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Assessment of User Preferences in Electric Vehicle Charge Billing System

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ABSTRACT

Despite the advantages of electric vehicles (EVs), however, their adoption rate in Tanzania remains low. The growth and sustainability of EVs remain questionable due to several factors including an insufficient network of charging infrastructure coupled with billing systems. This study analyzes user preferences related to EV charge billing requirements based on the qualitative assessment of semi-structured interviews with EV users. A survey was conducted around Dar es Salaam city and around 81 sample surveys were administered. The targeted parameters are current EV charge types, daily charging frequency, charging duration, billing system, bill payment, and expectations on public charging infrastructure. The factors were selected to enable an understanding of the drivers for improving acceptance of EV charge billing systems and deduce their market potential. For electric two-wheelers (e2Ws), the findings indicated that 60% of e-bicycle riders charge once per day, 30% charge twice per day, and 10% charge 3 times per day. Moreover, 34% of e-bicycle batteries were charged with 50% of energy remaining in the battery, which took 2 to 3 hours. Contrary, 40.74% of electric three-wheelers (e3Ws) were charging 2 times per day, 33.33% were charging 3 times per day, and 25.93% were charging 1 time per day. In terms of billing, e-bicycles' charging energy was metered but not billed while e3Ws' charging energy was not metered but billed at a flat rate regardless of the energy consumed. The majority of EV drivers expected more public charging stations to be equipped with accurate energy measuring systems to enable them to pay-per-use.

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1. Introduction

The escalation in the need for conventional energy sources [1-3] has triggered multiple outcomes that negatively harm the environment in terms of excessive greenhouse gas (GHG) generation [4-6], environmental damage [7], global warming, and climate change [8, 9]. Over the last two decades, the road transport sector has been pressing a significant challenge [10], with emissions increasing by 115% [11, 12], equivalent to approximately one-sixth of global emissions [13]. To achieve a carbon-neutral target by 2050, electric vehicles (EVs) become the key technology to decarbonize road transport [13, 14-19]. However, a significant transformation to the EVs requires an infrastructure of charging stations [20] equipped with information technology (IT), integration with renewable energy resources, and supportive government policies [9]. Despite the benefits of carbon offset [21], EVs are not yet a global phenomenon [13], with their market lagging far behind in many countries. As of 2023, global EV sales reached above 14 million units [13, 22]. The majority of economic emerging countries have had poor EV sales due to increased ownership costs and a lack of charging infrastructure [9, 13, 23, 24]. Furthermore, in economically developing countries, a substantial number of EVs are used for business activities such as cargo and passenger mobility, with few used for personal transportation. To ensure the growth and sustainability of EVs in these countries, a sufficient network of charging infrastructure [25, 26] coupled with billing systems is required to collect charging revenue.

Tanzania is making headway on e-mobility, with approximately 5000 EVs on the road operating in various sectors such as tourism, passenger mobility, commodities delivery, and healthcare access [27]. According to UN-HABITAT [27], two- and three-wheelers dominate Africa's EV transportation landscapes, including Tanzania, playing an important role in first/last mile connectivity. A research by Germany's Institute for Transport Research [28] emphasized the possibility of strategically located "charging points" at moto-taxi stops around Dar es Salaam city (Tanzania), allowing EV drivers to recharge swiftly while waiting for passengers. The existence of integrated charging infrastructure [21, 29, 30], together with cost-effective vehicles, ease the vehicle industry to shift toward electrification [28], spur EV sales, and increase electrified mileage [25].

