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A Decentralized Prototype Framework for Peer-to-Peer based Electric Car Sharing Services towards Sustainable Road Transportation

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Abstract

Purpose

Presently, existing electric car sharing platforms are based on a centralized architecture which are faced with inadequate trust, and pricing issues as these platforms requires an intermediary to maintain users' data and handle transactions between participants. Therefore, this article aims to develop a decentralized peer-to-peer electric car sharing prototype framework that offers trustable and cost transparency.

Design/methodology/approach

This study employs a systematic review and data was collected from the literature and existing technical report documents after which content analysis is carried out to identify current problems and state-of-the-art of electric car sharing. A use case scenario was then presented to preliminarily validate and show how the developed prototype framework addresses the trust-lessness in electric car sharing via Distributed Ledger Technologies (DLT).

Findings

Findings from this study present a use case scenario that depicts how businesses can design and implement a distributed peer-to-peer electric car sharing platforms based on IOTA technology, smart contracts, and IOTA eWallet. Main findings from this study unlock the tremendous potential of DLT to foster sustainable road transportation. By employing a token-based approach this study enables electric car sharing that promotes sustainable road transportation.

Originality/value

The key novelty of the article is introducing a decentralized prototype framework to be employed to develop an electric car sharing solution without a central control or governance, which improves cost transparency. As compared to prior centralized platforms the prototype framework employs IOTA technology smart contracts, and IOTA eWallet to improve mobility related services.

Social implications

The findings advocate that electric vehicle sharing has become an essential component of sustainable road transportation by increasing electric car utilization and decreasing the number of vehicles on the road.

Practical implication

Practically the developed decentralized prototype framework provides improved cost transparency and fairness guarantees as it is not based on a centralized price management system. The DLT based decentralized prototype framework aids to orchestrate the incentivize monetization and rewarding mechanisms among participants that share their electric cars enabling them to collaborate towards lessening CO_2 emissions.

Keywords: Sustainable road transportation; Electric car sharing; Peer-to-peer sharing; Distributed car sharing; Decentralized monetization and incentivization; Car sharing security and privacy.

1. Introduction

The mobility of people and goods is crucial in the context of sustainable road transportation. As people move within and across cities privately owned Electric Vehicles (EV) can be shared with other citizens who need transport (Anthony Jnr, 2021a). Researchers such as Khanji and Assaf, (2019); Valaštín et al. (2019) mentioned that cars are not in use and are parked for almost 95-96 % of the time. These EVs are mostly parked and unused almost 95 percent of the time(Khanji and Assaf, 2019). To improve road transportation these electric cars can be shared or leased out to form a collaborative mobility sharing ecosystem based on the sharing economy (Saurabh et al., 2021). Electric car sharing and leasing allows individuals to rent or share an electric car for a period of time enabling commercial EV sharing businesses and users to earn money from sharing or leasing their electric cars when they are not in use (Valaštín et al., 2019). Electric car sharing, or pooling has a significant potential in urban environments by reducing carbon emission, improving air quality, promotes cost saving, and increasing electric vehicles occupancy thereby reducing traffic jams and congestion particularly in areas with inadequate road transportation infrastructure (Chang and Chang, 2018).

Following this trend, businesses have built various centralized services and apps (e.g., Lyft and Uber) in the market and such car sharing services have two success elements: on-demand mobility availability and personalized mobility service (Sun et al., 2021). However, since these systems are based on centralized approaches there exist disputes and issues in the mobility sharing services provided, and the lack of transparent pricing scheme (Chang and Chang, 2018). Additionally, the adoption of shared electric vehicles is faced with other barriers which hinders the uptake such as the intermediary cost, trust problem, inflexible incentivization/offering, data monopolism, etc. (Saurabh et al., 2021). Decentralizing the management of electric car sharing is a promising method to address the current challenge faced within the electric mobility sharing (Khanji and Assaf, 2019). Accordingly, decentralized ledger technologies (DLT) are being adopted in mobility sector for collective recording, sharing, and governance of transport related data (Bokolo, 2022).

DLT has been used in other sectors primarily to improve interoperability, governance, and eliminating the need for a third party such as escrow to manage mobility related agreements and transactions using smart contracts to aid negotiations between participants (Renu and Banik, 2021). Therefore, this article aims to investigate the following research questions.

- How to design a decentralized peer-to-peer electric car sharing solution for sustainable road transportation?
- How to manage fair monetization and incentivization to reward participants involved in electric cars sharing?
- How to guarantee cost transparency for individuals involved in electric car sharing without the need for any intermediary?

To address the above research questions, this study investigates how a decentralized electric car sharing solution can be developed without a central governance control to improve cost transparency thereby decreasing costs between EV sharing companies, passengers, and drivers. Findings from this study orchestrate the monetization and incentivization of all participants based on the application of IOTA technology, smart contracts, and IOTA eWallet. The rest of this study is arranged as follows. In the next section the literature review is presented, and in Section 3 the methodology employed in this paper is discussed. Then, in Section 4, the findings are discussed. Next, in Section 5, discussion and implications are further presented and finally Section 6 concludes this study.

2. Literature Review

Presently, a few studies have employed decentralized approach to promote car sharing services as described in Table 1.

Table 1 Related works

Author(s), year, and contributions	Explored areas	Methodology employed	Context	Countries
Pirker et al. (2021) proposed a blockchain-based shared mobility application mainly for commercial and private vehicles by employing Ethereum Request for Comments 721 (ERC-721) tokens.	Shared Mobility Blockchain Smart Contract Ethereum Token	Proof-of-concept implementation	Further developed a smart contract connected with a hardware security module to safeguard the confidential key component.	Austria
Renu and Banik (2021) contributed towards the development of a secure ridesharing decentralized application (DApp) employing smart contracts within Ethereum blockchain.	Blockchain Smart City Smart Contract Dapp, Ethereum Cryptocurrency Shared Economy	Experiment	The authors used DApp and a matching algorithm to match passengers requesting rideshare to reduce entire travel distance.	India
Saurabh et al. (2021) proposed an approach to decentralized car-sharing. The study provides a use case based on a DApp to support the deployment of a novel collaborative peer-to-peer approach which provides a substitute service to private car ownership.	Social media Car-sharing Decentralization Blockchain	Prototype implementation, experiment, and modelling	The study further provided description towards a DApp based car-sharing social media prototype to be implementation.	Austria Spain Norway Netherlands North Macedonia
Vazquez and Landa-Silva (2021) presented a blockchain-driven ride-sharing platform and in specifically smart contracts to design decentralized ride-sharing applications.	Ridesharing Blockchain Smart contracts Smart transport systems	Experiment	The study employed distributed approach to maintain end-users‘ data and manages transactions between participants.	United Kingdom (UK)

