which is used to create a swarm with millions of simultaneous users. The rewarding process is showed in Figure 9. A single request contained the following function calls:

- **process-purchase** - this function receives a purchase list as input and preprocesses it before calling sen_txn. That means: Firstly, it obtains an eco-rating for each item in the purchase list from external resources, secondly, it requests the rewards policy defined by the given retail, and thirdly it calculates the total reward for purchasing to customer. The Eq. (1) shows how the total reward is calculated.

$$total\_reward = \frac{\sum_{i=1}^{n}(\frac{price_i \times number_i \times rp}{100})}{algo\_price} \times 100 \quad (1)$$

  - **i** represents the item on the purchase list.
  - *n* denotes the number of items in the purchase list.
  - *price* is a price per unit.
  - *number* is the number of pieces of the given item.
  - *algo_price* is the current exchange rate between the Algo and the Euro.
  - *rp* is a percentage share of the price of the item for the given eco-rating category and is defined by retail.

  One EcoRetail Coin is equivalent to 0.01 Algo Coins.
- **send-txn** - submits the transaction to the Algorand network with input arguments such as retail wallet address, customer wallet address, and reward.

The batch with a load of 100 is shown in Figure 8, where we can see a fairly stable test progression, where the average processing time was about 8 seconds and we achieved a throughput of about 20 calls (10 reward calculation processing and ten transaction processing) per second. To understand this in a real-world context, we can interpret these results to

[15]https://github.com/fiit-ba/blockchain-based_sustainable_retail_loyalty_program.git

Type	Name	# Requests	# Fails	Median (ms)	90%ile (ms)	99%ile (ms)	Average (ms)	Min (ms)	Max (ms)	Average size (bytes)	Current RPS	Current Failures/s
POST	/api/process-purchase/	1000	0	810	1000	1200	811	326	1309	735	10	0
POST	/api/send-txn/	900	0	7600	8100	8300	7569	6134	8447	35	10	0
	Aggregated	**1900**	**0**	**1100**	**7900**	**8300**	**4012**	**326**	**8447**	**403**	**20**	**0**

FIGURE 8. Batch with a load of 100 requests.

