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Developing a decentralized community of practice-based model for on-demand electric car-pooling towards sustainable shared mobility

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ABSTRACT

Presently, majority of car-pooling services depend on a central third party which makes these platforms susceptible to data privacy, security concerns, and a single point of failure. Moreover, drivers and passengers are charged with different services fees by the electric mobility service provider. The emergence of emerging technologies such as Distributed Ledger Technologies (DLT) can foster trust, boost electric car-pooling business models. Hence, DLT is utilized to store electric car-pooling trips, drivers, and passengers' information to ensure user privacy and maintain security. Similarly, social practice theories such as Community of Practice (CoP) is progressively considered as a significant structure within societies as it aids the development and sharing of resources across groups. But very little attention has been devoted to examined how CoP can be employed to support the design of decentralized on-demand electric car-pooling. Leveraging CoP and DLT, this paper proposes a decentralized community of practice-based model that enables drivers to publish electric car-pooling services and passengers to be matched to a driver without depending on a trusted third party. A systematic literature review was adopted to collect data and a case study of a decentralized on-demand electric car-pooling was presented. Findings from this study highlights conceptualization of CoP for improving decentralized on-demand electric car-pooling and provide insights on efficient decentralized mechanisms for electric car-pooling. Theoretically, this article identifies the current problems, state-of-the-art of decentralized electric car-pooling. For policy implications this study provides guidelines to effectively govern and manage the development of on-demand electric car-pooling for sustainable public transportation.

1. Introduction

In 2016 greenhouse gas emission recorded from the transportation sector was about 25gt and is anticipated to increase by 2050 (Khanji and Assaf, 2019). At the moment, the emergence of new organizational and economic activities has resulted to emergent business models such as the "sharing economy" which is rapidly gaining popularity (Baza et al., 2020). Moreover, with the development of the sharing economy, electric car-pooling is gradually becoming an important mode of travel. Electric car-pooling has been rapidly adopted by satisfying users' personalized mobility needs at a reduce cost and has become one of the best alternatives used by travelers for sustainable shared mobility (Wan et al., 2022). Electric car-pooling is a promising and sustainable mobility approach that can require matching of one passenger to one driver (one-to-one) or multiple passengers to a driver (many-to-one) to an electric car based on real-time data (Meshkani and Farooq, 2022). By increasing the occupancy number of private vehicle; electric car-pooling can reduce the number of vehicles resulting to immense societal impact with regards to congestion, pollution, decrease use of parking slots, and energy consumption (Li et al., 2020a).

Despite the aforementioned benefits existing electric car-pooling platforms brings privacy and security concerns, particularly in the aspect of establishing transparent pricing and trust (Zhang et al., 2019). In particular, passengers and drivers are normally different individuals without any trust. There is need to ensure safety to safeguard the well-being of individuals using electric car-pooling. Although techniques such as PIN system, passcode, etc. are being employed by companies such as Uber to ensure safety, these techniques are exclusive employed on centralized platform, making them not well fitted to ensure safety across the entire electric car-pooling ecosystem (Khanji and Assaf, 2019; Zhang et al., 2019; Li et al., 2020b). Furthermore, it is demanding to provide a broad identity verification platform whilst also respecting the

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privacy of untrusted individuals (Huang et al., 2022). Thus, the problem of privacy-preserving and identity verification in electric car-pooling platforms is of utmost interest and an approach is required to enable a decentralized and universal identity verification (Luo et al., 2018; Li et al., 2020b).

Recently, Distributed Ledger Technologies (DLT) has been suggested as a plausible enabler for sharing economies, such as in electric car-pooling systems (Li et al., 2020b; Bokolo, 2022). DLT employs a decentralized append-only ledger, where all data within the system is stored and accessed by network peers (Shivers et al., 2021). Furthermore, the term Community of Practice (CoP) has evolved to involve a group of individuals who share a passion or a concern for something they carry out and learn how to do it better as they collaborate regularly (Lave and Wenger, 1991; Wenger, 2011). CoP is progressively considered as a significant structure within organizations as it aids the development and sharing of practices and knowledge across groups (Winsor et al., 2003). In relation to the study area of on-demand electric car-pooling the passengers and drivers involved in CoP share a mutual interest in adopting EV sharing towards social, economic, and environmental benefits. But very little attention has been devoted to examined how CoP can be employed to support the design of decentralized on-demand electric car-pooling (Julsrud and Standal, 2022). Therefore, this article aims to investigate the following research questions.

- How can CoP support the design of decentralized on-demand electric car-pooling model?
- How to achieve a transparent pricing among individuals involved in decentralized on-demand electric car-pooling?
- How to ensure privacy and security of individuals in decentralized on-demand electric car-pooling?

To address the above research questions, a systematic literature review was adopted to examine how to design a decentralized on-demand model grounded on CoP and DLT. This study contributes to the literature by exploring how emerging technologies such as permissioned DLTs (e.g Hyperledger Fabric) and smart contracts can transform on-demand electric car-pooling to promote sustainable shared mobility. Evidence from this study provides a reference model for developing a decentralized electric car-pooling platform for safe and secure connection of passengers and drivers. In addition, this study contributes by proposing an approach to supplement the current stream of studies related to electric car-pooling enabled by decentralized technologies and CoP as parts of social practices. The rest of this article is structured as follows. Section 2 review relevant literature. Section 3 introduces the methodology. Section 4 presents the findings and Section 5 is the discussions and implications. Finally, Section 6 concludes the study.

2. Literature review

The adoption of car-pooling and sharing platforms have recently gained popularity as a convenient substitute to conventional modes of mobility (Shivers et al., 2021). As such a few studies have published in the study area, among these studies Baratella (2022) developed a decentralized Algorand smart contracts based car-pooling application. Kumar et al. (2021) presented a decentralized ride sharing blockchain based platform deployed in Ethereum DLT to ensures fairness in ride sharing system. Another study by Shivers et al. (2021) designed a framework for implementing a decentralized verifiably secure ride-hailing architecture. Additionally, Wang and Zhang (2020) developed a secure ride-sharing solution based on a consortium blockchain to address the security threats. Kudva et al. (2020) designed an efficient ride hailing service based practical Ethereum blockchain to keep track of car data. Khanji and Assaf (2019) researched how to improve the efficiency ridesharing using blockchain. Li et al., (2020b) presented a blockchain-based identity authentication for safe ridesharing using zero-knowledge proof.

Furthermore, Postorino and Sarné (2019) conducted a preliminary study that employed agents with blockchain to design a framework which supports dynamic car-pooling. Zondab and Meddeb (2020) designed a blockchain based architecture supported by proxy re-encryption scheme integrated within smart contracts to provide a fast, efficient, and secure application. Li et al. (2019) presented an efficient privacy-based carpooling system using blockchain and vehicular fog computing to proficiently establish a private communication key between a driver and a passenger. Kalczynski and Miklas-Kalczynska (2019) proposed a decentralized approach for addressing carpooling problem. Evidently, car-pooling and sharing services have attracted a lot of attention in the literature as digital platforms transforms the society to become greener and more sustainable (Baza et al., 2020). However, there are fewer studies that have examined decentralized electric car-pooling. Therefore, this study explores how to design a decentralized on-demand electric car-pooling model based on the community of practice and DLT by focusing on ensuring privacy and security of individuals participating in decentralized on-demand electric car-pooling and providing a transparent pricing, safe, and privacy scheme among drivers and passengers.

3. Methodology

A Systematic Literature Review (SLR) is employed in this study as a methodological approach. A SLR method helps researchers to actualize a high-level synopsis of knowledge in a particular research domain (Cook et al., 1997; Kitchenham and Charters, 2007). A SLR means adopting a transparent, scientific, and replicable detailed process that reduces bias (Mitropoulos et al., 2021), through an extensive literature search of scientific studies (Chandler and Hopewell, 2013; Anthony Jnr, 2022a). The SLR methodological approach adopted in this research comprises of six phases as shown in Fig. 1. Fig. 1 depicts the SLR methodological approach employed in this study. Each of these phases are briefly described below.

3.1. Specification of research objectives and questions

The research objectives of this study are mainly to examined how community of practice and distributed ledger technologies can be employed to support the design of decentralized on-demand electric car-pooling. Accordingly, this article aims to propose a decentralize electric car-pooling services that enables drivers to publish electric car-pooling

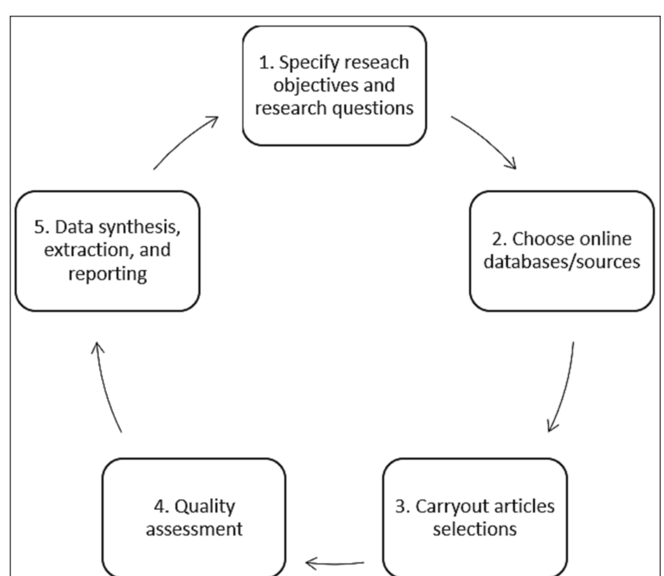

Fig. 1. Employed SLR methodological approach.

services without depending on a trusted third party. The research questions are presented in the introduction section to guide the study.