EV charge billing, as a part of charging infrastructure, aims at EV monetization, which means earning revenue from EV charging. Burnham *et al*. [31] reported that establishing affordable pricing for users is critical to promoting EV charging schemes. On the other side, Motoaki and Shirk [32] observed that varying charging pricing affects user recharging behavior. A qualitative study by Visaria *et al*. [33] involving 588 Danish EV users revealed that most of them had access to home chargers and private parking. Moreover, users choose EVs primarily to reduce their operating expenses, and they are willing to pay more for the daily convenience of cheaper (per kWh) charging rates. The studies of Lee *et al*. [34] and Chakraborty *et al*. [35] reported that EV users were more likely to utilize public charging stations if they were subscribers to a particular EV public charging service. Franke and Krems [36] investigated the psychological dynamics behind the charging behavior of 79 EV drivers using 6-month field data. They found that EV drivers were traveling 38 km a day, charged their EV three times a week on average, and usually had a significant amount of extra energy left over after recharging. In Dar es Salaam, the metro area population in 2022 was 7,405,000, a 5.08% increase from 2021. The metro area population of Dar es Salaam, which is comparatively youthful, hit around 7,776,000 (2023), a 5.01% increase from 2022 [37] indicating the high-mobility demand. The EVs that contribute to passenger mobility services are primarily imported, making the business capital-intensive [38]. Moreover, about 58% of EV drivers work on vehicle rent contracts [28], plying almost 120 to 130 km daily or an average of 13.4 hours per day. This dictates the necessity of public charging stations around the city. While the country is ranked as a lower-middle income country [39], with a GDP per capita of $1,080 [40] and relatively low electricity rates (~US$ 0.01 per kWh), yet EV charge billing and bill payment remain an obstacle. While the majority of EV charging stations are privately owned, there are no standardized billing and payment approaches that capture the characteristics of the charging demands of EVs. Understanding user preferences in the EV charge billing system would be crucial to sustaining the EV business and its ecosystem. Therefore, this study aims to understand user preferences in EV charge billing systems. The remaining parts are arranged as follows. In section 2, the overview and existing EV charging stations in Tanzania are highlighted. Section 3 describes how we conducted a field survey as part of the business study among potential EV users and peer providers in Dar es Salaam. The last section puts forward a discussion of the findings and conclusions of this study.

2. Materials and Methods

2.1. Overview of EVs in Tanzania

Tanzania is making quicker progress on e-mobility than any other East African country, with at least 5000 EVs on the road [38]. The EVs are presently playing a crucial role in lowering road emissions in a range of areas, including tourism, passenger mobility, commodities delivery, and healthcare access (Fig. **1**). The categories of EVs that have marked a turning point in Tanzania's transportation sector includes e-bicycles, e-mopeds, e-motorcycles, e-three wheelers (cargo and passengers three-wheelers), light-duty EVs, and electric multiple-unit EVs (electric train). Although some of these electric two-wheelers (e-bicycles, e-mopeds, e-motorcycles) are being used for personal mobility, the last mile delivery sector is also a major off-taker of these electric two-wheelers. Furthermore, electric two-wheelers have been deployed in food, medical (drugs), and parcel delivery services, exemplifying the demand and prospects for economical and reliable electric two-wheeler suppliers. Electric three-wheelers are a popular mode of urban transportation serving as taxis, providing city dwellers with their first/last connectivity while benefiting EV drivers [41]. For massive passenger mobility, electric multiple units (electric trains) are currently operational. An electric multiple-unit is the state-of-the-art infrastructure project linking the major port of Dar es Salaam and lakeside ports of Mwanza and Kigoma as well as neighboring countries of Rwanda, Burundi, and Congo DR [42]. The electric multiple-unit, which covers approximately 4669 km, is expected to significantly improve bulk cargo transportation (carrying up to 10,000 tonnes of cargo per trip at 120 km/h equivalent to 500 cargo trucks) while slashing passengers' commuting time from 4 to at least 1 hour and 40 minutes from Dar es Salaam to Morogoro [43, 44].

Figure 1: EV landscape in Tanzania.