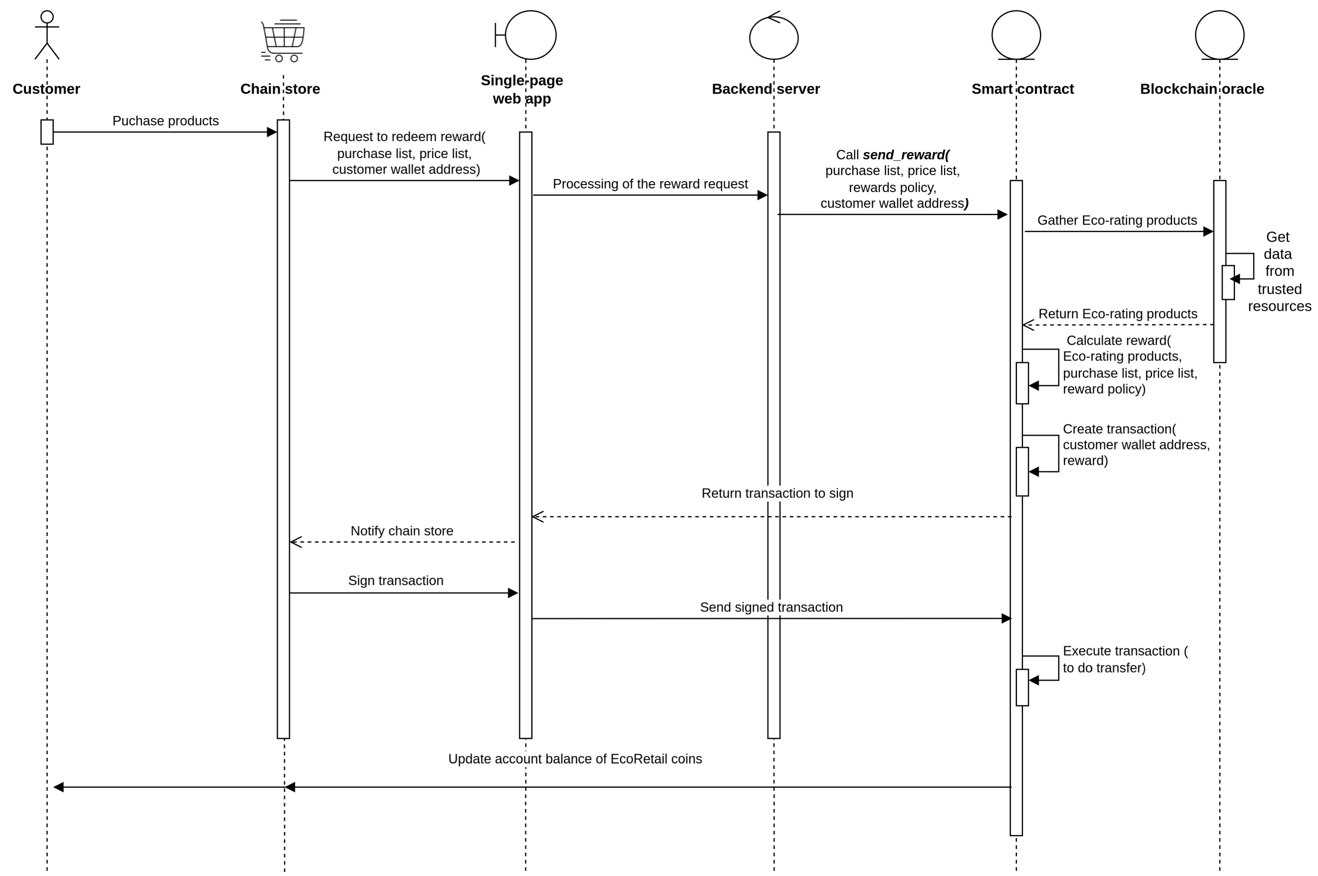

FIGURE 9. Sequence diagram for obtaining a reward for purchasing.

mean that if 100 different store checkout chains have calls coming in simultaneously, it takes about 8 seconds for them to be processed. However, this processing includes the final confirmation of transactions in the Algorand network. The transactions are written to the blockchain and can already be considered immutable. Without waiting for transactions to be confirmed, a speed of 1 to 2 seconds would be achievable, but we want to interpret the results for meaningful use in the real world.

In the second test, we sent batches with 100, 500, and 1000 individual requests to our application. The results of all batch sizes are compared in Figure 10, which shows that the processing time per request generally increased with larger batch sizes. The *send-txn* call took significantly longer for the batch size 500 than 100, by approximately 25 seconds. This delay was caused by the server's need to handle over 500 responses concurrently. They are crucial for us because they acknowledge receipt of the transactions by the Algorand network. In this case, we reached the source limitations of our server.

TABLE 2. The processing time of batches with different sizes.

Batch size	First block	Last block	Elapsed time	Number of blocks	TPS
1000	28910877	28910879	8.0	2	125.00
2000	28910594	28910597	11.0	3	181.82
4000	8864233	28864240	25.0	7	160.00
8000	29031251	29031265	52.0	14	153.85
12000	29030746	29030765	70.0	19	171.43

B. EVALUATION OF TRANSACTION THROUGHPUT

One of the problems with blockchain systems is that their throughput is markedly lower than that of centralized