3.2. Online Databases/Sources

The online databases are used to collect scientific material and primary studies using search keywords. The relevant scientific material and primary studies are collected based on the research objectives and research requestions. The search was conducted in August 2022 and later in March 2023 on keywords from the selected scientific libraries (Science Direct, ACM, emeraldinsight, Inderscience, Sage, Taylor & Francis, Google Scholar, Wiley online library, Worldscientific, IEEE Xplore, Proquest, and Springer). To carry out the search several keywords were constructed into search strings for the searches: *"car-pooling" or "electric car-pooling" or "decentralized electric car-pooling" or "blockchain based electric car-pooling" or "electric vehicle-pooling" and "EV-pooling *"and "electric car pooling*", and "road transportation" or "sustainable" and "smart car-pooling *" and "sustainable car-pooling*" and "distributed ledger technologies*" or "DLT" and "community of practice*" and "community of practice model*" or "community of practice framework" and "community of practice theory*"*. The SLR employed in this study focuses more on sources published in English language and also published in academic journals, conference proceedings, chapters of books, dissertations, thesis, and technical reports. 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 electric car-pooling service explored from the lens of *CoP and DLT*, and further provided discussion to expand and future development in sustainable shared mobility.

3.3. Article selection

In this phase the searched publications were checked to exclude potential duplicates and publications that were not related to electric car-pooling, such as publications focusing on micro mobilities, electric bicycle sharing, etc. The overall selection process is shown in Fig. 2 below.

As seen Fig. 2 a total of 131 articles were retrieved from the aforementioned online databases. After which a duplicate check was carried out and 41 sources were excluded resulting to 90 sources. Then 22 sources were excluded based on the title not fully aligned to CoP, DLT, and electric car-pooling, resulting to 68 sources. Next, 13 sources were removed due to the abstract not fully discussing electric car-pooling concepts and approaches. Additionally, 7 sources were deleted as the content of the document was not well positioned to address issues related to electric car-pooling. Lastly 48 articles well aligned to the research domain and further 22 articles (related to prior car-pooling studies, CoP, and SLR), were added via snowballing and cross references to strengthen the literature resulting to a total of 70 sources.

3.4. Quality assessment

To ensure that all selected sources included in this study are based on a quality assessment criterion is employed to assess the quality of selected sources. As this study examines decentralized on-demand electric car-pooling a quality assessment was performed on all selected sources based on the content of the included source in relation to the research questions. The quality assessment was applied to evaluate the title, abstracts, and contents of all selected 70 sources. Additionally, most of the included sources are journal articles and conference proceedings indexed in Scopus and/or Web of Science databases.

4. Findings

The synthesized and extracted data from the selected sources were analyzed employing content analysis to provide answers to research questions been examined and provide understanding on the overall concept of CoP and DLT for decentralized on-demand electric car-pooling towards sustainable public transportation. The findings are discussed in this section.

4.1. Background of electric car-pooling

Over the years car-pooling solutions such as UberPool, Flinc, Blablacar, Lyft Line, etc. (Baza et al., 2020), have emerged have received much attention over the years as an efficient method for increasing community access to mobility using existing transport infrastructure (Li et al., 2020b). These car-pooling solutions offer a centralized platforms for collaborative rider sharing between passengers and drivers (Shivers, 2019). Meanwhile, mobility service providers aimed to improve sustainable use of EVs to decrease ride costs when individuals are willing to share their ride trips with other users (Li et al., 2020a). As such car-pooling have emerged as an alternative mobility service that supports individuals to share cars cost-effectively (Baza et al., 2020). Therefore, car-pooling has coincided with the current push to incorporate sustainable transportation and has now developed as electric car-pooling due to the proliferation of electric cars in the society to address climatic changes and global warming towards a sustainable society (Anthony Jnr, 2021a).

The adoption of electric car-pooling has recently gained acceptance as a sustainable alternative to traditional modes of travel within and across cities (Anthony and Petersen, 2020; Meshkani and Farooq, 2022). In recent years electric car-pooling has come to the forefront as a green mobility service in cities across the world (Alyavina et al., 2020; Anthony Jnr, 2020), and is another sharing model being adopted to

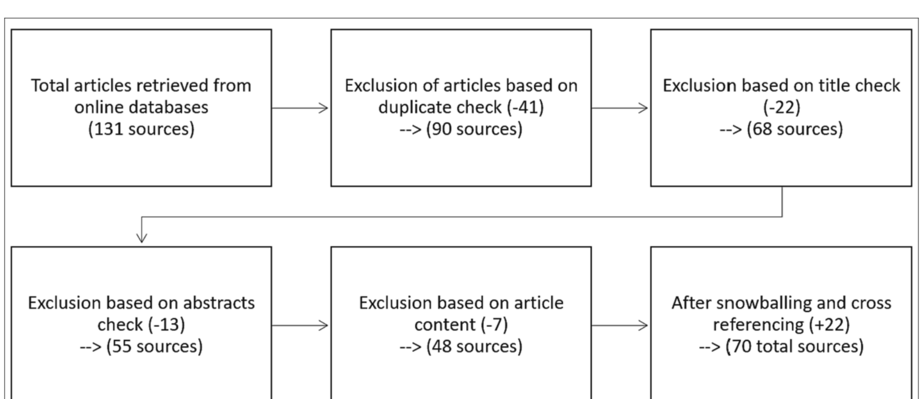

Fig. 2. Sources selection process for the study.

improve public transportation. Electric car-pooling is a mobility service that supports drivers to share their journeys with other riders as passengers, decreasing traffic congestion amidst rush hours, aids the shortage of taxis, and assist in decreasing Carbon Dioxide (CO_2) emission (Khanji and Assaf, 2019; Terrier and Audrin, 2022). Electric car-pooling offers an essential mean to promote environmental responsibility when operated in large communities such as in governmental institutions and universities (Bokolo et al., 2022). Electric car-pooling offers a promising solution for municipalities with poor public transportation and is suitable when fuel expenses are high (Khanji and Assaf, 2019; Mou et al., 2020).

Electric car-pooling is valuable for municipalities that are faced with increased emission, congestion, and traffic jams particularly in areas with inadequate public transportation infrastructure and high fuel expenses (Wan et al., 2022). Electric car-pooling offers a personalized environmentally friendly transportation service where drivers provide accessible electric car rides to passengers by responding to a ride-pooling service provider or a road-side request. Electric car-pooling service offers a typical two-sided demand-and-supply market scheme, which enables passengers and drivers to conveniently establish ride sharing model via digital platforms (Kudva et al., 2020). However, it is crucial to consider a security, privacy, and transparent pricing mechanism to encourage community involvement to use electric car-pooling as per some might be reluctant toward cost, security issues and user privacy (Khanji and Assaf, 2019; Zhang et al., 2019).

4.2. Ride-matching for electric car-pooling

In an electric car-pooling a driver shares his available car seats with other individuals who are traveling in similar direction contributing to sharing travel costs, increasing occupancy rates in EVs, extending social circles, decreasing road traffic, and reducing air pollution (Baza et al., 2020). Ride-matching for electric car-pooling is similar to dial-a-ride problem where an operator finds an EV from the available pooling based on a ride request. Among others there are one-to-one ride-matching service and many-to-one dynamic ride-matching, where one EV can simultaneously serve multiple passengers (Li et al., 2020a). Presently prior studies have examined one-to-one matching problem where a single driver/EV is matched with a single passenger. Other research focused on the many-to-one "dynamic ride-matching" where a single EV/driver serves multiple passengers (Meshkani and Farooq, 2022). Dynamic ride-matching is a mobility service that connects passengers and drivers with similar travel itineraries and date/time schedules in order to split the total travel costs. In dynamic ride-matching the passengers and drivers are matched in real-time (Meshkani and Farooq, 2022).

The electric mobility (eMobility) service provider matches ride demand and available supply based on the information provided by individuals (passengers and drivers) (Li et al., 2020a). Based on the ride matching the passenger selects the nearest driver (Yu et al., 2020). Relevant meta data of the potential drivers is sent to the successfully matched passenger and the passenger's travel plan are sent to the matched drivers, thus facilitating the drivers to provide the passenger(s) with electric car-pooling services (Wang et al., 2020; Ghosh et al., 2022). The ride matching process enable passengers and drivers with similar trips to share one electric car (Yu et al., 2020). In a scenario when they are more than one rider willing to share the same electric vehicle. The eMobility service provider performs group ridesharing matching to choose the most appropriate driver who has the least aggregate distance to the passengers' locations. For example, two passengers *{passenger 1, passenger 2}* want to car-pool to visit different destination. To execute car-pooling, each passenger submits their respective request to the electric car-pooling service provider which will orchestrate the electric car-pooling matching to determine the nearest driver *{driver 1, driver 2, driver n..}* for the passengers (Yu et al., 2020), as shown in Fig. 3.