2.2. Existing EV Charging Infrastructure

EV chargers come in a variety of forms and power levels to meet charging needs, decreasing range anxiety and promoting EV adoption. The chief roles of EV chargers are to manage and monitor the charging process and integrate safety features. Electricity is the primary energy required to energize the EV chargers. To date, in

Tanzania, there is an increase in electricity access (13% in 2008, 32% in 2017 [45], 37.7% in 2020 [46], and 45.8% in 2022 [47]), making public charging possible. The injection of 2,115 megawatts from the Julius Nyerere Hydropower Plant (JNHPP) alone has made the grid power regain its reliability [28]. Furthermore, the relatively low electricity rates (354 TZS/kWh or ~0.01 US$/kWh) compared to Kenya (1062 TZS/kWh or ~US$0.03) and Uganda (3540 TZS/kWh or US$0.1) make the EV charging business promising in Tanzania while benefiting EV users with low operating costs. However, till to date, there exist a few charging stations in the country (Fig. **2**). Majority of these charging stations are located in Dar es Salaam city (Fig. **2a-e**), the fastest-growing city in the country, a populous, with increasing passenger mobility demand. Fig. (**2a-b**) depict the charging points located at the Dar es Salaam Institute of Technology (DIT) workshop used for charging electric three-wheelers (e3W) used for passengers' mobility. In Fig. (**2a**), e3W batteries are charged directly at the socket outlets without metering the charging energy. Fig. (**2b**) is a sample of a commercial charging point located at DIT workshop but is not operational due to some reasons. The charging points equipped with metering units are depicted in Fig. (**2c**), and they are deployed for recharging e-bicycles used in urban deliveries. However, the metered energy data is not billed, instead, it was previously targeted for researching the charging energy pattern of e-bicycles. Fig. (**2d-e**) shows an example of a charging point located at Makumbusho where no more than four EV drivers can connect to charge their vehicles' batteries. Nevertheless, the charging energy is not metered, instead, all drivers are billed at flat rate of TZS 3000 (~US$ 1.11) per charging session regardless of the energy consumed. In some cases, the e3W drivers recharge in the street when it is convenient for them. Fig. (**2f**) shows the location at Posta with charging points exclusively used for electric two-wheelers (e2Ws). Here, majority of EVs are e-motorcycles which are used for personal mobility, and few for urban delivery. The current stations for charging electric four-wheelers are shown in Fig. (**2g-h**), which are respectively located at UNDP Tanzania (Dodoma office) and Hanspaul (Arusha). Unfortunately, the two stations are privately owned for recharging office vehicles. For the case of electric multiple-units, the electricity is metered and billed directly by the local electric utility.

Figure 2: Existing EV charging stations located (**a**) – (**c**) at DIT workshop (**d**) and (**e**) Makumbusho (**f**) Posta (**g**) UNDP Tanzania office in Dodoma region and (**h**) Hanspaul in Arusha region.

3. Survey

3.1. Study Area and Sample Data

The area in this study is the Dar es Salaam region, Tanzania, and was selected due to several reasons including steady growth of urbanization and high mobility demand [48]. This made the region lead in the number of EVs and charging stations. The study targeted the whole community of EV drivers and charging station operators. The majority of the charging stations in the study area are currently owned by companies or institutions, with few under small shops. The findings from this survey are crucial for understanding the unique charging and billing characteristics of EV drivers. As a result, they will provide insights into designing a billing system that meets the needs and expectations of EV drivers and charging station operators across the country.

The study collected primary data through face-to-face and phone interviews with EV drivers, charging station operators, and stakeholders. The interview questions were open-ended questions tailored to understand user experience, preferences, and pinpoints related needs to billing systems. The data sampled in this study were focused on three categories: charging experience and charging duration; current billing system and payment method; and user expectations. The sub-categories intend to understand their behaviors related to charging and payments, as well as their expected features. In the charging experience, the research was designed to understand the daily charging frequency as well as the charging duration per session. In the current billing system, the study focused on recognizing the current billing system implemented for EV drivers and considerate their perceptions together with the payment method. Lastly, on the user perception, the focus was to understand the EV drivers' expectations regarding the billing system and bill payment methods. The summary of the interview questions and their related sub-categories are listed in Table **1**.

Table 1: Categories and questions of sampled data.