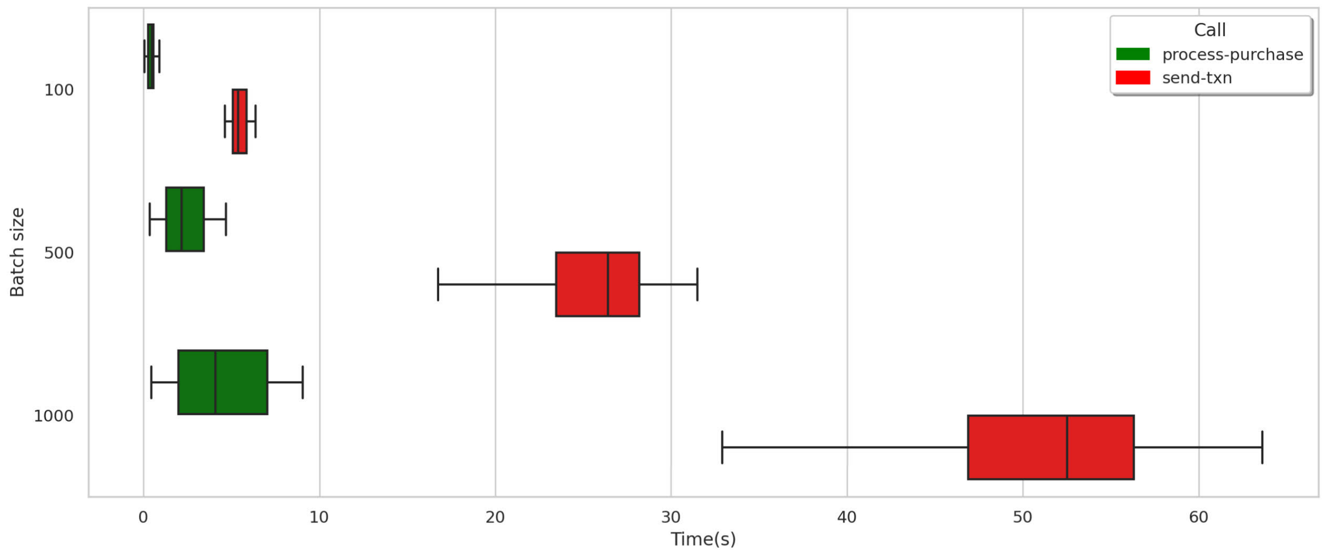

FIGURE 10. Comparing of processing of the different batch sizes by our application.

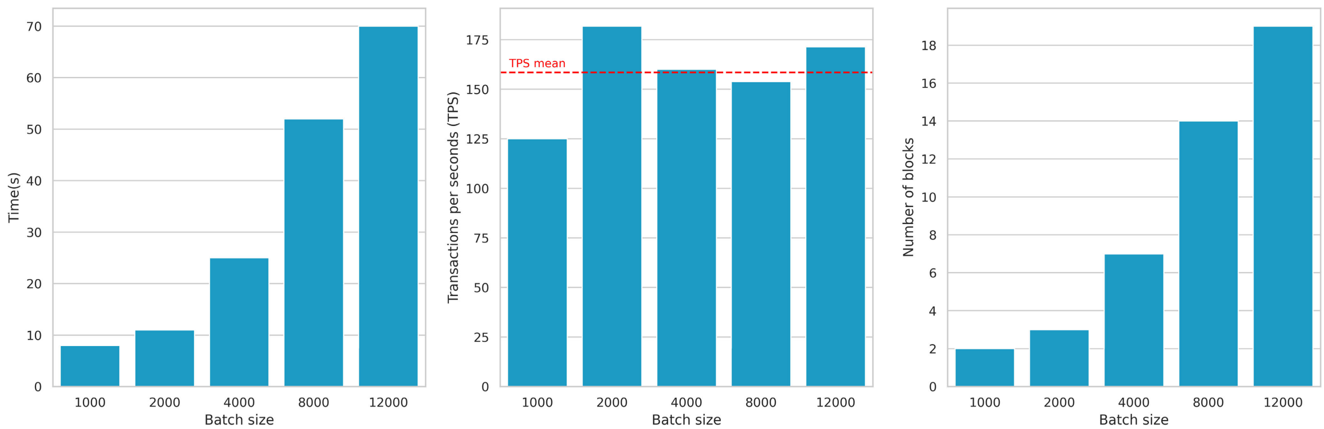

FIGURE 11. The duration time of the batch processing (left), throughput with different batch sizes (middle), and number of the blocks which include transactions of the batch (right).