An electric car-pooling solution strives to match passengers with

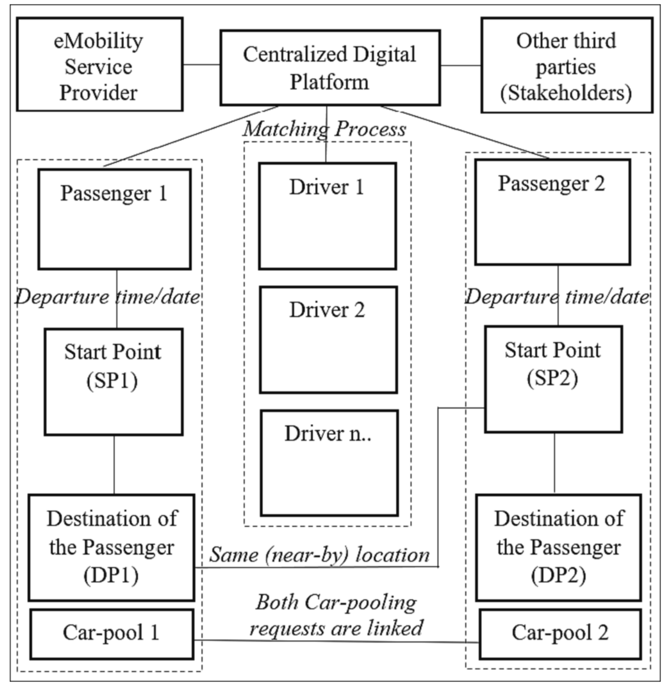

Fig. 3. A typical car-pooling case scenario for drivers and passengers.

appropriate drivers according to their respective ride requests (desired trips) and ride offers (planned trips). To enable an electric car-pooling solution, individuals (i.e., drivers and passengers) have to share with an eMobility service provider the journey detail information, including departure date, time and proposed start location, and possible end destination. The eMobility service provider works as an intermediary to support the communication between the driver and passenger and usually charges a commission fee for each successful ride-pooling (Baza et al., 2020; Ng and Phung, 2021). In an electric car-pooling case scenario, drivers and passengers publish their travel plan (e.g., *departure time, departure date, journey starting point, and possible destination*) on a centralized digital platform. Accordingly, an eMobility service provider can link a driver already taking a passenger to another passenger around the journey path taken by the driver (Li et al., 2020a), as shown in Fig. 3. Moreover, other third parties or stakeholders can be connected to the centralized digital platform such as the insurance company, government regulators, charging point providers, etc.

Accordingly, Fig. 3 depicts a typical car-pooling case scenario involving passengers, drivers, third parties, and eMobility service provider involved in matching rides for electric car-pooling using centralized digital platforms. As suggested by (Li et al., 2020a) (as showed in Fig. 3), "*Driver 1*" is transporting a passenger "*Passenger 1*" from the start point *(SP1)* to the destination of the passenger (*DP1*). Similarly, a different passenger "*Passenger 2*" is requesting for a ride from the eMobility service provider with start point (*SP2*), which coincides with the end point of "*Passenger 1*" or near the location where "*Passenger 1*" gets off. Thus, the start point of "*Passenger 2*" is just the endpoint of "*Passenger 1*". As such the eMobility service provider links the current "*car-pool 1*" (*Passenger 1*) to the future "*car-pool 2*" (*Passenger 2*) prior to the end of "*travel 1*" if there are no available drivers (*driver n..), within* the vicinity or planning to go or around the start point/location of "*Passenger 2*" (*SP2*). However, the current platforms employed to facilitate electric car-pooling is based on a centralized architecture which is faced with several issues due to incomplete contracts and asymmetric information, unsecured data, and users' privacy challenge (Wan et al., 2022).

Furthermore, one-to-one ride-matching service and many-to-one dynamic ride-matching for electric car-pooling is faced with privacy issues (Li et al., 2018). Therefore, to protect the location privacy, passengers send masked electric car requests to hide their precise pick-up/drop-off positions, and departure/arrival time and date(s). Also, an off-line matching technique is employed, and drivers sends their prospective journey offers which is encrypted to guarantee data confidentiality (Li et al., 2020a). After the driver publishes prospective ride-offers, the passengers can find a trip match supported by a matching algorithm which computes the price included in the ride offer. However, most of these electric car-pooling matching services are based on centralized architecture and is managed by a third party (Shaaban and Maher, 2020). This has resulted to data privacy and trust being one of main concerns in centralized based system. Besides, previous research did not consider how to ensure fair and transparent payment, although approaches such as pay-as-you-drive has been employed which is based on the distance travelled by driver(s) and passengers (Zhang et al., 2019).

4.3. Adoption of "Community of practice Theory" for electric car-pooling

Lave and Wenger (1991) first proposed the theory of a Community of Practice (CoP) in 1991, where they defined a CoP as a set of relations among individuals, activity, and domain. CoP involves group of people collaborating towards achieving specific goals through the sharing, usage, and leveraging of resources. These individuals may be from different backgrounds, but they cooperate towards achieving the same goal(s) via physical or digital means (du Plessis, 2008). In a CoP, groups of users who share a passion for something that they know how to do such as "sustainable mobility initiatives", interact repeatedly to do it better (Kimble et al., 2001; Ardichvili, 2008). CoP also acts as a catalyst for innovation within the society (du Plessis, 2008). As such the concept of CoP has been employed in practical applications such as in organizational design, business, education, government, professional associations, civic life, and development projects (Probst and Borzillo, 2008; Wenger, 2011).

Wenger (2004) described CoP as first comprising of individuals who interact with one another, towards establishing relationships and norms via mutual engagement. The author further highlighted that these individuals are linked based on an understanding of a sense of joint participation (as in electric car-pooling). Finally, the author stated that over time, the individuals produce a shared use of communal resources (shared EVs). As highlighted in the literature (Kimble et al., 2001), in the context of this study CoPs happen in a three-stage process. First the distributed CoP develops from an initial informal contact involving individuals (drivers, passengers, eMobility service providers, etc.), or from a legitimate grouping. It then develops into a CoP because of the way the individuals interact and travel together within and across cities. Secondly, it may involve developing links with individuals in other locations who are interested in similar shared mobility initiatives. These individuals may also be participants of other CoPs. Lastly, the developing CoP may then connect with a similar cluster possibly in a nearby country to promote cross county electric car-pooling, for example electric car-polling between nearby municipalities in Norway and Sweden. Overall, CoP comprises of three main elements as shown in Fig. 4.

Fig. 4 depicts the main CoP elements which characterized the community involvement in any societal or institutional issue (Guo and Lei, 2020). The "*domain*" involves the knowledge area that brings the community together such as sustainable shared mobility. The domain gives the community an identity (Wenger, 2004), as it defines the main issues that individuals need to address such as issues related to fair pricing, security, and privacy during electric car-pooling. Next the "*community*" involves the group of people (drivers, passengers, eMobility service providers, other stakeholders), for whom the domain is relevant (Wenger, 2004). The community also involves the democratic interactions among individuals. Lastly, the "*practice*" involves the methods or tools employed by the participants within the community (Wenger, 2004), to carry out the electric car-pooling. *The combination of domain, community, and practice is what fosters communities of practice across the society*. Thus, cultivating CoP requires considering all three elements (Wenger, 2004). The type of chosen CoP and how it functions is very specifically influenced by the domain and the specific environment where the individuals participate. It is nor static in nature, but mostly evolves over time if the business strategy changes (du Plessis, 2008).

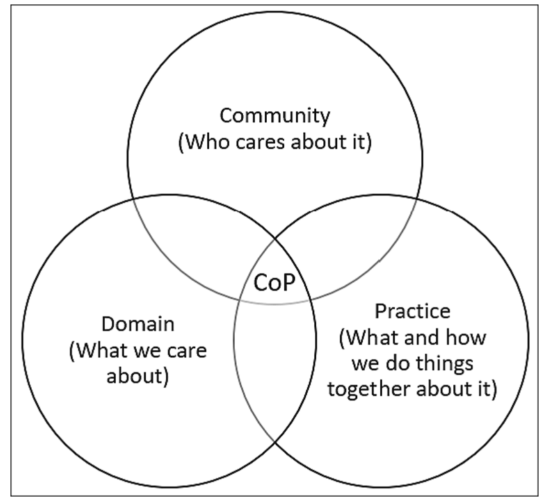

Fig. 4. Community of practice elements ().
adapted from Wenger, 2004

Despite the proliferation of CoPs in enterprise and institutional domains, very little is known about how CoP and DLT can be employed to facilitate decentralized on-demand electric car-pooling service. Drawing on the theoretical concepts CoP and DLT this study develops a model to explore the participation of individuals in the adoption of decentralized on-demand electric car-pooling. As the participation of individuals does not develop immediately instead it require community participation, trust, mutual engagement, etc. In today's digital society another question is whether it is plausible to gain legitimacy in an electric car-pooling community and perhaps the most challenging area is how to facilitate citizens participation (Kimble et al., 2001). As citizens participation is fundamental to the evolution of such electric car-pooling community. It is important to provide digital technologies that can help to build trust, security, privacy, and fairness. Hence this study advocates for the deployment of DLT with CoP as enabler to achieve a "*decentralized community of practice*" based electric car-pooling service.

4.4. DLT for electric car-pooling

Distributed Ledger Technologies (DLT) was first proposed in 2008 when Satoshi Nakamoto published a report on a peer-to-peer online cash platform known as Bitcoin. Ever since, the model of peer-to-peer cash schemes has been developed in many adaptations and its fundamental technology demonstrated favorable uses outside the original goal (Kudva et al., 2020). Due to its distinctive technological advantages, DLT has been extensively adopted by scholars and industry across different domains such as in smart cities, public administration, health care, energy trading, and sharing economy (Wan et al., 2022). Several vital industrial players envisioned employing DLT into practical use cases such as EV sharing scenarios where electric car-pooling can be effectively developed on top of DLT (Ferreira et al., 2021; Moschella et al., 2021). DLT is particularly useful in societal and corporate circumstances that involve multiple individuals which do not certainly trust one another to negotiate and perform business transactions digitally (Lu et al., 2021). As a disruptive technology it is known for its immutability, consistency, transparency, security, decentralized nature of data (Joseph et al., 2021). DLT utilizes cryptography to encrypt data to prevent information from being tampered with and forged to ensure openness, credibility, security, transparency, traceability, and tamper proof of data (Wang et al., 2020; Wan et al., 2022).