Palanisamy et al. (2020) developed a decentralized based social media application as a service to support car-sharing.	Resilient, Trustworthy Privacy Autonomy Robustness	Prototype implementation, experiment, and modelling	Findings from the study provided a description of a prototype for car-sharing application supported in a simulated scenario.	Norway Spain North Macedonia Austria Netherlands
Zonda and Meddeb (2020) implemented a proxy-based re-encryption approach to enhance privacy in blockchain driven carpooling.	Privacy Blockchain Proxy re-encryption smart contract mobility	Use case	Presented a blockchain architecture linked within smart contracts to offer a very fast, efficient, and secure application.	France
Khanji and Assaf (2019) the study explored how to boost ridesharing effectiveness via capitalizing on blockchain characteristics of trustless, decentralization, and scalability.	Blockchain Distributed ledger Ridesharing Decentralized application	Case study	Focused to improve ridesharing efficiency via blockchain based on an incentivization scheme for prospective users using token rewards.	Jordan
Madhusudan et al. (2019) employed smart contract to achieve a secure car sharing. The study presents an efficient means that aid users to share their personal, under-utilized cars in a decentralized approach, eliminating the need of an intermediary.	Smart Contracts Ethereum Car booking and payments Security Privacy Car sharing	Experiment	Using Ethereum testnet the study guarantee privacy and high security for booking and payments in a car sharing system.	Belgium Luxembourg UK
Pal and Ruj (2019) designed a blockchain based solution to guarantee the fairness of ride sharing for all participants within a peer-to-peer network.	Blockchain Car sharing Road side units Reputation system Fairness	Experiment	The authors focused to ensure fairness and developed a prototype in Ethereum based protected network and KOVAN test network.	India
Valaštín et al. (2019) designed a blockchain oriented car-sharing system. The researcher aimed to develop a peer-to-peer short term car-sharing platform based on blockchain and smart contracts.	Blockchain Car sharing Asset sharing Ethereum Smart contract	Test scenarios	The study depicted how to increase of data transparency and reduce cost.	Slovakia
Chang and Chang (2018) investigated the deployment of blockchain technology for smart city service such as a ridesharing.	Blockchain Decentralized organization Ridesharing Smart contract	Prototype implementation	Illustrated how to carry out a decentralized transactional platform managed by blockchain.	Taiwan

Findings from Table 1 suggested that the car sharing market has been dominated by incumbents in the mobility business, whose operational design is based on centralized architectural platform (Pirker et al., 2021). These centralized platforms employed by these businesses have helped to facilitate car sharing but are faced with challenges such as inadequate trust, and pricing issues. The adoption of DLT can help to deploy a trustable and immutable sharing system where users have control and access to their data. DLT also provides a data auditability and integrity infrastructure which can help all actors to comply with GDPR. Findings from the reviewed 11 studies described how issues faced by centralized platforms deployed for ride sharing or car sharing are being addressed. However, there are no mention of how to design "*decentralized electric car sharing frameworks*", how to manage "*fair monetization and incentivization*" in electric cars sharing, and how to *"guarantee data security and privacy"* of individuals involved in electric car sharing without the need for any intermediary. Accordingly, this current study advocates for the adoption of decentralized architectures by leveraging IOTA technology, smart contracts, and IOTA eWallet to improve peer-to-peer electric car sharing. Overall, this study uses IOTA which by default uses proof-of-work as proof of investment in contrast to prior research in the literature such as Pal and Ruj's (2019) reliance on proof-of-authority.

3. Methodology

3.1.Research Method

A Systematic Literature Review (SLR) approach is employed in this study to guide the research process (Kitchenham and Charters, 2007). A typical SLR process includes identifying, defining, interpreting, analyzing, and essentially evaluating the current body of knowledge about a particular research domain such as decentralized electric car sharing (Fink, 2019). This research method involves employing a specific predefined search strategy to find a complete and comprehensive knowledge about the research area (Anthony Jnr, 2022a). In comparison to standard literature reviews the results from SLR is more extensive, less biased, and offers an extensive summary of literature pertinent to the research questions being examined in the study (Abduljabbar et al., 2021). The SLR approach begins with a pre-defined and documented review protocol that supports researchers to identify their research questions, objectives, and methods to implement the review.

The SLR approach depend on a clearly specified search strategy to classify and structure the literature towards identifying the knowledge gaps (Abduljabbar et al., 2021). SLR approach also employs search scientific libraries/databases which contain inclusion and exclusion criteria to screen and categorize applicable studies. As seen in Figure 1, the SLR approach mainly comprises of defining the research aim and objectives, specifying the research questions, searching of scientific libraries/databases, and lastly to get appropriate information and content. The next phase involves describing and utilizing inclusion and exclusion criteria, assess the quality of sources, and lastly extracting and synthesizing secondary data to provide findings and make recommendations towards the research area being investigated.

3.2.Research Protocol and Search Strategy

The literature search was conducted in August 2022 and later in March 2023 on titles, abstracts, and keywords from the selected scientific libraries. Different sets of search terms were employed to select appropriate studies: *"electric car service" or "electric car sharing" or "electric* *mobility" or "electric car" or "electric vehicle" and "EV*"and "electric car pooling*", and "road transportation" or "smart cities" and "smart*" and "sustainable mobility*" and "distributed ledger technologies*" or "DLT" and "blockchain*" and "model*" or "framework" and " decentralized model*".* This study employed the search term AND/OR logic as recommended by Kitchenham and Charters (2007) in conducting SLR. The search terms were selected based on the study area and the research questions being examined as suggested in the literature (Kitchenham and Charters, 2007). In addition, search terms were selected from prior studies (Abduljabbar et al., 2021; Anthony Jnr, 2021a). The search is limited to only journal articles, conference proceeding, and book chapters (e.g., not technical reports), and articles written in English. Also, only studies published from 2000 till date (2023) were considered in this study. The articles selected also provide relevant data to address the research questions explored in the study, reported on the implementation of a decentralized car sharing solution, and further provided discussion to expand and future development of the area.

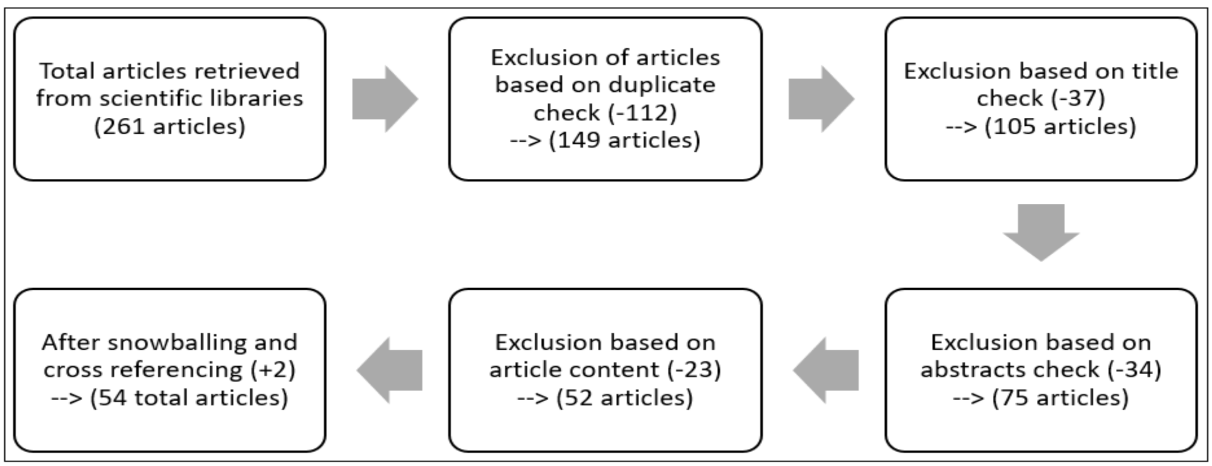

Figure 1 Articles selection process for the study

As seen Figure 1 a total of 261 articles were retrieved from different scientific libraries such as Google Scholar, Scopus, and Web of Science. After which a duplicate check was carried out and 112 articles were removed as most of the articles downloaded from Scopus and Web of Science were also retrieved in Google Scholar. This resulted to 149 articles. Then 37 articles were removed based on the title not fully aligned to car sharing or polling resulting to 105 articles. Next, 34 articles were removed due to the abstract not fully discussing car sharing approaches. Furthermore, 23 articles were removed as the content of the paper was not well positioned to address issues related to car sharing. Lastly 52 articles were aligned to the research domain and further 2 articles were added to guide the SLR (Kitchenham and Charters, 2007; Fink, 2019), resulting to a total of 54 articles.