systems [32]. Therefore, we focused on exploring *send_reward* transaction processing in the network. We tried to observe the throughput network and processing time for batches of different sizes. We designed batch sizes with 1000, 2000, 4000, 8000, and 12000 transactions. Four servers performed the transactions in parallel at the same time. The batch was evenly divided among all servers before sending. All servers were placed in the same area. We sent transactions directly from servers without a remote call to our application because of minimalizing delay caused by our application. The measurement results were obtained by Algorand Explorer[16] in which we investigated blocks containing transactions belonging to the batch.

In Figure 11, we can see the duration of batch processing and the throughput for each batch size. The average throughput is 160 transactions per second. An increase in the number of transactions in the batch does not significantly influence throughput. On the other hand, a larger amount of transactions is recorded in more blocks than in fewer transactions. We could not get closer to the theoretical throughput limit of the Algorand network. All data are given in Table 2.

V. DISCUSSION

To the best of our knowledge, we designed the first prototype of the decentralized application for the uniform loyalty system based on the Algorand blockchain with a negative carbon footprint. Besides, it is aimed at supporting the purchasing of sustainable products. The uniform loyalty system provides fair and transparent rewards for customers who buy eco-goods. Chain stores do not need to manage customers' personal information. Because of this fact, they can save some financial sources and prevent the leakage of private information. Customers communicate using their MyAlgo wallet, which is anonymous and managed by the self-customer.

[16]https://testnet.algoexplorer.io/

The smart contract is deployed on the public network of Algorand. Anyone can download the Algorand node software and build the Algorand node in a mode of participation to partake in consensus. It brings a high level of decentralization and transparency. If chain stores need to add private data into transactions, they can upload encrypted data to some storage, for example, IPFS, and share only links to data in transactions.

Privacy and data protection considerations are crucial in any blockchain-based system, including our proposed sustainable retail loyalty program. Current research topics in this area include several approaches, e.g., privacy-preserving transactions or anonymization, user consent and control over data, secure off-chain data storage, and compliance with data protection regulations. In our solution, we count on a so-called pseudonymous model of identities. It means that until the users reveal or connect their blockchain identity to a real-life identity, they behave only like an address in the Algorand blockchain and, therefore, can be considered anonymous. However, there is a minimal chance that the store giving the users their loyalty points for purchasing goods can connect the identity of a user with their blockchain wallet, but we try to mitigate this by not asking for any kind of information from users. We only need their wallet address, nothing more. Furthermore, if privacy is the real concern, there have already been proposed improvements by using zero-knowledge proofs and homomorphic encryption [33] to ensure that sensitive customer information remains confidential while still allowing for transaction verification and auditing. We can additionally think about self-sovereign identity, where customers have ownership and control over their loyalty program data and can selectively share them with retailers or third parties based on their preferences. All of these mentioned aspects are for another standalone research.

Another concern could be ensuring the program can handle a large user base and transaction volume. We consider Algorand as one of the blockchains which aimed to solve the trilemma problem [34] and the theoretical maximum transaction throughput measured by a transaction per second indicator is 6000 TPS as stated in the analysis. This number is currently enough to suit the needs of our system, furthermore, if a higher volume of transactions comes into process, the system will serve them all, but maybe with a higher latency. However, we are still talking only about a maximum of 20 seconds which is considered very feasible because, from our experience, the user checks the account balance on a more sporadic repetition, not instantly after purchasing goods. The authors of the paper [35] have tested the Algorand network with 5000 to 50 000 users concurrently trying to write a transaction into the ledger and achieved mentioned results.