In a nutshell DLT is a suitable choice for decentralized electric car-pooling due to its fault tolerance and immutability (Anthony Jnr, 2021b; Bokolo, 2022). DLT can facilitate the availability and correct execution of decentralized electric car-pooling without any single entity or authority using smart contracts (Kudva et al., 2020). The adoption of DLT can help with either one-to-one ride-matching service or many-to-one dynamic ride-matching and would allow owners of EVs to add their electric car to a community driven EV fleet when not in use (Lu et al., 2021). Considering data access and management of transaction, DLT can be categorized as *private, public, and consortium*. The "*private DLT*" is governed by a single organization or user, the data management permission is strictly governed by the creator, and the read permission is not completely open to the public. In a "*public DLT*" all network miners partake in the consensus determination process and the distributed ledger is absolutely visible to all participants. In a "*consortium DLT*" only trusted network nodes can take part in the validation of data or transactions and these trusted network nodes are not specified by a single entity or organization (Shivers, 2019). Accordingly, this study proposes to employ a consortium DLT to develop a decentralized on-demand electric car-pooling model as DLT is particularly useful in administrative and governance situations that include multiple distrustful users to support digital business transactions. Consortium DLTs that can be employed for electric car-pooling is discussed below.

4.4.1. The Ethereum DLT

Ethereum is a consortium blockchain that enables users and businesses to develop and implement their own decentralized applications (dApps) (Anthony Jnr, 2022b¸ Choi, and Shi, 2022). Users can create their own Ethereum account (@ https://ethereum.org/en/), which is assigned with a specified address (Kudva et al., 2020). The computational transaction in Ethereum is made in *"Gas price"* which helps to calculate the cost connected with each transaction (Baza et al., 2020; Kudva et al., 2020). All transactions executed in the smart contracts is based on a fixed cost. For example, the addition of two variables involves *"3 gas"*, whereas multiplication costs *"5 gas"* and computation involving a *SHA3* hash needs about *"30 gas"* in addition to *"6 gas"* for each *256 bits* of input (Baza et al., 2020). Cryptocurrency is a word given to the digital form of money. Cryptocurrency offers a decentralized digital monetary asset which utilizes cryptography to ensure secure transactions or exchange. The cost is payable applying the native Ethereum cryptocurrency named Ether (Baza et al., 2020). When individuals create new Ethereum accounts they load ethers to execute transactions (Kudva et al., 2020). Ethereum further provides a programming language called solidity which enables users to develop dApps and smart contracts (Kumar et al., 2021). To deploy car sharing and haling Ethereum DLT has been previously employed in the literature (Khanji and Assaf, 2019; Baza et al., 2020; Kudva et al., 2020; Kumar et al., 2021).

4.4.2. Hyperledger DLT

The Hyperledger is a consortium blockchain based permitted network which utilizes the decentralized network's historian record to guarantee that a saved transaction cannot be modified by just user (Covarrubias, 2021; Shivers et al., 2021). Thus, Hyperledger is a fully permissioned distributed ledger designed for operations involving confidential and sensitive data (Shivers et al., 2021). Hyperledger offers a private and access controlled DLT to be used by a private person or enterprise. As such the data stored within the Hyperledger cannot be read by everyone. It is restricted to the specific organization or group and the data access can be constrained via the Hyperledger's access control functionality. Hyperledger is mostly adopted as no transaction fee is needed for transactions to be carried out. Likewise, Hyperledger Fabric allows queries to be executed analogous to a regular database (Hossan et al., 2021). Hyperledger Fabric aids multiple channels in a single network, where each channel maintains an absolutely different ledger from the other channels within the network and this is utilized for data segregation (Shivers, 2019).

In Hyperledger Fabric, network nodes must be verified before they can participate within the distributed network. However, the network nodes are not essentially owned by one person. Hyperledger Fabric is compatible with smart contracts (termed as "chaincode"), that can be coded in any programming language which specifies all permissible interactions within the distributed network. Each individual chaincode function has its own access to govern the functionalities such that only some users or peers can execute it. When chaincode is deployed on a peer it turns into an "endorsing peer" and an endorsing peer can confirm transactions it returns an "endorsement" to the invoking participant which comprises the endorsing peers' cryptographic signature to reduce falsification. Overall, a participant must obtain the lowest possible number of endorsements (stipulated during chaincode implementation) before submission to the "ordering service" (Shivers et al., 2021). To deploy car sharing and haling Hyperledger Fabric has been employed in the literature (Shivers, 2019; Li et al., 2020b; Hossan et al., 2021; Shahbazi and Byun, 2022), and Hyperledger Indy (https://www.hyperledger.org/use/hyperledger-indy), and Hyperledger Fabric (https://www.hyperledger.org/use/fabric), was applied by Lu et al. (2021).

4.4.3. Smart contracts for electric car-pooling

During the 90 s, smart contracts was first developed by N. Szabo, created from the notion that a legal technological framework can support commerce to resolve disputes and reduce costs (Lu et al., 2021). Researchers such as (Baza et al., 2020) defined smart contracts as autonomous computer programs running on a distributed ledger network. Smart contracts are pre-defined program code aid individuals to define and deploy contracts within the DLT (Anthony Jnr, 2022c), thereby managing data storage, access, and governance (Wang et al., 2020; Lu et al., 2021). The program code manages the contractual logic clauses involving multiple parties and pre-states the trigger conditions and response procedures, when certain conditions are met (Kanza and Safra, 2018). Smart contracts are tamper-proof and immutable, and consequently no users can change the code or functionality with their implementation without the consent of all node users within the distributed network (Baza et al., 2020). The implementation of the functions within smart contracts can be seen as contractual constraints employed on the DLT that act as a binding agreement, and can execute or receive transactions (Kudva et al., 2020).

Smart contracts are intended to digitally verify and enforce the implementation of a contract, without requiring a third party or an intermediary (Kanza and Safra, 2018; Baza et al., 2020). The development of smart contracts is implemented using a Turing-complete scripting language so-called Solidity, after which the smart contracts are compiled into the DLT such as the Ethereum Virtual Machine (EVM) byte code to be deployed within the DLT (Kudva et al., 2020). In regard to electric car-pooling, via smart contracts DLTs such as Ethereum, Hyperledger, etc. employs a distributed auction for matching drivers and passengers to ensures transparency for all stakeholders (Shivers, 2019). Overall, the deployment of DLT in electric car-pooling can result to radical changes in terms of trust, security, and privacy. In centralized platforms electric car-pooling services, the privacy of the individuals may be compromised in achieving the availability of services. With the help of DLT the individual's data can be immutable and can be safely secured.

Also, centralized platforms are not fully reliable because if the server shuts down then the entire electric car-pooling will be offline, but in a Decentralized applications (dApps) driven by DLT there are no such issues as its distributed making it reliable and robust (Joseph et al., 2021). In a decentralized electric car-pooling approach, no particular corporation owns the data, has control over the data or can revoke access to the electric car-pooling service for particular users. Also, there is no single point of failure since the platform is managed by distributed network peers, and none of these users have a central role in the DLT platform. Besides, businesses that do not trust one another could collaborate through dApps (Kanza and Safra, 2018). Although researchers such as Khanji and Assaf (2019) advocated that regulatory framework should be a developed as rules that controls the use of DLT to guarantee the settling of disputes among individuals involved in car-pooling and sharing.

4.5. Proposed decentralized On-Demand electric Car-Pooling model

The decentralized on-demand electric car-pooling model is driven by the consortium and permissioned DLT (Hyperledger Fabric), which manages all car-pooling service transactions. This study opts for a permissioned DLT to support peer-to-peer (P2P) payments which allow the exchange of currencies between the different participants or stakeholders. Thus, Hyperledger Fabric, one of the most popular DLT platform which supports smart-contracts, was proposed in the developed decentralized on-demand electric car-pooling model (Baza et al., 2020). Hyperledger Fabric can also be mutually maintained by the eMobility service provider, drivers, passengers, government regulators and other stakeholders, meeting existing regulatory requirements and the needs of different actors (Wan et al., 2022). The proposed decentralized on-demand electric car-pooling model mainly involves two peers, the driver, and passenger(s). The passenger who is a rider can create requests for car-pool which is broadcasted within the dApps and is seen by all the nearby drivers, and the car-pool is confirmed if any of the drivers accepts to provide the ride. The fare is calculated by smart contracts before the trip based on specified parameters in a transparent way to the passenger(s) and driver before the start of the journey and at the end of the ride the fare amount is transferred to the digital wallet of the electric car (via standard currency or through token *FabToken*). The overall payment operations are handled by smart contracts running within the dApps (Kumar et al., 2021). The proposed decentralized community of practice based electric car-pooling service model is shown in Fig. 5.

Fig. 5 depicts the proposed decentralized community of practice based electric car-pooling service model. As outlined in the developed decentralized community of practice-based model (see Fig. 5), the development of community of electric car-pooling comes through users' engagement with emerging technology such as DLT (dApps) towards sustainable shared mobility. Overall, the main model components are discussed in Table 1.