Category	Sub-Categories	Questions
Charging experience and charging durations	Charging times	Daily charging frequency
	Charging duration	Charging hours per session
Current billing system and payment method	Billing method	Flat rate
		Pay-per-use
	Payment method	Cash
		Mobile money
		Credit card
User expectations	Billing method	Flat rate
		Pay-per-use
	Payment method	Cash
		Mobile money
		Credit card

3.2. Data Gathering

The questions were first tested with academic staff in the Section of Energy, Department of Electrical Engineering, Dar es Salaam Institute of Technology before beginning of the study. Three specialists from the Section of Energy and three statisticians from the Dar es Salaam Institute of Technology validated the questionnaires which were derived from the literature. Experts checked the questions' length, phrasing, relevance, and whether or not they addressed the idea of interest. The data were collected over two months from 2 April 2024 to 3 June 2024. The majority of questions were accurately responded to and were all found at their charging or servicing points, indicating that they were the right respondents in this e-mobility sector. Results revealed that the majority of the respondents had strong charging and billing issues and were interested in engaging themselves in new billing initiatives. This indicates that respondents possessed adequate information to take part in this study.

4. Results and Discussion

4.1. Charging Experience and Charging Duration

The objective of this category was to understand the EV drivers' charging experience by understanding their daily charging frequency and charging duration per session (Fig. **3a-c**) show the charging characteristics of e-bicycles. The findings were acquired from the delivery company serving at Dar es Salaam. The company has about 10 e-bicycles in operation. It can be seen in Fig. (**3a**) that 60% of e-bicycle riders charge once per day, while 30% of e-bicycle riders charge twice per day. The charging behavior of 60 and 30% population is a result of having a few deliveries or plying in short-distant trips within the city. On the other side, only 10% of e-bicycle riders charge 3 times per day. The charging behavior of this 10% only happens when the riders ply in longer routes than their normal routes. In Fig. (**3b**), it can be seen that 34% of e-bicycle batteries were charged while having 50% of energy remained in the battery, while 31 and 7% of e-bicycle batteries were charged with 75% state of charge and more, respectively. This indicates that the majority of e-bicycles either ply in medium-distant routes or had a few deliveries. Nevertheless, 28% of e-bicycle batteries were charged with up to 25% state of charge. Fig. (**3c**) displays an example of the e-bicycle recharge times of 7 riders metered in April 2024. From Fig. (**3c**), it can be revealed that the recharge times take around one to four hours. However, on average the recharge times ranged between two to three hours. In other words, considering the large proportion of e-bicycle riders who charge between 2 to 3 times daily with a state of charge below 50% for 2 to 3 hours, this indicates the need of more points for recharging, which are public charging stations. Furthermore, these varying charging durations indicate disparate charging behaviors among EV drivers. This implies that EV battery packs consume different amounts of energy, leading to potential variations in billing.