Figure 1 depicts the process employed for selecting articles utilized in this study to provide secondary data towards exploring the research questions as specified in the introduction section of this paper. Also, the aim and objectives of this study is to provide a deeper understanding of the state-of the-art of decentralized electric car sharing development, the challenges, and recommended initiatives for developing a decentralized electric car sharing towards sustainable road transportation. Finally, developing a prototype framework based on the application of IOTA technology, smart contracts, and IOTA eWallet to address challenges and limitations such as inadequate trust, and pricing which negatively impact electric car sharing. In this study trust refers to the extent to which different users are interested to collaborate and participate in peer-to-peer electric car sharing solution. In centralized systems there is need to rely on trust in a third party, but using IOTA as a DLT eliminates the need for a third party improving trustable and thereby confidence for citizens.

4. Findings

4.1. State-of-the-Art of Car Sharing Modes and Business Models

In general, car sharing can be defined as the use of a vehicle by a certain number of users to arrive at one or more destination along a pre-defined journey (Kalczynski and Miklas-Kalczynska, 2019). Collaborative car sharing is now adopted based on innovative business models centred around smart applications and digital platforms being employed to deliver car sharing services to clients (Nourian et al., 2018; Roblek et al., 2021;). As the pricing is based on distance or time offering a flexible schedule to consumers regarding when and where they would prefer to pick up and return the shared vehicle (Huang et al., 2020). Nowadays car sharing services are transiting into the use of green-energy electric vehicles (Anthony and Petersen, 2020; Huang et al., 2020). In this approach a prospective user (drivers), are required to confirm their identity by uploading a copy of their driving license (front and back), for verification (Nair et al., 2020). In a typical car sharing scenario participants residing at different origins intend to commute to a common or different destination or intends to be pick-up/drop-off in a predefined location (Kalczynski and Miklas-Kalczynska, 2019). Thus, potential drivers can post their driving routes or destinations using a digital platform to find possible passengers with similar journey plans, and passengers can accept to share vehicles or join vacant cars with other passenger(s) simultaneously (Li et al., 2018). Also, passengers need to search for a driver who is available to share a car with him/her based on a desired location (Zhu et al., 2019).

Each car sharing journey or trip comprises of the origin provided to the vehicle with a certain space allocation based on a static number of passenger seats available (Zivic, 2020). The trip is known and scheduled in advance, to be approved by all participants who are willing to carpool by sharing available passenger seats. However, the distance taken to reach a particular destination may varies due to detours taken to drop off or pick up (Kalczynski and Miklas-Kalczynska, 2019; Jabbar et al., 2020). Furthermore, the existing business model deployed by car sharing providers who own fleet of cars is mostly categorized into two main types which includes "*station-based car sharing*" and "*free-floating car sharing*" (Huang et al., 2020). The *station-based car sharing scheme* involve clients to pick up and return cars at established stations (Huang et al., 2020). Another station-based car sharing scheme is the "*roundtrip station-based*" or "*back* *to base*" method for car sharing where the leased car is picked up and returned to the same dedicated parking spot (Levina, 2016; Roblek et al., 2021). *Roundtrip home zone-based* is an alternative car sharing scheme where the car needs to be collected and returned back to the same area or home zone within the city (Li et al., 2018; García et al., 2020). This scheme is a little bit different as no dedicated parking spots are used in this scheme (Roblek et al., 2021).

4.2. Electric Car Sharing for Sustainable Road Transportation

In Europe, car sharing was introduced where people came up with the idea of substituting private cars with shared cars due to the negative impact of public transportation on the environment. Amidst this trend social groups and environmentalist started to draw attention to the impact of combustion-based engines and demanded action from the public authorities. This resulted to calls for a change in urban transport development policies in line with the concept of sustainability aimed at improving social well-being, economic, and natural harmony (Roblek et al., 2021). The increasing popularity of electric car sharing in cities in recent times is based on EV having lower operating costs as the additional price for charging of EVs fleets at designated charging stations are covered by the electric car sharing company. As such policymakers in European countries are progressively supporting electric car sharing services to decrease congestion-related pollution and decrease the need for further road infrastructure. Moreover, electric car sharing model allows individuals to temporarily use an electric vehicle on-demand at a variable cost, billed dependent on the time booked or distance traveled (Pirker et al., 2021; Saurabh et al., 2021).

Electric car sharing offers a promising solution for municipalities with less frequent road transportation and promotes urbans environmental responsibility when implemented in a large community such as in governmental institutions and universities (Khanji and Assaf, 2019; Dev and Biswas, 2022). It has a potential in lowering traffic jams and the use of available parking slots (Khanji and Assaf, 2019). Prior studies proposed key characteristics for EV sharing, including flexible, automated matching, cost-sharing, dynamic, non-recurring trips, and environmentally friendly (Saurabh et al., 2021). However, it is essential to assess which trust, and incentivization mechanisms can be employed to encourage individuals and businesses to share their electric cars (Khanji and Assaf, 2019). Most platforms supporting the sharing economy rely on a centralized architecture for managing information and settling transactional payments (Bokolo et al., 2022).

Unfortunately, these centralized platforms are not as trustworthy as they intend to be, as their pricing schemes are not fairly transparent to all participants (Madhusudan et al., 2019). Furthermore, centralized platforms store all mobility related data in single database, which can be prone to cyber-attacks, resulting to data breaches that violate users 'privacy (Madhusudan et al., 2019; Roblek et al., 2021). Moreover, apart from issues related to fairness and privacy, these platforms involve added cost for individuals and the mobility sharing service provider (Madhusudan et al., 2019). Electric car sharing or leasing enables passengers to share or rent an electric vehicle to lessen traveling time, traffic congestion and carbon emissions (Saurabh et al., 2021). Electric car sharing is a recent collaborative model which offers an alternative mobility solution to privately owned car (Anthony Jnr et al., 2020).

4.3. Adoption of Emerging Technologies for Electric Car Sharing

4.3.1. Centralized Technologies for Electric Car Sharing

These centralized platforms are based on a trusted third party which offers car sharing services to its clients in exchange in exchange for a service fee. Prominent car sharing businesses include Turo, Getaround, Zipcar, ShareNow, etc. ShareNow owns the cars and built a digital platform where individuals can borrow out cars owned by the company. Enterprises such as Turo, Car Next Door, and Getaround deploy a “*centralized peer-to-peer approach*”, where car owners rent out their under-used vehicles to individuals who temporarily need one (De Troch, 2020). Additionally, businesses such as Zipcar, ShareNow own their own “*free-floating*” fleet of cars in urban regions, where these cars are leased out to residents. These companies manage car sharing reservations through digital platforms made accessible via website and handheld devices which enables renters to search, access, pay, and get support while driving the shared cars.