4.5.1. Decentralized Car-Pooling matching process

To implement the decentralized car-pooling matching procedure, this study considers a set of car-pooling requests $CP = \{cp1, cp2, \ldots, cpn\}$ and a set of vehicles $EV = \{ev1, ev2, \ldots, evn\}$ with available seat capacity of "*totalseat*". The decentralized car-pooling matching procedure managed by smart contracts aims to assign passengers requests to electric car and finds linking driver schedules that aligns to the passengers planned schedule while satisfying some pre-defined constraints (Meshkani and Farooq, 2022). As such a car-pooling request is made by an individual who searches and request to car-pool to be picked up from a specified start location (*pickup*) and to be dropped off at a destination location (*dropoff*). In the decentralized car-pooling matching procedure, there may be more than one passenger assigned to a "*particular electric vehicle*" as seen in Fig. 6 captured as $ev \in EV$ is designated by *Pev*. An available electric car is an EV that has at least one available or free seat. Each available electric vehicle $ev \in EV$ can be allocated no more than its available free or idle seats that is denoted by *totalseat'ev*.

Each car-pooling request $cp \in CP$ comprises of a *car-pooling request-date "dcp"*, *car-pooling request-time "tcp"*, *Start Location "SL"*, and *Destination Location "DL"*. Furthermore, it is assumed that each car-pooling request *cp* provides a first departure time from the *Start Location "SL"*, and latest time the passenger would prefer to reach his/her destination location "DL". Also, there is car-pool time flexibility "*FlexTi*" which stipulates the difference between passenger's earliest departure time and the latest time he would like to "start the trip" $sti = IniTi + FlexTi$, where "*IniTi*" is the initially planned time entered into the dApps by the passenger specifying when the car-pooling supposed to start and is linked to the *Start Location "SL"* value.

4.5.2. Transparent pricing mechanisms

A decentralized matching mechanism is crucial to arrange the on-demand electric car-pooling. In reality, individuals generally form collaborative travel as a pair to share a car, as this decreases the complexity of reaching an agreement regarding who to join to travel and how the payment can be splitted. Prior research has investigated matching mechanisms in various domains, such as university admissions, social networks, job recruitment, etc. (Chau et al., 2020). But there is an issue related to sharing of cost in on-demand electric car-pooling scheme. The on-demand electric car-pooling service is a mostly based on an agreed cost-sharing mechanism for splitting the associated mobility costs among the individuals using electric car-

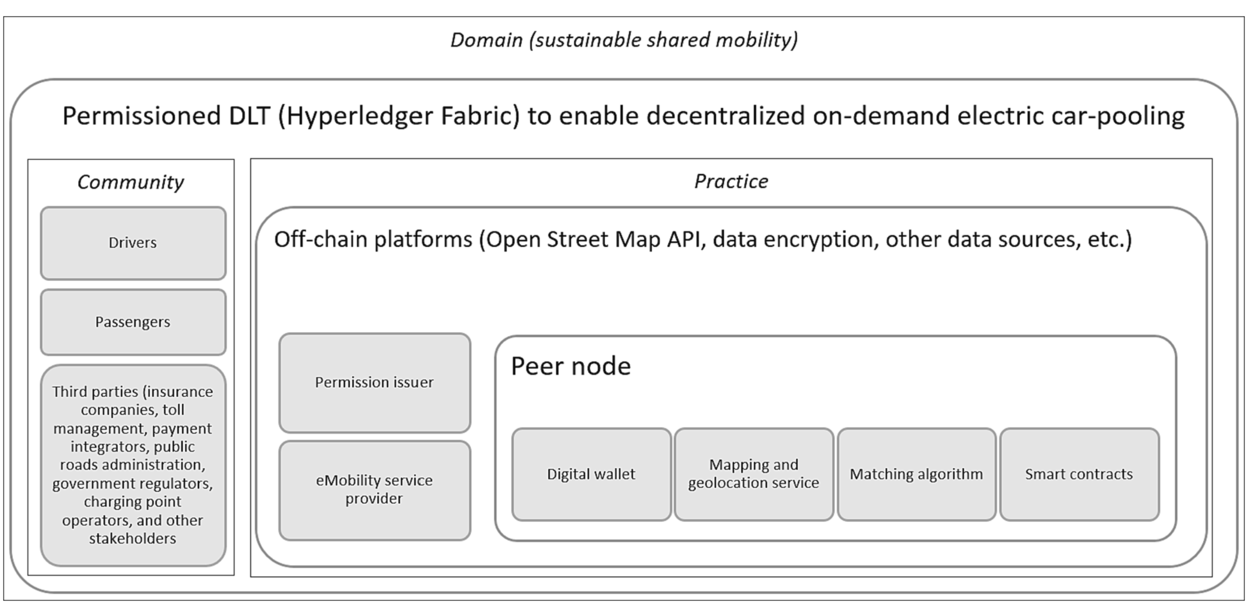

Fig. 5. Proposed decentralized community of practice-based model.

Table 1
Main components in the decentralized community of practice-based model.

#	Components	Description
1	Permissioned DLT	A permissioned DLT such as Hyperledger Fabric is suggested to be employed as the backend of the decentralized on-demand electric car-pooling model which serves as a tamperproof transactional ledger for saving trip information and proof records (Li et al., 2020b).
2	Peer node	This is the component that hosts the distributed ledger and smart contracts within the permissioned DLT platform. It also functions as the data verifier which integrates with off-chain platforms via Application Programming Interfaces (APIs) to authenticates drivers' identities for safety of passengers. In the proposed model, the peer nodes are implemented and maintained by a consortium of multiple eMobility service provider or businesses forming a decentralized network.
3	Smart contracts	As discussed in section 4.4.3, smart contracts help to manage the matching of passengers and drivers to ensure the deployment of decentralized on-demand electric car-pooling. It also supports transparent pricing (payment), among individuals involved in each trip based on distance or time based on how smart contracts was pre-defined.
4	Permission issuer	This is a trusted third party connected to the decentralized electric car-pooling network. They normally provide off-chain access to the permissioned DLT to enable digital identity management of information (e.g., verify validity of driver license number) via APIs as used in prior studies (Semenko and Saucez, 2019; Li et al., 2020b). In practice the permission issuer is thus data owners and data verifiers, and they can be or example Department of Motor Vehicles (DMV) in the USA, Norwegian Public Roads Administration, etc. can function as the permission issuer in the DLT network.
5	Drivers	This is an individual or commuter within decentralized electric car-pooling network who provides ride-sharing services to riders. The driver uses either his/her hand-held device to publish metadata of their travel itineraries, which include their departure time, date, place of departure, destination, available car seat, possible stops along the way, and their latest arrival time at the proposed destination. These data are encrypted and securely sent to the permissioned DLT and is managed by smart contracts.
6	Passengers	This is a commuter who wants accessible, affordable, and secure on-demand ride-sharing service, passengers use a handheld device to enter their planned travel information, which ranges from their proposed *departure location, their earliest and latest departure time, date, and preferred destination*. They also provide *the latest duration by which they must have reached their destination.* These data are encrypted and securely sent to the permissioned DLT and is managed by smart contracts. After which the passenger need only go to their location of departure and wait for the arrival of the driver (Wang et al., 2020).
7	eMobility service provider	This is the electric car company that provides EV fleets to be booked and used for electric-car polling. The eMobility service provider is responsible for managing the serving and operation of the EVs.
8	Off-chain platforms and other third parties	This involves external systems that connects to the permissioned DLT and other stakeholders that are involved in the decentralized on-demand electric car-pooling services.
9	Digital wallet and matching algorithm:	The digital wallet connects to smart contracts to manage payments and the matching algorithm aids for matching drivers to passengers to support decentralized on-demand electric car-pooling.

pooling. The optimal cost-sharing scheme is based on the fair distribution from the driver and passenger(s), where the driver and passenger(s) may not share the same *start location "SL"* and *destination location "DL"*.

A feasible fair cost-sharing method is to split the total mobility cost (which is based on time or distance travelled), equally between all individuals as suggested in the literature (Chau et al., 2020). This is to be computed by smart contracts automatically. Another plausible method is to divide the total mobility cost proportionally according to the original price of standalone trips. Also, smart contracts can be employed to split in a particular way to prompt equal savings from standalone trips (Chau et al., 2020). As the choices of cost-sharing methods will impact individual commuters' choice to partake in the electric car-pooling service. In this study the option of splitting the total mobility cost equally among all individual is preferable as its much lesser in comparison to the other methods to assigning the cost in relation to standalone trips which gives less economic gain to commuters.

4.5.3. Privacy and security in decentralized on-demand electric car-pooling

This study designs a DLT-based model to foster the adoption of electric car-pooling. The passenger who is a client within decentralized electric car-pooling network will wants to safely authenticate the identity of driver before the car-pooling trip starts. Therefore, the identity of a driver is validated via "*zero-knowledge proof protocol"* without disclosing the sensitive information to other individuals such as the passengers within the distributed network which maintains a distributed ledger for saving electric car-pooling trip information and proof records (Li et al., 2020b). Additionally, the passengers and drivers have complete autonomy, governance, access, and control of their data. The users of the decentralized on-demand electric car-pooling thus specifies the data access of his/her mobility related data (Anthony Jnr et al., 2020). Additionally, to ensure the data of the individuals who use the electric car-pooling are safe and secured. The information provided by the drivers and passengers are encrypted as ciphertext within the distributed ledger and is managed by the deployed DLT. "Ciphertext is an encrypted information converted from plaintext via an encryption algorithm. Ciphertext cannot be read except it has been decrypted or converted into plaintext (as metadata), with either a *public or private key*.".