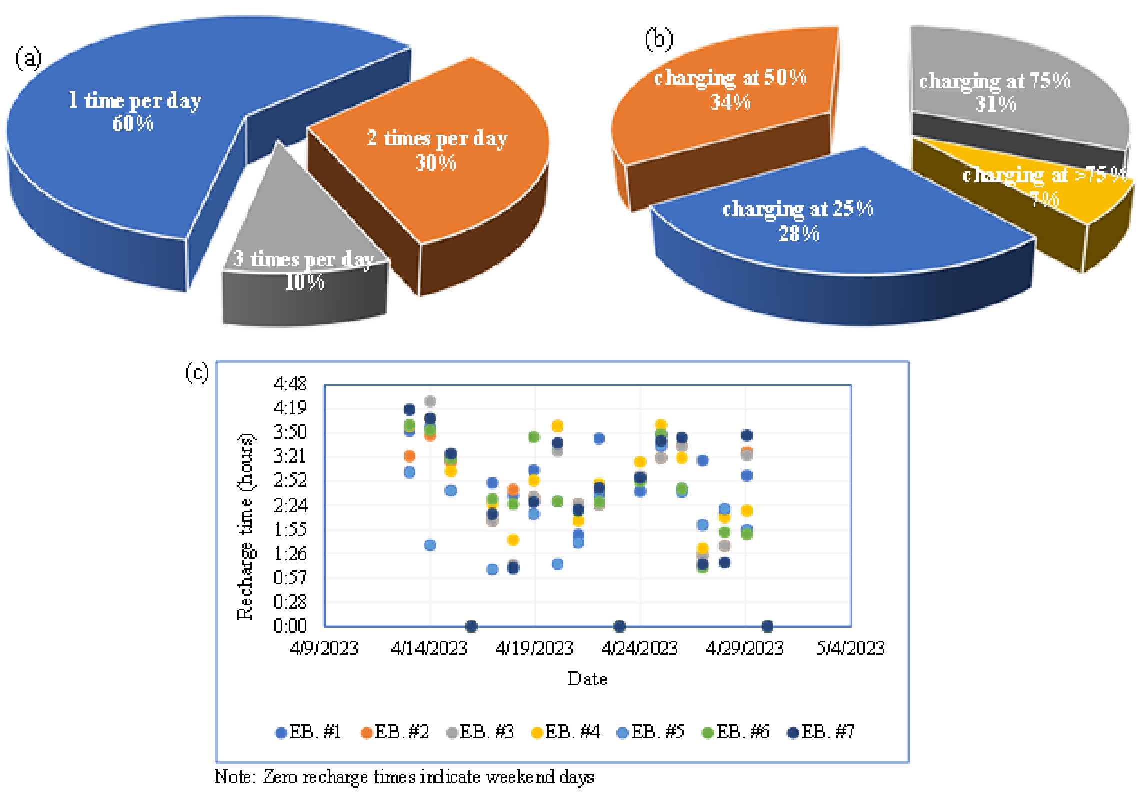

Figure 3: Charging experience of e-bicycle riders (**a**) charging frequency (**b**) state of charge prior to charging (**c**) charging times of e-bicycle batteries metered in April 2024.

In the case of e-three-wheelers (e3W), the charging experience is depicted in Fig. (**4a-b**). Here, 81 responses were received from the e3W drivers. It can be seen that 40.74% of respondents were charging 2 times per day, while 33.33% of respondents were charging 3 times per day. On the other side, only 25.93% were charging 1 time per day. The large proportions (40.74% and 33.33%) of respondents who were charging more than one time per day indicate the need for charging stations to support the EVs during their daytime operations. In other words, more EVs will need more points for recharging, which are public charging stations. Hence, raises the need for accurate energy billing.

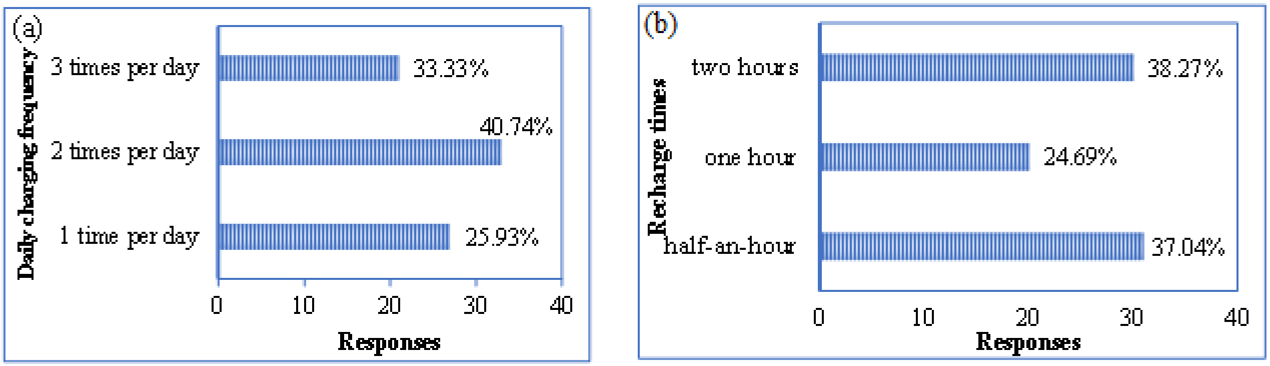

Figure 4: Charging experience of e-three-wheeler drivers (a) charging frequency (b) recharge times per session.

4.2. Current Billing System and Payment Method

Currently, the e2Ws in operation include e-bicycles and e-motorcycles. However, e-bicycles at the DIT Workshop described in sub-section 4.1 are not billed. For the e-motorcycles operated by some vendors, charging is done at their proximity points. The majority are plugging in unmetered and unbilled points to reduce operating costs. However, there is an insufficient number of e-motorcycles operating either in passenger mobility or deliveries. Hence, neither their charging energy bills nor payment modes were obtained.

