Martins *Sustainable Earth Reviews* (2025) 8:7
https://doi.org/10.1186/s42055-025-00106-0

Sustainable Earth Reviews

REVIEW

Open Access

Electric mobility initiatives in Kisumu: enablers, progress, barriers and impacts in a secondary African city

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Abstract
This paper examines the transition to electric mobility (e-mobility) in Kisumu, Kenya's third-largest city, focusing on the enablers, progress, barriers, and impacts of e-mobility initiatives in a secondary African city. In alignment with Kenya's commitment to a green economy, Kisumu has emerged as a key site for experimenting and implementing e-mobility solutions aimed at lowering greenhouse gas emissions while addressing critical transportation and energy challenges. These interventions are essential in the city's transition towards sustainable urban mobility. The study evaluates key projects which have introduced electric motorcycles and off-grid solar-powered charging hubs in urban and peri-urban regions. The overall goal of these initiatives is to mitigate the adverse environmental footprints of fossil-based vehicles while providing socioeconomic benefits to local operators such as cost reductions and job creation. Using a mixed-method approach of systematic literature review, data collection, and case study evaluations, the paper outlines the progress of e-mobility initiatives in Kisumu highlighting successes, challenges and impacts. It reveals that e-mobility has made some contribution to emissions reductions and financial gains for boda operators while significant hurdles include inadequate infrastructure, high upfront costs, and regulatory shortfalls. The paper concludes with recommendations on how to enable the scale-up of e-mobility initiatives in Kisumu, offering important lessons for secondary cities across sub-Saharan Africa that aspire to integrate e-mobility in their sustainable urban development efforts.

Keywords Electric mobility, Kisumu, Secondary cities, Renewable energy, Sub-Saharan Africa

Introduction

The global transition to e-mobility has gained momentum which is driven by technological innovations, supportive policies, and the increasing availability of renewable energy sources such as solar and wind power [1]. Electric mobility is progressively becoming a critical intervention for adopting a transformative approach to the sustainability and urban development challenges faced by cities worldwide. The transportation sector is responsible for over one-third of CO_2 emissions from end-use sectors and continues to rely heavily on fossil fuel products, which account for nearly 91% of its energy consumption [2]. Electric mobility, commonly referred to as e-mobility, presents a more environmentally sustainable alternative by reducing dependence on fossil fuels [3]. This shift towards electric vehicles (EVs) and other electric modes of transport is not only essential for meeting climate goals such as those outlined in the Paris Agreement, but also for addressing critical urban issues namely air pollution, traffic congestion, and energy inefficiency [4, 5].

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The developing regions of Africa, Asia and Latin-America are poised to become future leaders in e-mobility due to the convergence of three crucial development factors namely the increasing pace of urbanization, increase in economic development, and a growing focus on sustainable transport solutions [6]. In Africa, fast urbanization and the distinct mobility requirements of the people are propelling the change towards e-mobility where two-and-three wheelers are a cheap and accessible means of transport. Governments are becoming increasingly supportive, and the establishment of the African Continental Free Trade Agreement (AfCFTA) presents unique opportunities for movement, trade and local manufacturing [7]. In Asia, especially in India and China, there is aggressive government support which is driving a fast growth of the e-mobility market, with China being the global leader in electric vehicle production [8]. Low car ownership and high population densities in Latin America are seen to create windows for the adoption of electric vehicles in urban transport systems, as already demonstrated in several recent workshops held in the People's Partnership Centre in Bogota and schools in Mexico City focusing on stakeholder synergies [9].

The emerging trends of e-mobility in these regions contrasts with those of developed nations. While the latter focus more on personal electric cars, developing regions are moving towards a wider range of electric vehicles (EVs) including two-wheelers and three-wheelers which can be better adapted to their local environment of operation. given their comparative affordability and lower requirement for charging infrastructure [10]. These smaller e-vehicles are able to use the normal electrical plugs available in most households to charge their batteries reducing the need for a comprehensive charging infrastructure network [11]. Moreover, domestic production of the EVs also brings about huge potential for growth and the creation of local jobs while decreasing imports and creating a healthy domestic ecosystem [12].