In the *public-key* cryptography or as asymmetric key algorithm different keys are employed for encryption and decryption. Where, in the *private-key* cryptography or as called symmetric key algorithm a single key is utilized for encryption and decryption. The decryption cipher also is an algorithm that converts back the ciphertext into plaintext (*metadata*). This help to ensure security and privacy of both passengers and drivers' data. DLT then proceeds to execute ride matching supported by smart contracts which identifies if the driver's travel properties meet the requirements of any prospective passenger's travel request information. DLT then re-encrypts the passenger's private information to generate an associated ciphertext, which is sent to the possible matching driver as metadata of the passenger's ride request. Afterwards the driver receives the re-encrypted ciphertext, the driver decrypts it using his private of public key to acquire the passenger's proposed itinerary. Then during the electric car-pooling, the driver departs from his/her start location and picks up the passenger from the agreed point of departure, and then brings the passenger to the fixed destination of the passenger, which may be the same destination of the driver. If not after the driver drops off the passenger he/she proceeds to go to his/her destination (Wang et al., 2020).

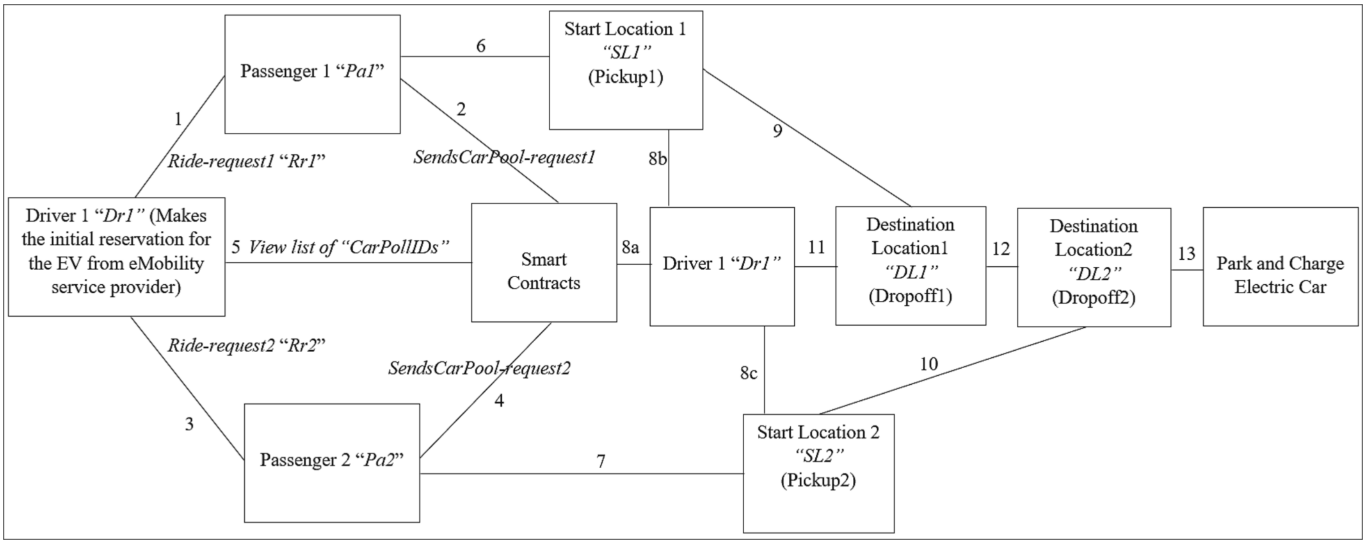

Fig. 6. Case study of a decentralized on-demand electric car-pooling.

4.5.4. Procedure calls to the employed in the model

One of the procedures calls in the proposed decentralized electric car-pooling model is the "register-user/unregister-user" where a new user profile is created in the permissioned DLT using new user object within the dApps using a unique *UserID* as the key and the method parameters for values. For user to register either as a driver and/or passenger. The individual first sign-up to the decentralized application. Amidst this step, the user can choose either passenger and/or driver as their profile category. For account registration for drivers a permission issuer is invoked by the permissioned DLT to verify the driver license through secured protocol via off-chain API. The permissioned DLT provides the driver "*Dr*" with a private keys *PRk*, public key *PUk*, and a unique id *UserId* from "cryptographic module" of permissioned DLT network server (Kudva et al., 2020), in a secure manner after a successful driver license verification.

For account registration for passengers, the user also signs up via the decentralized application using their handheld devices via a secure protocol. After registration the passenger "*Pa*" receives his/her own private keys *PRk*, public key *PUk*, and *UserId* from cryptographic module of the permissioned DLT. The passenger can use their digital identities such as *UserId* to access the decentralized application (Kudva et al., 2020). The values that are assigned to each user (*UserId*), are mostly the salt and hash of the passenger/driver's password and an array of trip structs which are filled when the passenger/driver provides or requests rides. Overall, the decentralized on-demand electric car-pooling service comprises of the following procedure calls managed by the permissioned DLT as seen in Table 2.

4.5.5. A case study of a decentralized on-demand electric car-pooling

A case study of typical decentralized on-demand electric car-pooling service is depicted in Fig. 6 where two passengers (*Pa1* and *Pa2*) request to car-pool from a particular driver *Dr1*. Fig. 6 depicts a case study of a decentralized on-demand electric car-pooling which comprises of two passengers and a driver. The numbers within Fig. 6 depicts the process flow involved in executing the decentralized on-demand electric car-pooling between the driver and two passengers. In the case study shown in Fig. 6 the driver first books for the electric car and make an announcement to provide electric car-pooling based on certain information. In this case study the driver *Dr1* who is willing to share an electric car first book for the EV based on a particular *date, time, start location, destination, and end location*. After confirmation the book of the EV he/she proceeds to provide option for car-pooling and then waits for any potential passengers based on the information provided within the distributed ledger network. The driver then gets notification for new car-pool requests. Then the driver proceeds to search by querying the permissioned DLT to view car-pooling requests from passengers and accept car-pooling requests (Shivers et al., 2021).

The passengers are then assigned to a ride-request-key within the smart contracts based on specific values assigned to the passenger *UserId (RideID, DriverID, Status, PickupLocation, DropoffLocation, PickupTime, DropoffTime, Co-PassengerID, Co-PassengerPickup-Location, Co-Passenger-Dropoff-Location)* (Shivers et al., 2021). In this case study the driver first picks up *Pa1* at a location before *Pa2's* is pickup possible at another location and *Pa2* is still in the electric car when *Pa1*'s gets off. This car-pooling process is reflected during the execution of transactions by smart contracts within the in the permissioned DLT (Hyperledger Fabric network) (Shivers et al., 2021). The travel itinerary information of all commuters *Pa1*, *Pa2*, and *Dr1* should show the pickup location for *Pa1* and *Pa2*, but not the dropping off location for the individuals based on the longitude and latitude using geolocation to ensure the privacy of the users are preserved. *Pa1*'s travel information *(departure location, their earliest and latest departure time, date, preferred destination, and latest duration by which they must have reached their destination)* is provided.

Additionally, similar travel information of *Pa2's* is provided by the passenger. The longitudes and latitudes for the locations provided by the passengers are identified via mapping service and geolocation service integrated to the permissioned DLT via API gotten from "*Open Street Map*" or pulls the location from the handheld device Global Positioning System (GPS). These locations are stored in longitude and latitude pairs within the permissioned DLT as a reference to be used by the driver. As seen in Fig. 6 when a driver arrives at *"Pa1"s* pickup position and starts moving to the destination another car-pool request is made by *"Pa2"*. The driver "*Dr1*"can either accept or reject the on-demand electric car-pooling. But, if the driver accepts the ride the smart contracts update the travel information. After the EV reaching *Pa2* for pickup, the information is also shown to *Pa1* so that the information can be later referred to from the *UserId*. Moreover, as seen in Fig. 6, *Pa1* was already in the EV when *Pa2* was pickup so this information must be accessible to *Pa1* to show transparency. The driver "*Dr1*" can access the passenger's pickup and drop-off locations information as he/she has access to all of this information during the car-pool session. Once the car-pool trip is over all users can only access data that is directly relevant to them (Shivers et al., 2021). Thus, the ride information about the car-pool will only be visible to the passengers and drivers who are part of the car-pool (Joseph et al., 2021). After the end of the car-pool the fee is calculated by smart contracts among the drivers and two passengers using two

Table 2
Procedure calls to the utilized in a decentralized on-demand electric car-pooling service.