For the e3Ws, their billing systems and payment methods were easily acquired and assessed. The objective was to understand the current billing system implemented for e3W drivers and understand their perceptions together with the payment method. In this category 81 EV drivers were interviewed and the outcomes are depicted in Fig. (**5**). From Fig. (**5a**), it can be seen that the majority of e3W drivers are billed by flat rate mode. On the other hand, the interviewed charging operators disclosed that for every charging session, the EV driver pays TZS 3000. This amount was billed regardless time and energy used to charge. It should be noted that the billed energy is unmetered, hence, neither charging operators nor EV drivers were sure with the amount of energy consumed or accurate bills. However, the charging operators were seen to be comfortable with the flat rate mode. Contrary, EV drivers were not satisfied with flat-rate billing systems. This current billing system (flat rate billing) is a burden to the majority of e3W drivers. By noting that an e3W is fitted with either 50 Ah single battery or 100 Ah double batteries with a maximum working voltage of 72 V. With 50 Ah single battery or 100 Ah double batteries, if they are charged to 100% state of charge, they consume either 3.6 or 7.2 kWh, respectively. When billed by a standard unit cost of 354 TZS/unit, they either cost approximately TZS 1300 or TZS 2600. Unfortunately, the existing charging points charge a flat rate of TZS 3000 per session. These charging costs are 2.30 and 1.15 times higher for 50 Ah and 100 Ah batteries, respectively. In economic point of view, e3W drivers who charge once, twice, and thrice per day, lose about TZS 1700 and TZS 400; TZS 3400 and TZS 800; and TZS 6800 and TZS 1200 for 50 Ah and 100 Ah batteries, respectively. It is further noted that the e3W drivers with 50 Ah pay less and lose more compared to those having 100 Ah batteries. Over a month, the e3W drivers who charge once daily will lose about TZS 51,000 for 50 Ah compared to TZS 12,000 for 100 Ah batteries. In that light, a proper billing method is necessary to cut down on these losses.

In conventional public mobility activities, most of the time passengers are paying cash on hand rather than other methods like mobile money and swapping cards. This makes drivers to have more cash to pay for fuel. Similarly, in e-mobility, almost all respondents declared to pay the charging bills in cash (Fig. **5b**). While e3Ws present a more sustainable option, an important driver behind EV adoption is the charging cost. Public charging appears as the most critical location for charging and they will play an even more significant role in improving the user experience by providing access for charging at intercity locations. In the future, once the EV market spikes, many e-mobility passengers might request transport and pay via online methods, leaving EV drivers with less cash on hand forcing them to pay the charging bills via other methods such as mobile money or credit cards.

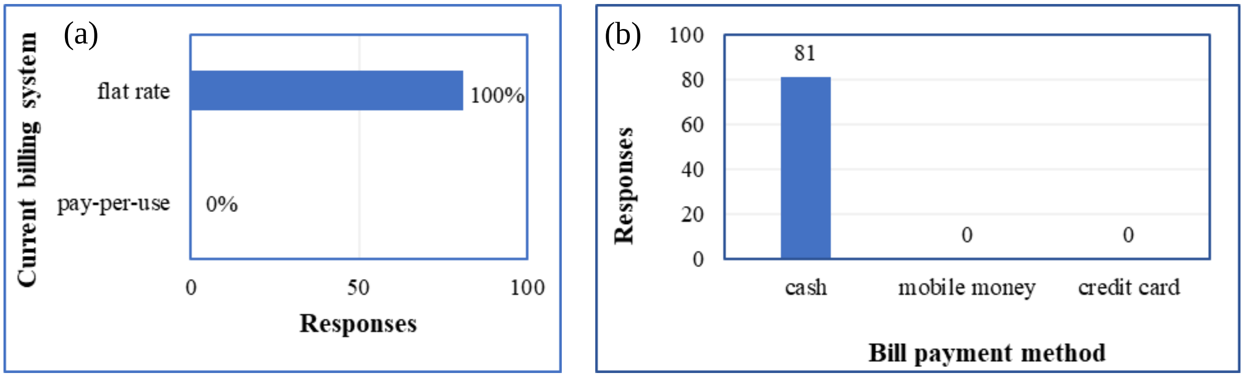

Figure 5: Current systems for (**a**) billing and (**b**) payment of e3Ws charging bills.