These countries are also adopting appropriate policies to provide support to better make these parts obtainable by the taxation and tariff discounts when the EVs will be imported and assembled within the country [13]. The use of alternating current for charging is anticipated to make the e-mobility even simpler. This is very crucial in that it helps bring different ranges of the population into the EVs through different innovative features such as PAYGO schemes and lease to own models [14]. All in all, these regions are strategically positioned to lead the world towards the shift to clean transport through local manufacture, business model innovation and government policy supports and renewable energy use [15, 16].

Zooming into Africa, the potential benefits of e-mobility are substantial, particularly in rapidly urbanizing regions where transportation infrastructure remains underdeveloped and heavily dependent on fossil fuels [17]. Urban sustainability is threatened by rising populations and vehicle numbers as the air quality continues to deteriorate in these cities [18]. There is a potential to skip the traditional fossil-fuel-based transportation systems altogether and move straight to cleaner technologies by deploying e-mobility solutions supported by vast renewable energy resources such as solar. Nevertheless, e-mobility adoption in sub-Saharan Africa is challenged by the high upfront costs of electric vehicles, weak policy frameworks and public acceptance issues [19].

Motorized public mobility in Africa encompasses several forms of vehicles such as larger buses and lighter vehicles namely motorcycles, tuk-tuks, and minibuses each targeting different segments of the population and having varied infrastructural needs [20]. This variety arises because these vehicle forms meet the mobility needs of the public in a context where formal public transportation remains inadequate to meet the diverse mobility needs of its population [21]. Unlike developed contexts where motorized public mobility is centred on private vehicles and public buses, Africa's use of lighter two-and-three wheelers is unique and advantageous, similar only to contexts like Asia [22]. From an e-mobility perspective, the advantage is that transitions from fossil fuel to electricity as a power source for lighter vehicles like motorcycles can be implemented with comparative ease given that electric motorcycles can use regular power outlets for charging [23]. This leapfrogging potential is critical in increasing urban mobility with little capital investments in infrastructure [24].

More and more countries across the continent of Africa are beginning to understand the advantages of e-mobility because of the increasing need for modern transportation, the desire to lower greenhouse gas emissions and the presence of renewable energy sources [25]. East African countries have made some significant positive steps towards e-mobility integration with urban development efforts in Kenya, Rwanda, Tanzania, and Uganda [26]. The East African Community (EAC) has pledged to decrease transport-derived emissions and various pilot projects are running [27].

Kenya, in particular, is at the forefront with ongoing implementation of renewable-energy-based strategies to support electrification of the transport sector [28]. This aligns with the country's wider national objectives toward a green economy, as presented in Vision 2030 and the National Climate Change Action Plan [29]. The country is also working on raising the local manufacturing sector of the economy as an engine to create jobs, spur economic development, develop strong local procurement and lessen overdependence on imported goods. This is particularly relevant for e-mobility initiatives which still relay on importation and foreign direct investment [30].

While most of the country's e-mobility initiatives are more targeted towards the capital city Nairobi, given its economic and political significance, there have been trends observed in Kisumu demonstrating a significant potential for e-mobility adoption and impact in a secondary city.

The overall objective of this paper is to critically examine the electrification of urban and peri-urban transport systems in Kisumu, focusing on the impact of clean electric mobility initiatives on sustainable urban development. Drawing from the evaluation of key projects in the region, this study highlights the successes and challenges faced by Kisumu in its e-mobility journey, as a way of developing lessons for informing broader policy strategies to adopting electrification at scale in Kisumu and other sub-Saharan African secondary cities.

Methods

The review was undertaken as a mixed-methods study incorporating qualitative and quantitative methods to assess the state of progress towards implementation and development of electric mobility measures in both urban and peri-urban environments within Kisumu. This process follows a methodology that integrates a systematic literature review, data collection and categorization, qualitative comparative analysis (QCA), and case study evaluation as described in the following sections. The information sources reviewed were extensive and included academic research, industry reports, and case studies with an emphasis on projects that have been implemented in Kisumu within the last five years.