#	Procedure Calls	Description
1	*UserAuthentication*	This phase aims to verify the category of the user if he/she is a driver or passenger. The smart contracts deployed in the permissioned DLT authenticates if the user address is valid. After successful verification, the users can start using the decentralized on-demand electric car-pooling service (Kudva et al., 2020).
2	*DriverStartsRide*	A driver is uniquely identified by his *UserId* within the distributed network. When the driver accesses the permissioned DLT (Kudva et al., 2020), smart contracts are deployed within the distributed network to collect some deposit from the driver's digital wallet to the digital wallet of the electric car (Jnr, 2023), either via standard currency or through token "FabToken" which is the cryptocurrency of Hyperledger Fabric.
3	*RequestRide*	This creates procedure to store the on-demand electric car-pooling ride that is being requested where data will be stored from the start to end of the journey. Each individual will retrieve the data relevant to them which is permanently stored within the distributed ledger at the end of the journey. From the passenger perspective who is requesting for the electric car-pooling. The passenger sends a request for electric car-pooling within the permissioned DLT creates a ride-request "*Rr*" enters start location "*SL*" and destination location "*DL*". Next, the total distance of travel "*TotalDis"* is computed by smart contracts to specify a transparent pricing. This procedure also needs to generate a passenger travel request event "*PT"* that will be received by the listening drivers waiting to accept and offer a ride to passengers (Kudva et al., 2020; Shivers et al., 2021).
4	*RideMatching*	When an electric car-pooling request is sent by a passenger "*Pa"* the smart contracts deployed within the permissioned DLT tries to execute one-to-many dynamic matching based on the start location "*Sl*" of the passenger(s) and returns a list of currently available driver "*Dr*" details (metadata). Drivers who are interested regularly execute query the system for requests from passengers (Kudva et al., 2020). The driver can then accept to car-pool sending their response and the ride range is calculated and made available via smart contracts based on per mile quote and the numbers of commuters.
5	*GetUserInfo*	This procedure is employed to retrieves the values (metadata), that are saved on users (drivers and passengers), based on their *UserId* values which is linked to the stored information provided during registration. The user can also use this procedure to view list of *CarPollIDs* associated he/she has been associated with and also to retrieve their forgotten password hash and salt based on their *UserId* and some secret questions set during registration (Shivers, 2019).
6	*GetLocation*	The mapping service and geolocation service are employed via an Application Programming Interface (API) for longitude and latitude gotten from Open Street Map (https://www.openstreetmap.org). The approximate latitude and longitude are used to obtain pickup and drop off locations via a visual map employed by the drivers to connects to events on the RequestRide procedure (Shivers et al., 2021).
7	*AcceptRide*	This procedure mainly updates the passenger request status once the driver accepts to provide electric car-pooling. It also provides metadata of the driver to the passenger and also invokes an event that will notify the requesting passenger when the driver is on route (Shivers et al., 2021).
8	*AssignRideDestination*	Involves specifying the ride destination coordinates based on the drop off location provided by the passenger once the confirmation has been received from the driver (Shivers et al., 2021).
9	*PickupPassenger*	This procedure is invoked when the driver arrives at the passenger's location. This helps to carryout checks to ensure the car-pooling is still continuing and the driver is at the right location and then an event is triggers in smart contracts to alert the passenger of the arrival of the driver (Shivers et al., 2021). This procedure enables the passenger to communicate with the matched driver who accepted the car-pooling for further follow-ups such as a detail pickup location and get off location (Kudva et al., 2020). During pickup, the passenger is changed an initial payment by smart contracts (Jnr, 2023).
10	*DropoffPassenger*	Once the driver arrives at the destination specified by the passenger, smart contracts create an event to notify the driver and passenger(s) that the ride is ending (Shivers et al., 2021). On ride completion, both driver and passenger(s) are automatically charged the complete fee by smart contracts in a transparent way (Kudva et al., 2020).
11	*ParkElectricCar*	After the passenger(s) are drop-off the driver proceeds to park the electric car to a designated parking and charging spot to be used by another user. This procedure triggers ends the car-pooling ride session.
12	*CancelCarPool*	In case the passenger does not want to car-pool with the driver and rejects the driver's acceptance smart contracts cancels the request. But, if the passenger accepts to car-pool with the driver smart contracts sends a confirmation message to the driver that is chosen by the passenger (Kudva et al., 2020). Likewise, if the driver later cancels the accepted car-pooling for some reason, he/she will be charged from the initial deposit which is to be transferred to passenger's digital wallet (Jnr, 2023).
13	*De-Registration*	As suggested in the literature (Lu et al., 2021) users can request to delete their profile in the system. If the user intends to delete his/her account to adhere to privacy policies such as General Data Protection Regulation (GDPR), the users will have to delete their key from the distributed ledger which is linked to the unique UserID associated with the user's information (Shivers et al., 2021; Jnr, 2023).

parameters such as the base price and a multiplying factor linked with the distance travelled (Joseph et al., 2021).

5. Discussion and implications

5.1. Discussion

According to the statistics from the United Nations about 68 per cent of the world's inhabitants will reside in urban areas by 2050. Such rapid increase in urbanization raises the demand for shared mobility (Bokolo et al., 2018). Thus, to simultaneously fulfill this demand and lessen the negative effects of transportation (e.g CO_2 emissions, road congestion, etc.), more sustainable shared mobility is needed to be adopted (Bokolo et al., 2022; Meshkani and Farooq, 2022). Recently, car-pooling systems, that are mostly based upon on-demand accessibility business model, allows passengers to book a shared vehicle with a few taps via their mobile application (Kudva et al., 2020). The adoption of car-pooling services has increased over the years, due to the promotion of share economy and the improved connectivity of users (i.e., passengers and drivers). Car-pooling services allow passengers and drivers to send ride requests and responses via user-friendly mobile applications and set up on-demand car-pooling conveniently (Li et al., 2019). As reported by Statista (2022), the user penetration of car-pooling and sharing services globally rose to 15.4 % in 2020 and is estimated to reached 20.0 % by 2023, and revenue in car-pooling and sharing services amounts to about $216,810 million in 2020. In electric car-pooling, a driver shares his/her vacant EV seats with other passengers.

The on-demand mobility market, including car-pooling and sharing, is becoming progressively important (Shivers et al., 2021). By increasing the use of existing electric vehicles and empty seats, electric car-pooling can offer many benefits including decreased traffic congestion and environmental impact as EVs produce zero emission (Anthony Jnr et al., 2020). As such electric car-pooling services are drawing much attention from both industry and academia. They have radically improved individuals' mobility experience by offering fast and convenient rides (Li et al., 2020a). Electric car-pooling has several advantages as it increases occupancy rates, sharing mobility costs, extending social circles, decreasing fuel consumption as EV are employed and reduce air pollution (Baza et al., 2019). Electric car-pooling allows commuters to come together spontaneously for transport cost sharing. This has become a common trend in the evolving paradigm of sharing economy. One essential component that support effective electric car-pooling is the employed matching mechanism that pairs up suitable passengers and drivers. Even though the existing electric car-pooling services have transformed the transportation sector in today's world, they are particularly centralized. In a centralized approach a dominant entity has all the control and manages data about the drivers and passengers. As such adoption of centralized approach raise concerns about data privacy policies. In such systems in case of data tampering or cyber security attacks, all the mobility data is either compromised or lost. Managing and maintaining of the central server is associated with hidden cost and is mostly vulnerable to distributed denial of service (DDoS) attacks. Besides, in centralized based platforms the service response time of queries from a remote cloud server will result to increased response delay caused by processing overhead and high bandwidth usage. This makes the centralized car-pooling systems questionable in terms of data integrity, flexibility, and stability (Kudva et al., 2020).

Also, there are fewer studies that examine how cost sharing can be implemented in a decentralized way to promote electric car-pooling in cities. This article develops a decentralized on-demand electric car-pooling model to serve as an architecture to connect the passengers directly with available drivers offering transparency between users without the involvement of any third-party in a cost-effective manner. A permissioned DLT (Hyperledger Fabric) and smart contracts are employed to manage transactions and provide extra layer of transparency and improve security and privacy for users. By employing community of practice theory, the model enables individual to participate in the decentralized on-demand electric car-pooling either as a driver, or a passenger based on his/her current needs. This also helps individuals to socialize and saves transportation related costs and at the same time care for the environment (Kumar et al., 2021).To this end, decentralized car-pooling matching procedure was employed in this study to manage the matching of driver with passengers willing to car-pool. This study employed the decentralized method as it has the ability to further reduce the operating cost with effective sharing of electric cars, while providing waiting and total travel time. The decentralized on-demand electric car-pooling service is more economical for individuals because the trip price is split among the passengers and driver making it more affordable it is less expensive than single passenger car-hailing trips or buying and maintaining an electric vehicle (Meshkani and Farooq, 2022).

CoP is employed in this study as it enables individuals that are geographically dispersed, to collaborate in a specific area as the effectiveness of sharing economy hinges on the strength of the collaboration among the involved people (Julsrud and Standal, 2022). In a CoP, participants are connected together based on their collectively understanding of what their community (electric car-pooling), comprises and they are accountable towards the actualization of the domain (sustainable public transportation) based on mutual engagement. They interact with each other, establishing norms that reflect these interactions (via practice), to utilize a shared communal resource (such as electric cars). Nevertheless, studies on the application of CoP have been previously carried out across different sectors, there remains limited and lack of convincing empirical evidence on the application of CoP in the area of on-demand electric car-pooling. Hence, additional inquiry is needed to better grasp how CoP can promote sustainable public transportation. This study contributes to the understanding of the role of CoP towards decentralized on-demand electric car-pooling by drawing on research in the field of decentralized technologies focusing on how DLT can be employed with CoP. As in the CoP, individuals engage with the decentralized technology to explore its usefulness as aligned with on-demand electric car-pooling services. This study employing community of practice theory and a permissioned DLT (such as Hyperledger Fabric) to deploy a decentralized on-demand electric car-pooling service, this study enables a collaborative mobility system between passengers and drivers. This study eliminates the need for a trusted centralized authority, by employing a community of participants who share transactional data across a distributed network of nodes. This removes intermediaries that carryout any gatekeeping task. Hence, mobility related transactions are managed in a distributed ledger which is accessed by all the node users within the DLT network enabling building a more transparent, irreversible, trustworthiness, immutable, and secure on-demand electric car-pooling.