For individuals to participate, they must register and upload a valid driver’s license. After which the users are given temporary access to available cars, and are charge service fee (De Troch, 2020).Both the centralized peer-to-peer and free-floating platforms are faced with privacy risk and security breaches. As both platforms provide access to sensitive user data such as driver’s licenses, location, car usage patterns, payment information, etc. Also, these current platforms do not offer fair and transparent pricing. To reduce these practices in car sharing servicers a decentralized approach can be adopted, where no single unit has full control over the car sharing system (De Troch, 2020).

4.3.2. Applicability of Distributed Ledger Technologies for Electric Car Sharing

Centralized car sharing platforms provide flexibility in planning car sharing either in advance or within same day. However, electric car sharing services depend on a central entity that manages the platform and charges individuals (e.g., escrow, deposit) which is not completely in a transparent way (Saurabh et al., 2021). Traditionally, trust has underpinned business, often requiring a dependable third party, which is expensive (Abubaker et al., 2019; Sun et al., 2021). In the absence of market competition, transparency, and trust can result to high costs and possibly monopoly. Therefore, there is need to develop decentralized car sharing solutions. From the standpoint of a sharing service, emerging technologies such as DLT provide digital platforms with real-time information and advanced analytics (Brousmiche et al., 2018; Anthony Jnr, 2021b), of available green mobility options to help citizens make more intelligent choices about alternative under-utilized EV assets. With DLT, the world’s most essential business interactions can be re-imagined; the door to invent new patterns of digital exchanges in a trust-less sharing services has emerged. DLT could help to preserve the anonymity among participants and preserve the integrity of data (Vazquez and Landa-Silva, 2021).

The dynamic of people being trust-free in a DLT based business model is centered on transparency and privacy in the service relationship between digital technology and human (Sun et al., 2021). DLT can offers new opportunities that provides a user-friendly, transparent, and trustworthy (trust-free) applications required for realizing the process of electric car sharing (Bauer et al., 2019; Anthony Jnr, 2022a). DLT enables individuals to access their transactional records, as it saves transaction history at every node of the distributed ledger, as DLT offers data provenance for traceability of transactions (Anthony Jnr, 2022b). Moreover, DLT enables the incentivization of passengers and drivers via token rewards which can be used to pay for ride sharing. DLT can enable a flexible governance structure which enhances the security, privacy towards a safe interactions and communication (Bokolo, 2022), between drivers and passengers. It can support with accessing and managing electric cars information (e.g., size, performance, number of allowed passengers), providing information on the battery state (type, performance, status, etc.) based on the travel needs of users, EV localization based on spatial position (Orecchini et al., 2018).

4.3.3. Developed Decentralized Prototype Framework for Smart Electric Car Sharing

The prototype framework is shown is Figure 2. The developed decentralized prototype framework is based on a business-to-business (B2B) and business-to-customer (B2C) business model where a platform is provided that offers electric car sharing solution for businesses such as ZipCar.

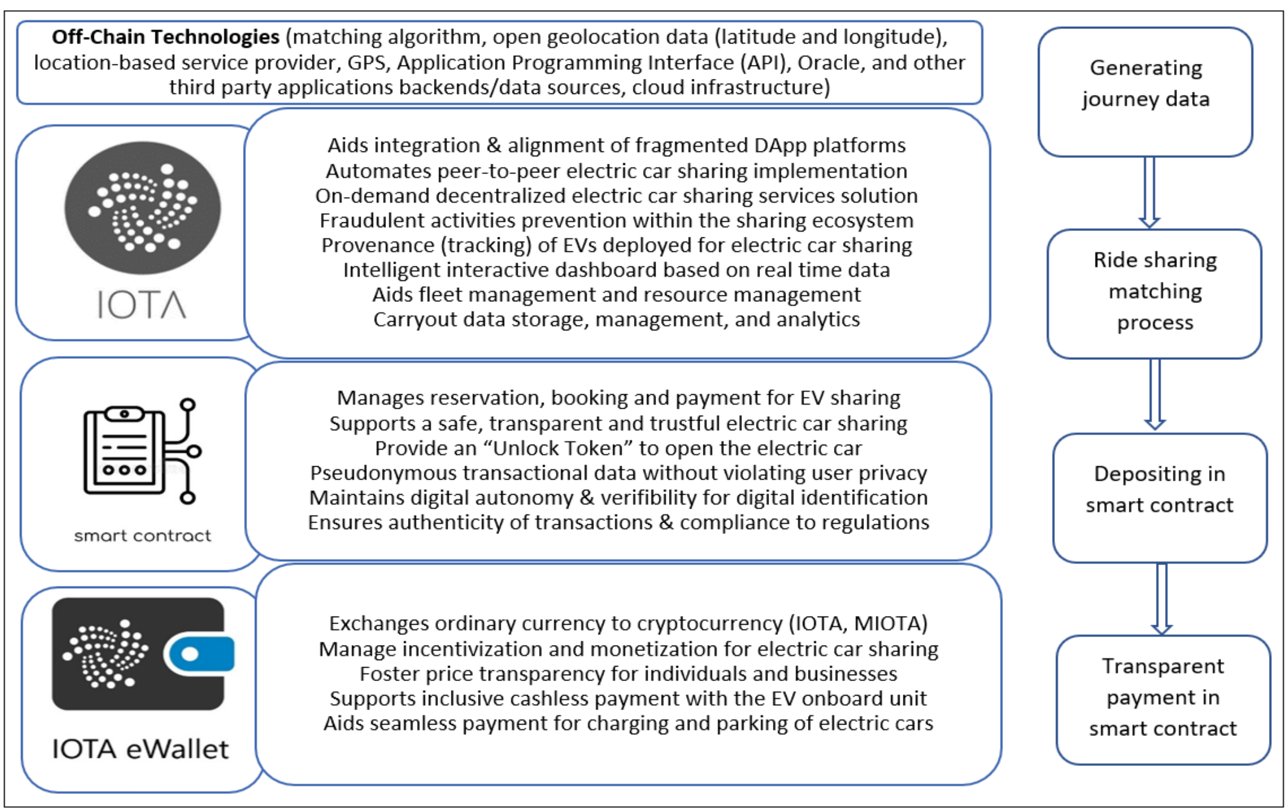

Figure 2. Decentralized prototype framework for smart electric car sharing solution

An EV rental company can also use the prototype framework to provides electric car fleet, which can be leased by individuals and other businesses using master unlock tokens created to provide access to the cars (Valaštín et al., 2019). It mainly comprises of IOTA technology, smart contracts, IOTA electronic car wallet (eWallet), and off-chain technologies.