Systematic literature review

The foundation of this review is built on a systematic search for peer-reviewed articles, reports, and publications on e-mobility and renewable energy. Academic databases, including Google Scholar, Scopus, and SpringerLink, were utilized to identify and access relevant literature. It focused on key phrases such as "e-mobility in East Africa," "renewable energy and transport," "electric motorcycles in Kenya," and "electric mobility infrastructure." Additionally, the selection criteria filtered for projects that specifically focused on electric mobility projects in East Africa and integrated renewable energy sources such as solar and geothermal power. The review synthesized the current knowledge outlining the barriers, enablers, and impacts of e-mobility in Kisumu.

Data collection and categorization

Information was gathered from multiple existing sources through desk research such as academic papers, project reports, government publications, and statistical databases to support the study. The specific quantitative data included emission reductions, business cost savings, and public health impacts related to e-mobility adoption. Qualitative data included stakeholder perspectives, policy evaluations, and opinion polls. This data was then systematically segregated into five core themes namely *environmental sustainability, economic development, infrastructure, policy support, and social acceptance.* This classification, as summarized in Table 1 below, supported the systematic analysis of qualitatively identified barriers and success factors for implementation of e-mobility projects in Kisumu.

Qualitative comparative analysis (QCA)

The progress in Kisumu (or lack of) was explored through several steps which included developing a theory of change as discussed in the introduction, identifying the case studies of interest which were the larger electric mobility initiatives in Kisumu as well as efforts by selected private companies, identification of key themes and enablers for electric mobility implementation as discussed in the literature review section, evaluating e-mobility in Kisumu and how the selected initiatives have addressed the themes, analysing the findings, synthesizing the lessons learned and formulating policy recommendations. This approach is a modification of the QCA methodology originally developed by Charles Ragin in the 1970s [31].

Case study evaluation

Key case studies that could help to understand the impacts of various projects in Kisumu were evaluated. The case studies were selected electric mobility initiatives in Kisumu and information was availed through the

Table 1 Data collection and thematic categorization

Category	Examples of data collected	Sources
Environmental sustainability	Project objectives, geographic focus, partnerships involved, implementation plans, impact reports	Project documents, partnership agreements, and reports from involved organizations
Economic development	Job creation, operational cost savings for boda-boda operators, financial incentives	Reports, financial data from project evaluations, employment statistics
Infrastructure development	Availability of charging stations, grid reliability, solar-powered charging hubs	Infrastructure reports, renewable energy integration studies
Policy support	Regulations for EVs, government subsidies, import duty exemptions	Policy documents, government reports on electric vehicle incentives, regulatory analyses
Social acceptance	Public attitudes towards e-mobility, awareness campaigns, adoption rates by operators	Surveys from boda-boda operators, public engagement reports, adoption statistics

various sources described in sections "Systematic literature review" and "Data collection and categorization".

Synthesis and reporting

Based on literature review, comparison evaluation, and case studies, the results were finally synthesized providing an instrumental view of Kisumu's e-mobility progress. The synthesis processed key learnings, successes, and challenges that have emerged from the collective initiatives on clean mobility in transitioning Kisumu. The final reporting presents the policy lessons and possible avenues for improvement, against a backdrop of evidence reasoned from different data sources.

Literature review

This section delves into an overview of Kenya's achievements in e-mobility in recent years, highlighting enablers, progress made on policy frameworks, infrastructure development, and public transport initiatives as well as the experiences with electrifying motorcycle taxis (boda-bodas). The review synthesizes new research, policy reports and case studies to highlight trends, opportunities, and challenges for e-mobility in Kenya with a specific interest in Kisumu.

Enablers for exploiting Kenya's e-mobility potential

There are key enablers and opportunities for e-mobility in Kenya that have made progress possible. Amongst the enablers are Kenya's rich sustainable energy resources, private sector investments, favourable government policies, and growth opportunities in terms of economy and job creation. This section delves deeper into the role of these enablers and opportunities.