A. COST ANALYSIS

The Algorand transaction fee system is based on a fixed fee per byte in the transaction. When there is a lot of traffic on the network, users can pay an additional fee to increase the likelihood that their transaction will be accepted and processed quickly. On the contrary, Ethereum uses gas fees that reflect the computational resources or power required for processing transactions.

The Algorand SDK[17] provides two main methods to determine the fees associated with a transaction. The first method involves obtaining the suggested fee parameters from an Algod REST server, which includes the recommended fee per byte. This value is then multiplied by the estimated transaction size in bytes, which gives the total transaction fee. If the calculated fee is lower than the minimum required fee, then the minimum fee is used instead.

The second method uses a flat fee, which is currently set at 1,000 microAlgos per transaction. However, in the case of network congestion, the nodes may require a higher fee or even reject the transaction altogether. Then, the fee is initially calculated as a fixed rate per byte, starting at 1 microAlgo per byte. If network congestion persists, the fee gradually increases until the congestion issue is resolved.

During our testing, we were only asked to pay a fee of 1000 microAlgos per transaction. If a retailer submits 1000 transactions, they will pay a total transaction fee of 1 Algo. As of 29 March 2023, the current exchange rate is approximately 0.21 EUR per Algo.

VI. CONCLUSION

This paper has shown that a blockchain-based sustainable retail loyalty program has the potential to promote sustainability and eco-friendliness in the retail industry. By using blockchain technology and smart contracts, retailers can encourage customers to purchase sustainable products and reward them for their loyalty. This program can be implemented in various sectors and countries and has the potential to reduce the negative environmental impacts caused by human activity. Overall, this solution is a step towards a more sustainable future for the retail industry.

Our performance tests have shown that the system has the potential to achieve the theoretical limit of TPS on the Algorand network. Cost analysis showed that transaction fees are relatively low, making it an attractive option for retailers. Customers can accumulate loyalty points and use them as discounts for future purchases, while retailers can manage the points they offer for different categories of eco-friendly products. These results offer valuable findings on establishing a unified reward program that connects retailers and customers, motivating customers to buy sustainable and eco-friendly products, and providing retailers with a way to manage reward levels based on Eco-score categories.

In terms of future work, we aim to further optimize the performance of our prototype and conduct more extensive tests to validate our results. We also hope to collaborate with retailers and customers to gather feedback and improve the user experience of our system. Overall, we believe that the

[17]https://developer.algorand.org/docs/get-details/transactions/#fees

prototype has the potential to revolutionize loyalty systems and promote sustainable practices. From a more interdisciplinary point of view, one possible future improvement could be the implementation of our own algorithm for the ecological evaluation of products, which would be publicly known, providing the required transparency. However, the design of such an algorithm would require more extensive research on all factors influencing product sustainability. There is also scope for more comprehensive management of the product database, which also relates to the involvement of the various institutions that have a significant role to play in the sector, e.g., a decentralized autonomous organization (DAO).

REFERENCES

[1] M. Kan and S. A. Miller, "Environmental impacts of plastic packaging of food products," *Resour., Conservation Recycling*, vol. 180, May 2022, Art. no. 106156.

[2] (2022). *17 Staggering Customer Loyalty Stats That Will Change Your Perspective*. Accessed: Jan. 23, 2023. [Online]. Available: https://www.ebbo.com/insights/blog/17-staggering-customer-loyalty-stats-that-will-change-your-perspective/

[3] I. Bashir, *Mastering Blockchain: A deep Dive Into Distributed Ledgers, Consensus Protocols, Smart Contracts, DApps, Cryptocurrencies, Ethereum, and More*. Birmingham, U.K.: Packt, 2020.

[4] A. N. Q. Huynh, D. Duong, T. Burggraf, H. T. T. Luong, and N. H. Bui, "Energy consumption and Bitcoin market," *Asia–Pacific Financial Markets*, vol. 29, no. 1, pp. 79–93, Mar. 2022.