4.3.4. Use Case Scenario Description for Decentralized Electric Car Sharing

A use case scenario is employed to preliminarily validate the developed framework (in Figure 2), as seen in Figure 3. As shown in Figure 2 the decentralized electric car sharing starts from generating journey data, ride sharing matching process, depositing in smart contract, and transparent payment in smart contract as suggested by Vazquez and Landa-Silva (2021).

i. Generating Journey Data

A passenger publishes a car sharing request within the decentralized IOTA prototype supported by smart contract. The closet pickup and then drop-off geolocation (latitude and longitude), information is retrieved from off-chain and saved within IOTA and spatial cloaking technique suggested in the literature (Vazquez and Landa-Silva, 2021), is used to conceal an individuals' exact geolocation into a spatial region in order to maintain user privacy.

ii. Ride Sharing Matching Process

Next, off chain based matching algorithm is deployed to assess which drivers' destinations matches the potential passengers spatial cloaked location. Then, matched drivers are requested to publish a journey/trip offer with possible price range published to all matched drivers to ensure a fair biding system (Gudymenko et al., 2019). Also, the current location of the EV (driver) is encrypted by using public key of passengers to make certain that only passengers who need to share an electric car can see the approximate location of the EV (driver).

iii. Depositing in Smart Contract

To promote trust among both drivers and passengers, the passenger chooses the preferred driver offer, sends a deposit fee to the smart contract to confirm interest to join and share the trip. The driver is also required to transfer a deposit fee to the smart contract as a sign of commitment to share ride with the passenger(s) (Hossan et al., 2021). The smart contract verifies the transaction. In case of change to the travel itinerary for example if the passenger decides not to show up or terminates the ride sharing request almost to the time of the journey, the smart contract will auto release the deposit fee of the passenger to the driver as compensation. Likewise, if the driver does not turn up at the scheduled time or cancels the ride offer late, the smart contract will auto-reimburse the passenger with the driver's deposit fee (Vazquez and Landa-Silva, 2021). But, if the driver successfully arrives at the agreed pick-up location and the passenger is there, the smart contract auto-release both deposit fee as partial payment as both driver and passengers need to pay the electric car via IOTA eWallet. The money is later transfer from the EV to the electric car sharing provider.

iv. Transparent Payment in Smart Contract

As soon as the journey starts, smart contract automatically calculates the fee for both driver and passengers and collects the agree fees from the driver and passengers eWallet and transfers the amount to the eWallet of the EV. Once the trip is completed, the smart contract validates that the journey has been successfully completed and then issues payment receipts to all individuals. IOTA technology provides a public and permissive, enabling passengers and drivers of electric car sharing to read and write transactions within the distributed network. Using IOTA eWallet the designed prototype framework allows the exchange of local currencies to IOTA currency (MIOTA), enabling transactions to be executed in smart contracts. Overall, IOTA technology enables passengers and drivers to use their handheld devices to communicate with the electric car and among each other supported by off-chain technologies such as GPS, location-based service provider that helps to confirm that the driver has reached the trip starting point.

Furthermore, apart from "*IOTA technology*" and "*smart contracts*" the decentralized electric car sharing comprises of "*IOTA eWallet*" and "*off-chain technologies*" as disused below.

a) eWallet in Electric Car Sharing

To manage incentivization and monetization within the electric car sharing ecosystem an IOTA electronic car wallet (eWallet) is proposed to be integrated to enables the electric cars to create value acting as a separate business entity. As suggested in the literature (Kohlbrenner et al., 2019) IOTA eWallet can be integrated to other mobility systems that handles and processes data with different electric car service providers. Using the IOTA eWallet payment can be automatically made by participants sharing an electric car and associated costs generated by the electric car such parking and charging of the car can be billed directed to the electric car supporting nano or micro payments (Kohlbrenner et al., 2019). Furthermore, IOTA eWallet provides a safe and secure payment mechanism for drivers and passengers, as, the IOTA eWallet provides price transparency and also reduces operational costs (Kohlbrenner et al., 2019).

b) Off-chain Technologies

Off-chain technologies involves how some data processing or other integration services are carried out outside the DLT platform (Jeong et al., 2020). Off-chain technologies can be carried out using public contracts/private contracts, oracles, or Application programming Interfaces (API) which provides external link to the DLT platforms to enable decentralized electric car sharing services (Jeong et al., 2020; Bokolo, 2022). During the integration and alignment data are encrypted and stored on-chain and off-chain to reinforce data security and privacy preventing the data to be directly disclosed. Also, off-chain technologies can be employed to improve transactional processing speed within the DLT by reading data from the on-chain DLT to execute the state change transaction within the on-chain (Jeong et al., 2020).

c) Usefulness of the Designed Decentralized Prototype Framework

Using IOTA technology when an individual wants to lease an electric car, he/she just select the EV, duration of the leasing period, and then make payment based on the preferred currency (USD/EUR/NOR, etc.). IOTA eWallet exchanges local currency to cryptocurrency (IOTA, MIOTA), and then smart contract is executed to provide an "*Unlock Token*" to open the electric car. For this to work the electric car is seen as an Internet of Things (IoT) device which receives unlock token from the individual using their handheld devices via Bluetooth connection. Once the electric car gets an unlock token, it verifies the authenticity of the code within the IOTA technology. If the unlock token is valid the electric car can be used (Valaštín et al., 2019). Individuals can decide to either buy MIOTA cryptocurrency which is later converted into other fungible tokens. In addition, the framework can automatically convert local currency to MIOTA exactly in time when individuals need it (Valaštín et al., 2019). The use of IOTA technology provides the underlying infrastructure that validates and stores the pseudonymous transactional data of individuals travel patterns and related personal data in an encrypted format. It also offers an intelligent interactive dashboard that provides insights and important information to end-users for enhancing car sharing services for businesses and revenues to individuals for improving their mobility experience and earning additional revenues (Dezalos et al., 2021).

It facilitates "*provenance of EVs*" by collecting and validating the vehicle usage history data to be used to improve maintenance of the EV fleets. DLT safely collects, store, trace and share anonymized car data in real time with the engine factory and car sharing providers (Zhao et al., 2018). The prototype framework handles access permissions of individuals geolocation data using IOTA technology for managing encrypted data linked with transactional activities in a decentralized approach without violating user privacy (Dorri et al., 2017; Palanisamy et al., 2020; Saurabh et al., 2021). The prototype framework provides support for integrating and aligning fragmented DApp platforms deploying RESTful Application Programming Interface (API) connected to the decentralized network. Using smart contract, the framework aids individuals, and businesses to achieve a safe, transparent, and trustable electric car sharing interaction while improving monetization opportunities stakeholders. To enable a decentralized electric car sharing solution the prototype framework provides an operational and customized virtual infrastructure to automates peer-to-peer electric car sharing implementation, monitoring and adaptation in real time.

The developed decentralized prototype framework provides environmental and economic impacts towards sustainable road transportation. As reported in the literature (Khanji and Assaf, 2019), both drivers and passengers will get reimbursed for sharing electric car via smart contracts. The individuals are incentivized and paid to their IOTA eWallet resulting to direct cost saving that is due to reduce EV charging cost from the shared journeys to the same destination for three possible electric car sharing scenarios (2 commuters, 3 commuters and 4 commuters). Additionally, there are other the indirect cost benefits associated with health care, excess energy/fuel consumption travel of time delay, and others (Khanji and Assaf, 2019).

d) Decentralized Electric Car Sharing Prototype Implementation

Based on the developed decentralized prototype framework as seen in Figure 2 the decentralized electric car sharing prototype can be implemented to manage decentralized electric car sharing as seen in Figure 3. Figure 3 depicts feasible deployment of decentralized electric car sharing based on a peer-to-peer platform built on top of IOTA technology by using Solidity language for smart contracts and ReactJS or NodeJS can be used for client side of the DApp to communicate with IOTA. Web3 will also be used as a connector to the IOTA network. The DApp will employ uses different RESTful APIs to access open data to be integrated with IOTA to instantiate decentralized electric car sharing peer-to-peer network based on different protocols employed as data is transmitted from either the drivers or passengers via JSON encoded strings.