Abundant renewable energy resources

Kenya's large renewable energy reserves are critical to facilitating its shift towards e-mobility. The country is an African leader in renewable energy, boasting of over 70% of the country's electricity needs being powered by clean sources, particularly geothermal, solar, and wind [32]. Its energy resources include the region of Rift Valley with its largely untapped geothermal energy potential that can support a steady and reliable energy source to power electric vehicles [33]. In rural and peri-urban areas with poor access to the main electricity grid, abundant solar energy is a further promising resource for off-grid charging solutions [34, 35].

Apart from reducing the carbon footprint of transportation, implementing renewable energy in conjunction with e-mobility can help decrease operation costs for electric vehicles (EVs) stakeholders compared to volatile fuel prices faced by internal combustion engine (ICE) vehicles [36, 37]. Kenya's potential to expand its renewable energy use makes it well-placed to meet the increasing energy demands of the e-mobility sector and meet its GHG reduction commitments under the Paris Agreement [27].

Government policy support

The policy framework in Kenya is also increasingly supportive of e-mobility growth. Various initiatives spearheaded by the government indicate its commitment to moving towards cleaner transportation this includes, the setting up of an E-Mobility Taskforce in 2023 which will be responsible for formulating policies and strategies for quickly adopting electric vehicles and development of charging infrastructure [38]. The National Climate Change Action Plan (NCCAP) and the Green Economy Strategy and Implementation Plan (GESIP) both underscore the role of efficient and sustainable transport in mitigating emissions while fostering green growth [18].

The government has further reduced import duties and introduced tax exemptions on electric vehicles, which have consequently started to reduce the upfront costs of EVs, hence making them accessible to the general public [39]. Additional policy drivers including subsidies for EV sales and machine-to-machine charging incentives will engrain e-mobility in consumer behaviour. Urban planning frameworks in Kenya, especially for its cities like Nairobi and Kisumu provide space to further e-mobility integration based on an opportunity presented by the establishment of sustainable advanced, electric public transport systems [40].

Private sector innovation and investment

In driving e-mobility adoption in Kenya, the private sector is playing a pivotal role. Leading the electric vehicle (EV) revolution, private companies offer electric bikes, taxis, buses, and ride-hailing services powered by renewable energy [41]. They have entered the market as social entrepreneurs seeking to make profit while contributing positively to social and environmental goals [42].

Electric mobility requires charging infrastructure. Given the many competing interests that governments in East Africa face, Kenya included, they are unable to fully meet the growing needs of the industry. [43] In response to this, private sector partnerships with the government, including public-private partnerships (PPPs) have emerged to develop charging infrastructure, which is key to scaling e-mobility solutions across Kenya [44].

Not only are these companies reducing the environmental impact of transportation but also contributing to job creation and economic development by building local manufacturing and service industries around electric vehicles [45]. This can lower the costs of electric vehicles and create potential jobs, such as assembling and maintenance of electric motorcycles and buses to be produced locally by Roam, a Swedish-Kenyan electric mobility company that designs and develops such vehicles for emerging markets, starting in Kenya [46, 47].

Electrification of public transport and boda-bodas

Public transport electrification presents a significant opportunity for reducing urban emissions and improving air quality in Kenya's cities. With Nairobi, Mombasa, and Kisumu as key urban centres, electrifying public buses, matatus (mini-busses), and boda-bodas would have a substantial impact on reducing emissions, given the high reliance on these modes of transport [48]. Pilot projects that focus on integrating renewable energy with e-mobility have demonstrated the potential for electric vehicles to reduce GHG emissions and offer a sustainable alternative to diesel-powered public transport [49].

The electrification of boda-bodas presents a particularly interesting opportunity. In Kenya, boda-bodas are the foundation of the informal transport industry that employs thousands of riders and is a key method for urban and rural transportation [50]. The wide adoption of electric boda-bodas would cut Kenya's transport emissions and operational costs for riders, who are amongst the country's lower income group and spend a substantial percentage of their income on fuel. Electric motorcycles could become more attractive with the incorporation of battery-swapping stations [51].