5.2. Implications for theory

The sharing economy offers a peer-to-peer transactions facilitated by digital platforms, making the sharing of tangible and intangible resources more accessible and less expensive. Car-polling is a prominent example of the sharing economy, which progresses economic sharing activities in a peer-to-peer manner. Car-pooling offers an effective approach to improve traffic congestion, parking availability, and air quality (Chau et al., 2020). Furthermore, governments around the world are initiating policies to encourage car-pooling (Chau et al., 2020). As such there is an increasing practice of shareability in public transportation. The popular trend of on-demand car-pooling services (e.g., Lyft Line, UberPool, Didi Hitch), allows commuters to arrange shared vehicle services conveniently via digital platforms (Chau et al., 2020; Vaclavik et al., 2020; Wang et al., 2020). To enable electric car-pooling service in the current system drivers and passengers have to share with an eMobility service provider the journey information, including departure date, time, start location, and destination location. The eMobility service provider acts as a middleman to enable the communication between the individuals and usually charges a fee for each successful car-pooling (Baza et al., 2019). In such services individuals are matched based on the drivers offers (i.e., scheduled trips) and passengers ride requests (i.e., preferred trips) (Baza et al., 2019).

In the last decades, social practice theories have emerged as a powerful conceptual lens for examining the sociotechnical aspects of how new technologies are diffused with organizations and the society. Lately, there have been various calls to extend links between the strands of social practice theories and emerging technologies. Accordingly, this study explores how the communities of practice theory can be combined with a distributed ledger technologies to develop a decentralized on-demand electric car-pooling model to contribute towards sustainable public transportation. Analogous to Julsrud and Standal (2022), this study contributes to a stream of research on user-oriented mobility where car-pooling applications have increasingly been addressed. The model proposed in this study also relates to research on decentralized technologies which is concerned with how the deployment and adoption of emerging technologies in the society evolves. The community-oriented electric car-pooling (see Fig. 6), suggested in this study contributes by suggesting a nuanced and richer model that promotes mutual engagement and active participation within shared mobility. As previously stated ride matching has been implemented based on a centralized approach, whereby an eMobility service provider organizes electric car-pooling according to trip time, date, cost of all commuters, etc. Remarkably, while in principle electric car-pooling forms a type of collaborative economy that allows individuals to directly interact with each other. This current approach does not transparently show how trip cost is fairly been distributed between the drivers and passengers. Therefore, this article sheds light to decision makers on how decentralized ride matching mechanisms can be designed to support effective car-pooling among commuters aimed to provide the basis for decentralized architecture as compared to the centralized approach adopted by most car-pooling service platforms. The developed decentralized on-demand electric car-pooling model helps in achieving decentralization aiding drivers and passengers to directly connect to each other via a dApp without any participation of a main controller who implements procedures such as ride matching, price calculation and payment. Smart contracts are employed which makes the proposed approach to be more transparent and increases its fairness and reliability.

5.3. Implications for practice

Presently, the security, trust, and privacy issues are not well addressed in the literature. Inspired by the aforementioned challenges, it is of important to investigate how to achieve a secure, trustworthy, price traceable, and privacy efficient electric car-polling service. This study adds to knowledge by employing the decentralized approach to match passengers with rides (drivers) in a distributed approach without trusting on a third parties of any centralized intermediary making the system much secured and considering the privacy of individuals. Additionally, there are concerns towards the safety, security, and privacy of user's data in centralized platforms which makes the infrastructure susceptible to a single point of attack and failure (Baza et al., 2019). Moreover, the existing centralized system appears to be less inflexible, transparent, and mostly based on a centralized architecture (Kudva et al., 2020). DLT has been previously employed to address the aforementioned concerns due to its decentralized data auditability, immutability, and anonymity. In contrast to the centralized applications, DLT is an immutable, verifiable, and distributed ledger that allows entities that do not trust each other to transact without relying on a dominant third party. DLT based electric car-pooling provides the opportunity to deviate from centralized driven systems to decentralized ones. Considering the challenges stated above, this study is motivated to explore how to actualize a decentralized and practical on-demand electric car-pooling, which supports flexible car-pool matching of drivers with multiple passengers. A decentralized on-demand electric car-pooling model based on community of practice, the permissioned DLT (Hyperledger Fabric), and smart contracts is designed. The model is decentralized, and all interactions made by drivers and passengers are supported by DLT, without the need for any centralized authority to manage the electric car-pooling operations.

This study has important practical implications for sustainable public transportation by proposing a method employs smart contracts to mitigate the single point of failure issues, pricing mechanisms, trust, and security challenges presented in the centralized-based architecture while preserving the privacy of passengers and drivers. Using DLT all matching information, transactions, transparent cost calculation, and mobility related data are stored on a distributed ledger. The distributed ledger will be available to all the peers (drivers and passengers), in the decentralized network. Overall, the model helps to improve dynamic car-pooling matching operations towards a more sustainable shared mobility. Findings from this study will be useful for the design and operations of decentralized on-demand electric car-pooling using electric vehicles in dense urban areas, where traffic congestion is a persistent issue. This article demonstrated a practical case study of typical decentralized on-demand electric car-pooling service of DLT in fields beyond cryptocurrencies. The proposed model can be applicable for the first mile and last mile service for users who commute weekly based on a fixed origin and/or destination. Furthermore, findings from this study presents electric car-pooling matching algorithm with procedures for enabling the dynamic one-to-many decentralized car-pooling matching for shared on-demand EV sharing services in cities.

5.4. Implications for policy

On-demand electric car-pooling is part of the sharing economy which provides several environmentally friendly benefits to the society. For passengers it provides a cost effective and efficient mobility alternative. Unlike conventional taxi services, eMobility service providers provide a centralized platform for passengers to request for car-pool form drivers who are willing to share vacant car seats after they book an electric car (Baza et al., 2019). It enables drivers to decrease traveling costs, reduction in traffic congestion, decrease in parking space demand, decrease in travel cost, and reduces the emissions of CO_2 (Huang et al., 2022; Meshkani and Farooq, 2022). As such there has been interest in car-pooling and sharing services (Yu et al., 2020), with automated payment to improve mobility of individuals as compared to the convenient car hailing or traditional taxi service (Kudva et al., 2020). Irrespective of the numerous benefits of these system, there exists some challenges such as pricing and fixed service policies driven by centralized authorities (which provides the car-pooling services), owns all of the control and can dictate service conditions and policies to individuals (Kudva et al., 2020).

According, this study employs DLT to design a dynamic one-to-many electric car-pooling that is flexible enough to accommodate multiple passengers and driver simultaneously sharing a particular electric car. A model is developed leveraging the community of practice theory and DLT to enable a collaborative electric car-pooling to decrease carbon emissions, orchestrate security, privacy, and transparent pricing among individuals (driver and passengers). More importantly this study provides an understanding of how decentralized mechanisms not only benefits individuals, but also fosters socially transparent approach for our society and helps eMobility service providers to evolve to a more democratized mechanisms towards sustainable public transportation. Overall, the developed decentralized community of practice-based model can enable changes in travel practices of citizens in cities and support a shift to zero-emission mobility. Policymakers and municipalities can implement various supporting measures that promotes the adoption of decentralized community processes as this will trigger the public interest and motivation for using applications supported by emerging technologies such as DLT.

6. Conclusion

Presently existing car-pooling services deploys a centralized approach which makes these platforms susceptible to data privacy, security concerns, and a single point of failure. Besides, drivers and passengers are charged with different services fees by the eMobility service providers without a transparent trustworthy pricing mechanism. Additionally, only fewer studies have been devoted to investigating how community of practice and permissioned DLT such as Hyperledger Fabric can be employed to support the design of decentralized on-demand electric car-pooling. Therefore, this study contributes to the literature by leveraging CoP, DLT, and smart contracts this paper proposes a decentralize electric car-pooling service that enables drivers to publish electric car-pooling services without depending on a trusted third party. Data is collected from the literature and content analysis is carried out to understand how to conceptualize a decentralized on-demand electric car-pooling model. Furthermore, a model is proposed deploying community of practice, the permissioned DLT (Hyperledger Fabric), and smart contracts to offer real-time and prompt electric car-polling services within and across cities. The model employs the decentralization and distribution nature of DLT to create the decentralized car-pooling matching to find ride, book ride, pay for ride, etc.

This study provides discussion on community of practice can support the design of decentralized on-demand electric car-pooling model, how to achieve a transparent pricing among individuals involved in decentralized on-demand electric car-pooling and how to ensure privacy and security of individuals participating in decentralized on-demand electric car-pooling. In summary the key findings present a decentralized car-pooling matching procedure, transparent pricing mechanisms, procedure calls to the utilized in a decentralized on-demand electric car-pooling service, and a case study of a decentralized on-demand electric car-pooling. Findings from this article offers an extensive understanding of how decentralized on-demand electric car-pooling can be deployed to improve sustainable shared mobility which has not been well researched in the literature from the lens of CoP, DLT, and smart contracts. Moreover, findings from this study can help eMobility service providers to deploy a decentralized mechanisms to support effective on-demand electric car-pooling without a single-point of failure.

Like other studies, this article has a few limitations as no primary data was collected only secondary data was employed. Also, the developed approach model was not validated using primary data from qualitative or quantitative method. The key factors that may impact community to be engaged or participate in decentralized on-demand electric car-pooling was not investigated. Future work will collect primary data to further validate the developed model components using qualitative data from interview or focus group workshop from eMobility service providers and users of on-demand electric car-pooling services. Future research can also continue to investigate how CoP can be a transformative theory to improve the mobility experience of passengers and drivers involved in decentralized car-pooling matching. Another recommended topic for future research concerns the factors that may impact CoP as related to decentralized on-demand electric car-pooling for sustainable shared mobility.

CRediT authorship contribution statement

Bokolo Anthony: Writing – original draft, Conceptualization, Methodology, Investigation, Visualization, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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