According to Dezalos *et al.* (2021) to help the network nodes within the distributed ledger to differentiate between different types of data, different procedures or functions are proposed as shown in Figure 4. As suggested in the literature (Lamberti *et al*., 2019), the verification of the driver is done during the initial registration where the identity of the driver will be verified if the user has an active driver's license, this is checked and automatically approved within the tangle by the electric mobility service provider or via an API which gets access to the department of public transportation. However, foreigner drivers from other countries must upload a copy of his/her driver license which is verified during registration by the electric mobility service provider connected by tangle and then confirmation is sent by e-mail. Thus, he/she must also provide e-mail address, telephone number, address and payment option which is linked to the IOTA wallet verified by tangle.

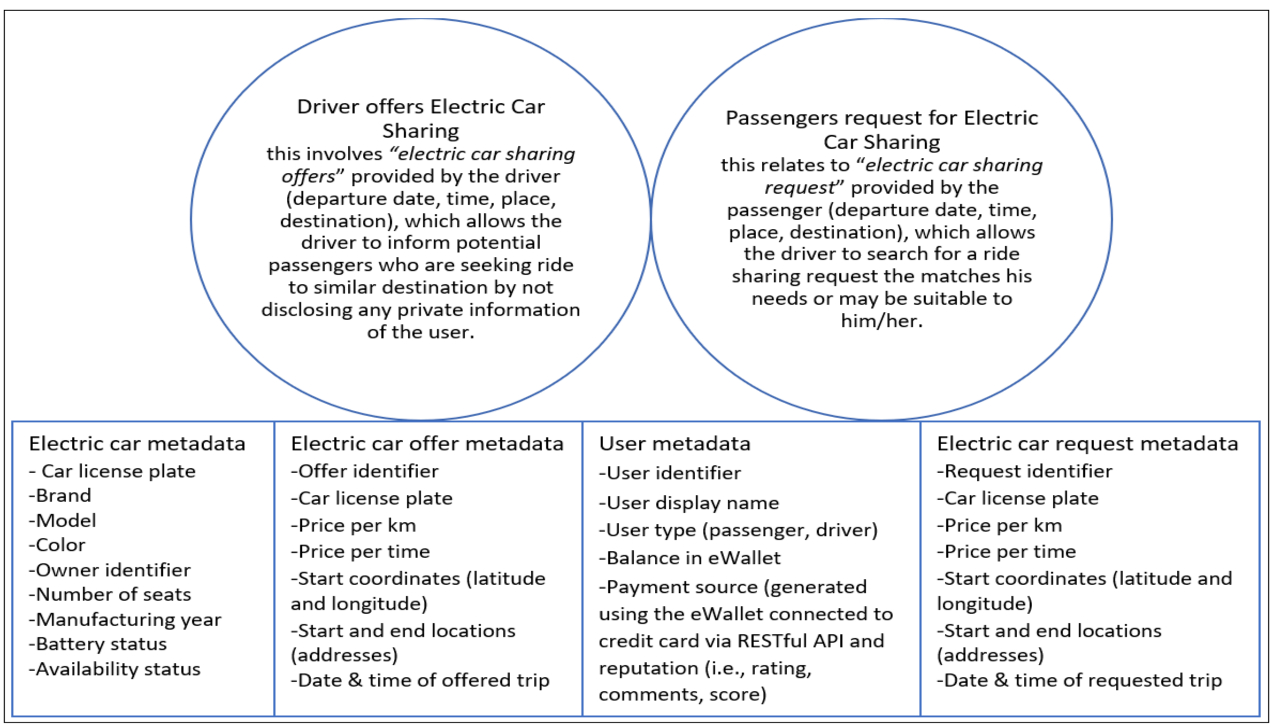

Figure 3. Feasible deployment of decentralized electric car sharing

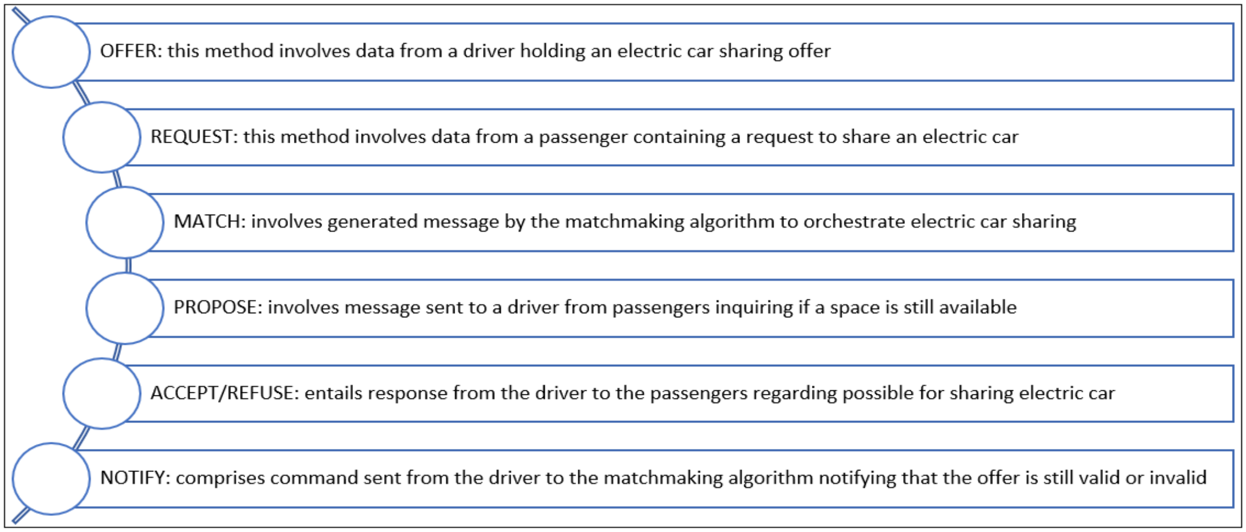

Figure 4. Procedures or functions to enable decentralized electric car sharing

Figure 4 outlines the main procedures or functions employed to support decentralized electric car sharing. These functions are triggered with smart contracts and IOTA which establishes connection with the electric car sharing service providers and end users. This help for managing mismatches between electric car sharing demands (e.g., trips, passengers, drivers, requests) and supplies (electric cars), to offer a personalized end-to-end seamless travel experience. Additionally, using third party geolocation data IOTA provide geospatial positioning and coordinates of available electric cars to boost electric car-sharing for businesses for optimizing fleet management and estimating travel time among drivers and passengers. For individuals these insights offered can be used to provide information of the parked electric cars, places/locations allowed for parking and charging EVs without penalties, possibly monetary rewards for parking and charging the EV in a recommended destination, and metadata of users who will join or waiting to join a trip. Using road traffic/weather forecast data from open data sources via RESTful APIs the decentralized prototype framework can help drivers to avoid traffic jams, improving collaboration, and revenue. The data processed by the decentralized prototype framework can be used for aggregation, analytics, prescriptive, and visualization offered to individuals and businesses as a dynamic visualization dashboard (e.g., electric car sharing heat-map zones).