The electrification of boda-bodas could aid in better public health outcomes by decreasing air pollution in densely populated urban areas [52]. It is an easy win as both government and private sectors stand to gain [53].

Economic growth and job creation

The growth of the e-mobility sector in Kenya is a significant opportunity for economic development and job creation. Electrification of transport systems requires investment in manufacturing, infrastructure development, and maintenance services, which can create new employment opportunities in the vehicle assembly and renewable energy sectors [54]. Local manufacturing of electric motorcycles and buses, reduces Kenya's reliance on imported vehicles and builds local capacity for producing and maintaining electric vehicles [55].

Moreover, the expansion of charging infrastructure offers opportunities for new businesses in the energy sector, particularly in developing off-grid renewable energy solutions for rural and peri-urban areas [56, 57]. These developments could contribute to the creation of a green economy in Kenya, providing employment for skilled and unskilled workers and supporting broader economic growth [58].

Regional and international cooperation

Regional and international collaborations are crucial for the growth of e-mobility in Kenya. There are several regional initiatives in which Kenya participates that aim to scale up sustainable transport solutions, such as the East African Community's (EAC) agenda on electric mobility and infrastructure planning and construction [59].

Additionally, numerous international companies and organizations are investing in the Kenyan e-mobility space. Given the expensive nature of e-mobility transitions, local companies have become innovative in partnering with global companies, thereby increasing the technologies, expertise, and factory capital in Kenya's growing electric vehicle market [60]. These partnerships enhance capability for e-mobility development and position Kenya as an African green transport revolution.

Progress toward e-mobility in Kenya

Given these enablers and opportunities, Kenya has made notable progress in the uptake of electric mobility in the last couple of years as it pursues a broader strategy to transition to a cleaner transport system. The government has committed to transitioning to a green economy, as defined in Vision 2030 and the National Climate Change Action Plan (NCCAP), thereby enabling these efforts and influencing several e-mobility initiatives aimed at reducing Greenhouse Gas (GHG) emissions and improving air quality [61]. The sub-sections below highlight some of the key advancements made.

Progress in policy

The shift towards e-mobility in Kenya is a consequence of several policy provisions in the national development agenda that has sustainability and environmental stewardship as top priorities. The National Climate Change Action Plan (NCCAP) and the National Energy Policy (2018) promote clean energy integration in the transport sector calling for reduced reliance on fossil fuels and lower emissions [62]. The Kenya Green Economy Strategy and Implementation Plan (GESIP) additionally seeks to help the nation move towards a low-carbon, resource-efficient fiscal setup with green transportation recognized as one of the central elements of this system. It clearly outlines emission reduction targets in public transport as well as focuses on electric vehicle adaptation. In addition, the introduction of EV tax relief and lower import duties have helped to reduce the cost barriers for electric mobility [63].

In 2023, Kenya established the E-Mobility Taskforce which was authorized to fast-track the use of electric vehicles (EVs) and electric motorcycles (e-bikes). Its primarily function is to develop policies for enabling the electrification of public transport, promoting private sector investment towards e-mobility, and ensuring the availability of adequate charging infrastructure [23]. One of the key successes of the E-mobility Taskforce was the introduction of fiscal incentives for e-Mobility under the Finance Act, 2023 which included the zero rating of VAT on the importation or sale of e-Mobility vehicles and components.[1]

Despite these positive policies, some policy gaps exist. For example, there remains a lack of comprehensive regulation covering the deployment of charging infrastructure, vehicle certification, and safety standards for EVs. This lack of regulation continues to create uncertainty among investors, consumers, and other stakeholders [64, 65].

Progress in public-private-partnerships (PPPs)

Despite the renewable energy advantage mentioned earlier, the development of government-led charging infrastructure has not kept pace with the growing potential for electric mobility. Charging infrastructure is crucial for the uptake of electric mobility. To address this gap, the government has gradually opened its doors to partnerships with the private sector [66].