4.3. User Expectations

The expectations of EV drivers on the billing and payment methods were assessed through the data acquired from e2W and e3W drivers. This category received responses from 81 and 10 e3W and e2W drivers, respectively. The expectations from e3W drivers are depicted in Fig. (**6a**-**b**). It can be seen that 100% of respondents suggested that the newly developed billing system should enable them to pay-per-use. Meaning that EV drivers were willing to pay for exactly the amount of energy used for charging. This raises the need for an accurate energy measuring system for providing accurate energy bills. For e2W drivers, the majority are expecting more public charging stations to extend their riding range per route while also expanding their commute options. It is further revealed that e2W drivers prefer to continue paying with cash. This increases the requirement for an accurate energy measuring system and a simple payment option.

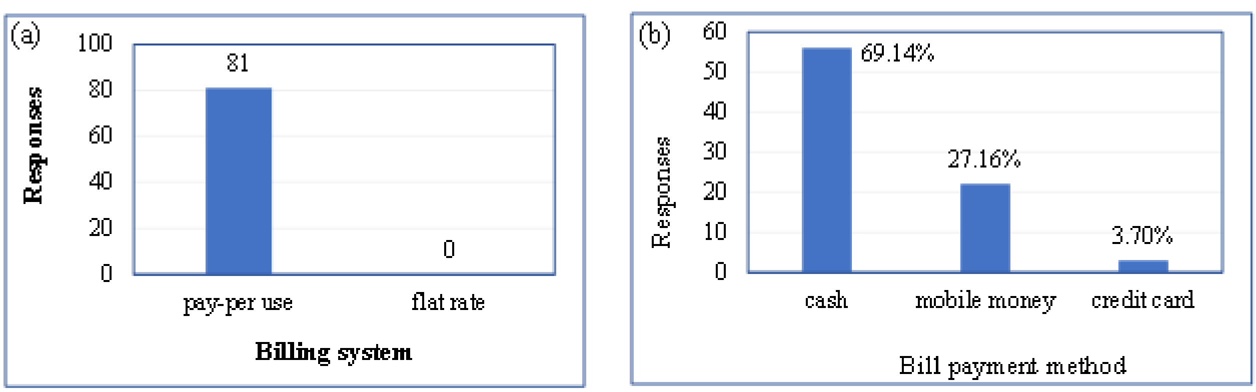

Figure 6: Expectations from e3W drivers in (**a**) billing system and (**b**) bill payment methods.

5. Conclusion and Recommendation

This study assesses EV charge billing requirements for e-mobility activities in Tanzania. In this assessment, electric vehicles (EVs) involved in the study include electric two-wheelers (e2Ws), electric three-wheelers (e3Ws), and electric four-wheelers (e4Ws). The assessment covered the charging experience, billing method and payment, and user expectations. The following conclusions were drawn:

- E-bicycle riders charge once, twice, and thrice daily, with 60% charging once and 30% charging twice. This charging behavior is influenced by short-distant trips or few deliveries, while 10% charge three times due to longer routes.
- During charging, the majority of e-bicycle batteries typically had 50% state of charge (SOC), with 34% charging with 50% SOC, 31% with 75% SOC, and 7% with 25% SOC.
- E-bicycle riders charge 2-3 times daily, with average recharge times ranging from one to four hours, with SOC below 50% for 2 to 3 hours.
- Likewise, e-three-wheeler drivers charge once, twice, and thrice daily, with 40.74% charging twice and 33.33% charging thrice, and 25.93% charging once per day.
- The charging energy e-motorcycles and e4Ws are unmetered while e-bicycles are metered but not billed. For e3Ws, the majority are billed without metering their charging energy. For billing the charging energy, the flat rate method is commonly adopted, charging about TZS 3000 per charging session regardless of the energy consumed.
- The majority of EV drivers expect more public charging stations equipped with accurate energy measuring systems to enable them to pay-per-use.