4.3.5. Recommendation to Improve Privacy and Security

Although existing decentralized car sharing platforms are now attempting to adhere to privacy regulations to become GDPR compliant, it is still possible to track mobility pattern of drivers and individuals by identifying their origin and destination. To enhance the confidentiality of individuals data, there is need for off-chain techniques to be applied within the DLT,so that other node users within the distributed ledger cannot have access to stored individuals' data, and also cannot link car sharing service provider transaction with individuals. The control can be improved be suggesting a secure exchange protocol that enables data to be shared between individual members (Zonda and Meddeb, 2020). Techniques such as anonymous signatures can be utilized, where anonymous signatures are schemes employed where signatures do not disclose the signer's digital identity, since some parts of the information are unknown.

Besides, homomorphic encryption which is a robust cryptography technique can be carried out on certain kinds of computations directly on ciphertext to safeguard that the procedures executed on the encrypted data will produce identical results to those executed by the same procedures on the plaintext. Homomorphic encryption technique presents privacy protection and supports complete access to encrypted data (Zonda and Meddeb, 2020). Additionally, privacy-preserving record linkage (PPRL) method can be employed. PPRL aims to find and link data that relate to the same real-world users across different data sources managed by distinct groups without disclosing any private information about these users. It mainly comprises of two main stages, Privacy Preserving Blocking (PPB) and Privacy Preserving Matching (PPM). Lastly, the proxy re-encryption technique can be employed which is a unique type of public-key encryption that authorizes a proxy to convert ciphertexts from a public key to a different one, without allowing the proxy to gather information regarding the original message. Therefore, it offers a method for managing decryption rights, opening up access to different applications that need authorized access to encrypted data (Zonda and Meddeb, 2020).

5. Discussion and Implications

5.1. Discussion

Sustainable road transportation today means the use of public transport, cycling and walking and is seen as one of the essential strategies to transform cities into sustainable cities (Roblek et al., 2021). Car sharing has substantial social benefits as it offers accessible travels, reduces traveling time for passengers (Papageorgiou and Demetriou, 2020; Toumanidis et al., 2019), and decreases the number of cars on road, thus improving urban mobility and easing traffic congestion. It also provides environmental benefits by decreasing noises and vehicle emissions (Li et al., 2018). Car sharing services is also beneficial to residents and families who do not have access to the conventional public transportation or live in an area with sufficient transit access. Car sharing services can significantly impact the course of urban planning, transportation policies, and economic development of the city (Roblek et al., 2021). Moreover, the transport sector is currently experiencing a rapid change as it becomes more driven by data resulting to digitalization of mobility services provided to citizens by businesses (Masuch et al., 2020; Bokolo et al., 2022).

To date, most electric car sharing is based on a centralized approach which usually relied upon a trusted third party which manages the platform based on agreed high fees. This centralized approach is employed to authenticate users, verify requirements, and resolve payment between interacting parties. However, security attacks or failures (e.g., denial of service, man in the middle attack, phishing, etc.), undermine the resilience of these centralized based platforms (Khanji and Assaf, 2019). Also, massive amounts of user data are used to optimize electric car sharing services. This gives the electric car sharing service providers more control over their users. Unfortunately, this autonomy has been exploited several times and this has affected the trust of user for who privacy is ever more important (De Troch, 2020). DLT is one promising digital solution that offers a distributed nature and high resilient architecture to adopt the changing technological needs (privacy, security, and trust), of dynamic transport environment (Khanji and Assaf, 2019). DLT can be seen as an "*enabler"* for the development of the sharing economy (Roblek et al., 2021). It enables a peer-to-peer (P2P) business model at acquiring and providing access to goods and services between parties or between businesses and customers (B2C), business to business (B2B), and consumer-to-consumer (C2C) through standard contracts. DLT can help to provide an innovate car sharing approach, in which an autonomous platform can use data provided to match drivers with passengers and deploy smart contracts to execute related mobility transactions involved in the car sharing service. DLT can help to implement an efficient and safe connection between passengers and drivers while ethically utilizing data for calculating frequent trips and common travel patterns. Fully decentralized car sharing solutions driven by DLT can address fairness issues faced by centralized platforms (Madhusudan et al., 2019).

Findings from Kaiser et al. (2018) highlighted that automotive vehicle manufacturers such as Ford, BMW, Renault, and GM have begun to explore the adoption of DLTs such as blockchain by lunching the Mobility Open Blockchain Initiative (MOBI) in collaboration with academic and other industrial partners such as IBM, IOTA, Hyperledger, Bosch, Fetch.ai, and Blockchain at Berkeley. Also, other incumbent vehicle manufacturers are assessing employing DLT or are now working on viable projects related to application of DLT (Kaiser et al., 2018). Among these industries, Daimler in 2017 initiated a project where blockchain technology is used to handle financial transactions. Likewise, the automotive dealer ZF collaborated with UBS and IBM to work on a blockchain-driven automotive system known as "*Car eWallet*" with the aim of initializing the way for autonomous driverless vehicles by facilitating automated payments and also provide other user driven features (Kaiser et al., 2018). Hence, DLT has undeniably gained attention in the automotive sector. However, there is need to design concrete innovative business cases to show the full potential of DLT towards improve sustainable road transportation.

Accordingly, this study employs DLT based on IOTA technology, smart contracts, and IOTA eWallet to develop a decentralized peer-to-peer electric car sharing framework that improves data privacy. The developed decentralized prototype framework provides improved price transparency and fairness guarantees as it is not based on a centralized price management system. As compared to prior centralized platforms the prototype framework employ IOTA technology against data security breach since there is no main point of failure based on a decentralized peer-to-peer car sharing method between the car owners and users without the involvement of any intermediary. Similar to results from prior studies (Madhusudan et al., 2019), all data within the prototype framework are cryptographically saved on the distributed ledger using encryption with a unique recipient's public key to prevent any fraudulent transaction over the network. Enabling the participants in the car sharing scheme to trust the data on distributed ledger than data manage by an unknown third-party (Renu and Banik, 2021). Findings from this study is similar to results presented by Chang and Chang (2018) by efficiently accelerating electric car sharing processes between drivers and passengers.

Furthermore, analogous with findings from Renu and Banik (2021), the prototype framework differs from prior approaches as it offers a cost-effective car sharing without hidden fees sue to IOTA being a feeless DLT. In this study IOTA is employed as offers transparency of mobility related transactions providing data provenance for users to trace back their information without any restrictions. Besides, based on the available data both drivers and passengers can have a transparent meta data view of each other in advance or during car sharing. Using smart contracts, the prototype framework enables users to make safe seamless payment directly either to the car sharing provider, the car, or to the drivers using either IOTA tokens via IOTA wallets or via credit card connected to the decentralized platform as suggested in the literature (Bokolo, 2022). Moreover, Findings from Zhao et al. (2018) mentioned that the application of DLTs such as chained blocks can help in the car sharing economy by managing payment, finance, and insurance, incentivize EV sharing and validating all transactions for process improvement. Analogous to these findings the prototype framework aids for managing on-demand car sharing, providing information on EV insurance contract, automating payment for EV, incentivize participants, prevent fraud, and reinforces security and privacy of user data while promoting data sovereignty across the car sharing service.