[5] *European Ecoscore*. Accessed: Jan. 23, 2023. [Online]. Available: https://europeanecoscore.com/problem-solution/

[6] F. Southey. (2021). *First Nutri-Score for Nutrition, Now Eco-Score for the Environment: New Fop Lands in France*. Accessed: Jan. 23, 2023. [Online]. Available: https://www.foodnavigator.com/Article/2021/01/12/Eco-Score-New-FOP-label-measures-the-environmental-impact-of-food

[7] B. Sillitoe. *Green Reward: H&M Offers Loyalty Points for Eco-Conscious Shopping*. Accessed: Jan. 23, 2023. [Online]. Available: https://greenretail.world/2021/03/31/green-rewardhm-offers-loyalty-points-for-eco-conscious-shopping/

[8] H&M. (2022). *H&M Group Expands Partnership With Textilegenesis*. Accessed: Jan. 23, 2023. [Online]. Available: https://hmgroup.com/news/hm-group-expandspartnership-with-textilegenesis

[9] Next Nature Network. (2018). *The Eco Coin Whitepaper V1.0.* Accessed: 23.01.2023. [Online]. Available: https://uploads-ssl.webflow.com/5c1b58255c613376879c2558/5c4970105b4d237571564f43_ECOcoin_white_paper_v1.0.pdf

[10] (2021). *Why Sharding Is Great: Demystifying the Technical Properties*. Accessed: Jan. 23, 2023. [Online]. Available: https://vitalik.ca/general/2021/04/07/sharding.html

[11] S. Nakamoto. *Bitcoin: A Peer-to-Peer Electronic Cash System*. Accessed: Jan. 23, 2023. [Online]. Available: https://bitcoin.org/bitcoin.pdf

[12] V. Buterin, "A next-generation smart contract and decentralized application platform," *White Paper*, vol. 3, no. 37, pp. 1–2, 2014.

[13] E. Androulaki, A. Barger, V. Bortnikov, C. Cachin, K. Christidis, A. De Caro, D. Enyeart, C. Ferris, G. Laventman, and Y. Manevich "Hyperledger fabric: A distributed operating system for permissioned blockchains," in *Proc. 13th EuroSys Conf.*, 2018, pp. 1–15.

[14] J. Nick, A. Poelstra, and G. Sanders. (2020). *Liquid: A Bitcoin Sidechain*. Liquid White Paper. [Online]. Available: https://blockstream.com/assets/downloads/pdf/liquid-whitepaper.pdf

[15] X. Yang, Y. Zhang, S. Wang, B. Yu, F. Li, Y. Li, and W. Yan, "LedgerDB: A centralized ledger database for universal audit and verification," *Proc. VLDB Endowment*, vol. 13, no. 12, pp. 3138–3151, Aug. 2020.

[16] T. McConaghy et al., "BigchainDB: A scalable blockchain database," BigchainDB GmbH, Berlin, Germany, White Paper, 2016. Accessed: Jan. 23, 2023. [Online]. Available: https://www.bigchaindb.com/whitepaper/bigchaindb-whitepaper.pdf

[17] D. L. Fekete and A. Kiss, "A survey of ledger technology-based databases," *Future Internet*, vol. 13, no. 8, p. 197, Jul. 2021.

[18] S. Lupaiescu, P. Cioata, C. E. Turcu, O. Gherman, C. O. Turcu, and G. Paslaru, "Centralized vs. decentralized: Performance comparison between BigchainDB and Amazon QLDB," *Appl. Sci.*, vol. 13, no. 1, p. 499, Dec. 2022.

[19] M. Platt, J. Sedlmeir, D. Platt, J. Xu, P. Tasca, N. Vadgama, and J. I. Ibañez, "The energy footprint of blockchain consensus mechanisms beyond proof-of-work," in *Proc. IEEE 21st Int. Conf. Softw. Quality, Rel. Secur. Companion (QRS-C)*, 2021, pp. 1135–1144.