The charging stations currently involved in this study were all powered by conventional utility grid. Consequently, charging station operators refer the energy bills to that of the conventional utility grid. The impacts (e.g., energy bills, emission reduction in electricity generation, reliability, and convenience) of using renewable energy resources for charging EVs need to be explored. Future studies should deeply analyze the metered charging energy of EVs and observe the implications of working days (weekdays, weekends, and public holidays). Currently, the EV charging station is not seen as a serious business. More economic studies on accurate metering and billing methods could be valuable for motivating more EV charging station operators to invest in this business. With more charging stations coming into operation, studies should identify the most urgently needed areas for installing the stations, e.g., urban vs. rural areas or along highways. Studies should go beyond the practicality of charging and billing systems by assessing user awareness or interest in the environmental benefits as EVs can help reduce emissions. Factors such as route length, driving behaviors, road types, climatic conditions, loading, drivers' age, and others need to be evaluated as they influence the charging frequency of EVs. Moreover, the charging behaviors between commercial and personal EV users would be of great importance if well evaluated. As part of the recommendation, lack of policy and technology availability in the domains of EV charging infrastructure and EV charge billing is identified as a restriction of the EV potential in the Tanzanian context which must be addressed. To further address the remaining barriers to EV adoption, policymakers should reinforce incentives [49], and encourage EV stakeholders to establish more affordable charging points in the EV market, particularly along important toll highways. With the strong EV policy, the volume of EVs might increase considerably. Additional factors, such as convenient and rapid public charging, primarily for longer trips, will increase EV usage and improve the user experience. As of now, the country is drafting the national EV policy framework, which contains pillars such as deepening the role of local manufacturing, scaling up passenger EVs and e-buses, charging infrastructure, and reducing greenhouse gases. Alternatively, the country exempts e4Ws and e-buses from excise duty, which can range from 0% to 44%. However, eE2Ws are not included in the tax incentives, despite being popular with an estimated 10,000 units in use, while E4Ws are rare, and e-buses don't have a presence yet. Unfortunately, the country classifies e-scooters as e-bicycles, which exempts them from the 10% excise duty applied to e-motorcycles [50]. To further support the adoption, the Tanzania E-Mobility Association (TAEMA) could work with the government to recognize the sector and implement supportive policy as well as put a strong emphasis on consumer attitudes, perceptions, and behaviors to improve EV acceptance and proliferation. Moreover, TAEMA could explore the potential and advise the government on moving to complete knockdown (CKD) imports and allow companies to access the East African countries (EAC) CKD rates to reduce taxation by a third and make EVs more affordable. Overall, while operating cost is one of the key driving factors for EV usage, convenience also plays a critical role in enhancing the user experience. Therefore, a strategy for the expansion of public and private charging stations is required. This would make the business case for fast chargers more compelling. With an increasing number of EV users, establishing a set of social standards for appropriate behavior and charging point usage would be beneficial to minimize overuse or a lack of access to those who require the service. New charging station operators may need to learn from Tesla and adopt some of its strategies to improve the EV user experience. For instance, Tesla's idle fees, which are levied when users do not disconnect from chargers after charging (in cases of peak demand) help to alleviate the frustrations and increase charging system efficiency. Lastly, since the EV penetration is growing in an unprecedented way, the insufficient charging infrastructure to support charging in all locations might slow the development of the EV market [26]. In that case, fitting stationary charging stations at all locations may not be financially feasible. In that context, mobile charging stations [26, 51] can be foreseen as a futuristic solution to enhance the adoption by providing charging at users' convenient times and places.

Conflicts of 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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Data Availability

The authors confirm that the data supporting the findings of this study are available within the article.

Authors' Contribution

EM, GBG, and PVC: Conceptualization, Methodology, Data Collection, Data curation, Investigation, Writing – original draft.

EAN and GR: Writing –review.

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