5.2.Implications for Policy

In relation to transport policy this study addresses issues related to trust, time-criticality, and mobility democratization (Saurabh et al., 2021), by improving monetization, mobility inclusion through the deployment of decentralized applications (DApps). In this paper, the decentralized prototype framework allows individuals to temporarily share an electric vehicle on-demand based on a flexible fee, charged based on the time used or distance travelled. This is enabled by a peer-to-peer (P2P) electric car-sharing approach, which intends to satisfy road transportation demand in a sustainable means by lessening CO_2 emissions (due to use of electric cars and fewer vehicles on the road) and per-EV (encouraging the usage of electric or hybrid cars), and minimizing traffic, charging, and parking congestions (Palanisamy et al., 2020). The decentralized prototype framework can be employed by businesses to transit from a hierarchical model to a decentralized approach, thereby progressively transforming a top-down mode of decision-making mainly to a bottom-up approach. This transition can help to further democratize and distribute power from centralized self-control corporation (for example Lyft and Uber) to enable an emergence of community-driven mobility ecosystem.

The decentralized prototype framework offers a promising approach that has tremendous economic and environmental impacts on the society while incentivizing drivers and passengers that share electric cars. In comparison to regular car sharing schemes the approach presented in this study offers business and governmental institutions with a mean to achieve their environmental responsibilities through reducing their carbon footprint. Additionally, the prototype framework can use electric car sharing data to improve the mobility related service, suggest potential passengers to drivers, and improve community engagement on sustainable road transportation. Besides, the smart contracts have an escrow that depends on the users' reputation, measured according to the service policies. On top of these services, smart contracts employ reward mechanisms and computes EV fleet allocation procedures aim to provide monetary benefits for individuals and businesses by decreasing the impact of external events, eliminating fleet idle times, and enhancing the passengers and drivers' mobility sharing experiences (Palanisamy et al., 2020; Saurabh et al., 2021).

5.3.Implications for Research

Prior research dealing with the carsharing mainly focuses on centralized approaches aimed mostly at addressing environmental issues, decreasing traffic congestion, and lowering fuel emissions (Kalczynski and Miklas-Kalczynska, 2019). Also, issues related to privacy, trust, and data security in electric car sharing are not well addressed in the literature. Therefore, this study advocates for the application of smart contracts and IOTA tangle to help preserves individuals' privacy, trust, and anonymity during electric car sharingthereby promoting *data democratization*. This enables individuals to have ownership and control over their data and they can revoke access when needed, thus supporting *data sovereignty*. Besides, businesses and individuals who do not trust each other could collaborate through the system, e.g., a company that provides EVs and passengers and drivers that use the electric cars while remaining anonymous (Kanza and Safra, 2018).

Moreover, the use of IOTA technology can support anonymous identities, offering drivers and passengers a secure, unbreakable, and permanent link their personal data without violating users' privacy and improve the trustworthiness with improved collaboration during electric car sharing. As seen in Figure 2 the decentralized prototype framework provides implication on how businesses can improve the communication between electric cars and individuals and incentivization of individuals for their participation in sharing EVs. Agreements such the SLA are managed via smart contracts and the decentralized consensus deployed within the DLT platform. Furthermore, the decentralized prototype framework supports different business models thereby improving interoperability and interconnectivity among different electric car sharing and pooling operators.

5.4.Implications for Practice

The key novelty of the article is introducing a decentralized prototype framework to enable electric car sharing solution without a central control or governance. This approach helps to maintains users' data, manages transactions between passengers and drivers. The DLT based decentralized prototype framework aids to orchestrate the monetization and rewarding mechanisms among participants to incentivize them to share their electric cars enabling them to collaborate towards lessening CO_2 emissions while being rewarded analogous to prior study Khanji and Assaf (2019), but powered by IOTA technology, smart contracts programmed in Solidity programming language (Mhamdi et al., 2021), and IOTA eWallet. IOTA technology provides full decentralization and eliminates a central authority, as stated in the literature (De Troch, 2020), has the capability to raise service fees and access users' privacy. The use of smart contracts with IOTA technology supports different individuals and multiple electric cars resulting to anonymized large number of drivers and passengers which support data privacy, whilst nonetheless ensuring accurate execution of the payment using IOTA eWallet. This study employed smart contracts to achieve a trustable and secure interactions for sharing electric cars on-demand at a variable fee, charged to the passengers and drivers depending on the time used or distance travelled, while the individuals have complete control over their personal data.

6. Conclusion

Electric car sharing can help to make public transportation more sustainable and smarter for cities around the world. The increasing number of handheld devices such as smart phones and the provision and adoption of digital platforms in cities have made mobility solutions such as electric car sharing more appealing. Existing electric car sharing platforms employ a centralized approach where third parties manage data and transactions between passengers, drivers, and electric car sharing providers. Also, due to the increased amount of data used for road transportation, the threat of data privacy and security is important. Thus, securing the safety and privacy of the electric car sharing towards maintaining its stability in a centralized based platforms is costly in terms of labor, time, and resources needed in the development, implementation, management, and future maintenance. This article proposes the idea of developing an electric car sharing platform in a decentralized manner by leveraging the power of IOTA technology, smart contracts, and IOTA eWallet to offers cost transparency, data privacy, and security of user data.

The decentralized electric car sharing approach is based on a peer-to-peer business model that enables economic efficiency via tokenization managed by autonomously by smart contract. This enables the electric car to connect to passengers and drivers via their handheld devices to make payment via IOTA eWallet (see Figure 2). The decentralized prototype framework has the benefits of decreasing associated costs, mainly as in a distributed network where all participating node users are responsible to maintain the operational stability and integrity of the platform as such the share of all costs are equitable distributed (Chang and Chang, 2018). Findings from this study examined the less researched area of *sustainable road transportation* by providing evidence on how to design a decentralized peer-to-peer electric car sharing solution for sustainable road transportation, and how to manage fair monetization and incentivization to reward participants involved in electric cars sharing. The findings also provide recommendations on how to guarantee information security and privacy of individuals involved in electric car sharing without the need for any intermediary. The decentralized prototype framework provides a way forward to design a decentralized DLT driven architecture for the road transportation.

Furthermore, using IOTA eWallet local currencies are automatically exchanged to cryptocurrency to facilitate incentivization and monetization of all stakeholders involved in the electric car sharing. Although this current study mainly developed the decentralized prototype framework, future work aims to further implement the decentralized prototype to enable electric car sharing based on IOTA technology as the backbone of the distributed mobility service. Besides, only secondary data from the literature was employed no data was collected from participants. Thus, primary data will be collected using open ended interview and focus group workshop to get functional requirements needs to improve the decentralized prototype framework. Lastly, AI techniques will be employed to optimize the EV fleet allocation based on the electric car sharing demand/sharing location, prediction to be computed by analyzing electric car sharing driving pattern within and across cities using geolocation data and prior travel data to improve decentralized electric car sharing services provided to all stakeholders involved the ecosystem.

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