[20] J. Chen and S. Micali, "Algorand: A secure and efficient distributed ledger," *Theor. Comput. Sci.*, vol. 777, pp. 155–183, Jul. 2019.

[21] C. Bassi. (2021). *Sustainable Blockchain: Estimating the Carbon Footprint of Algorand's Pure Proof-of-Stake*. Accessed: Jan. 23, 2023. [Online]. Available: https://www.algorand.com/resources/blog/sustainable-blockchain-calculating-the-carbon-footprint

[22] C. Lepore, M. Ceria, A. Visconti, U. P. Rao, K. A. Shah, and L. Zanolini, "A survey on blockchain consensus with a performance comparison of PoW, PoS and pure PoS," *Mathematics*, vol. 8, no. 10, p. 1782, Oct. 2020.

[23] M. Kõlvart, M. Poola, and A. Rull, *Smart Contracts*. Cham, Switzerland: Springer, 2016, pp. 133–147.

[24] (2021). *What is a Blockchain Oracle?* Accessed: Jan. 23, 2023. [Online]. Available: https://chain.link/education/blockchain-oracles

[25] Qiibee Foundation. (2019). *Qiibee Whitepaper*. Accessed: Jan. 23, 2023. [Online]. Available: https://static.qiibee.com/qiibee-White-Paper.pdf

[26] (2017). *Bitrewards White Paper*. Accessed: Jan. 23, 2023. [Online]. Available: https://www.allcryptowhitepapers.com/wp-content/uploads/2018/11/BitRewards.pdf

[27] M. Agrawal, D. Amin, H. Dalvi, and R. Gala, "Blockchain-based universal loyalty platform," in *Proc. Int. Conf. Adv. Comput., Commun. Control (ICAC)*, Dec. 2019, pp. 1–6.

[28] B. K. Pramanik, A. Z. M. S. Rahman, and M. Li, "Blockchain-based reward point exchange systems," *Multimedia Tools Appl.*, vol. 79, nos. 15–16, pp. 9785–9798, Apr. 2020.

[29] S.-F. Tu, C.-S. Hsu, and Y.-T. Wu, "A loyalty system incorporated with blockchain and call auction," *J. Theor. Appl. Electron. Commerce Res.*, vol. 17, no. 3, pp. 1107–1123, Aug. 2022.

[30] O. Sönmeztürk, T. Ayav, and Y. M. Erten, "Loyalty program using blockchain," in *Proc. IEEE Int. Conf. Blockchain (Blockchain)*, Nov. 2020, pp. 509–516.

[31] I. Hameed, Z. Hyder, M. Imran, and K. Shafiq, "Greenwash and green purchase behavior: An environmentally sustainable perspective," *Environ., Develop. Sustainability*, vol. 23, pp. 13113–13134, Jan. 2021.

[32] C. Fan, S. Ghaemi, H. Khazaei, and P. Musilek, "Performance evaluation of blockchain systems: A systematic survey," *IEEE Access*, vol. 8, pp. 126927–126950, 2020.

[33] K. Stevenson, O. Skoglund, M. Raikwar, and D. Gligoroski, "Efficient novel privacy preserving PoS protocol proof-of-concept with algorand," in *Proc. 3rd Blockchain Internet Things Conf.*, Jul. 2021, pp. 44–52.

[34] M. Conti, A. Gangwal, and M. Todero, "Blockchain trilemma solver algorand has dilemma over undecidable messages," in *Proc. 14th Int. Conf. Availability, Rel. Secur.*, Aug. 2019, pp. 1–8.

[35] Y. Gilad, R. Hemo, S. Micali, G. Vlachos, and N. Zeldovich, "Algorand: Scaling Byzantine agreements for cryptocurrencies," in *Proc. 26th Symp. Operating Syst. Princ.* New York, NY, USA: Association for Computing Machinery, Oct. 2017, pp. 51–68, doi: 10.1145/3132747.3132757.

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