The County Government of Kisumu, together with the UN Environment Programme have partnered with private companies to pilot electric motorcycles in Nairobi and Kisumu. The Kenya Power as part of this initiative is rolling out EV charging stations, in Nairobi and Kisumu [67]. Recent reports indicate that the installation of EV charging stations is gaining momentum, with over 100 stations expected to be operational by 2025 [68]. The growth of charging infrastructure is complemented by a parallel rise in the availability of electric vehicles.

Progress in local assembly and manufacturing

In 2022, a significant milestone was achieved when Ampersand opened Kenya's first electric motorcycle assembly plant, making a shift towards local manufacturing and job creation in the e-mobility sector [69]. These electric motorcycles are powered by renewable energy, particularly solar, and offer boda-boda riders lower operational costs compared to their petrol counterparts. Additionally, electric motorcycles emit zero tailpipe emissions, contributing to improved air quality in cities like Nairobi and Kisumu [70]. This development is key since boda-bodas are the leading mode for carrying passengers and goods. By using clean electricity, the Ampersand's electric motorcycles represent a more sustainable option compared to petrol-fuelled bikes [71]. Companies like Ampersand have introduced electric motorcycles designed specifically for the African market which offer both financial and environmental benefits [72].

Public transport remains a critical area of focus for e-mobility in Kenya. Most urban residents in Nairobi, Mombasa, and Kisumu rely on informal minibus systems known as "matatus" for their daily commute [73]. Over the last few years, there have been efforts to modernize and electrify Kenya's public transport system, with electric buses seen as a key solution. Nairobi alone is projected to have over 200 electric buses by 2025, which would significantly reduce the city's carbon footprint [74].

A Kenyan-Swedish electric mobility startup launched Africa's first electric bus and began retrofitting existing vehicles to become electric [75]. Several other startups, such as Ekorent and Nopia Ride, have introduced electric ride-hailing services that operate primarily in Nairobi and its environs, contributing to the growing e-mobility ecosystem [26]. The entry of these private companies has provided a much-needed intervention from the private sector where government mechanisms have been slow.

Barriers to e-mobility implementation in Kenya

Despite Kenya's progress towards electrifying its transport sector, the adoption of electric mobility (e-mobility) has faced several critical barriers that limit its widespread implementation. These barriers are a mix of infrastructural, economic, regulatory, and socio-cultural challenges that hinder the integration of electric vehicles (EVs), electric motorcycles, and renewable-powered transport systems [68]. Understanding these barriers is essential to developing effective strategies for accelerating Kenya's transition to a more sustainable transport system. This section critically reviews the key obstacles to e-mobility adoption, drawing on recent research and case studies from 2022 onwards.

High initial costs of electric vehicles

The substantial initial cost of electric vehicles continues to be an important barrier to the adoption of e-mobility in Kenya. Despite the long-term savings associated with lower fuel and maintenance costs, the purchase price of EVs is still prohibitively high for many consumers, especially in low- and middle-income communities [76]. While electric vehicles reduce lifetime vehicle costs, many Kenyans are unable to afford the initial outlay required to purchase these vehicles [77].

Electric motorcycles, which are essential to many peoples' livelihood in the informal transport sector through the widespread use of boda-bodas (motorcycle taxis), also encounter cost related challenges [78]. The initial capital investment required for their purchase is a significant deterrent for boda-boda operators, many of whom operate on narrow profit margins [79]. The absence of affordable financing options for EV purchases intensifies the problem, limiting the ability of low-income consumers to participate in the e-mobility transition [80]. Financing structures for EVs remain underdeveloped,

[1] https://aln.africa/insight/kenya-establishes-e-mobility-taskforce-led-by-aln-kenya-managing-partner-daniel-ngumy/

preventing operators from adopting EVs in significant numbers [81].

Regulatory and policy gaps

Kenya's regulatory and policy framework for e-mobility is still in its infancy, and several gaps exist that hinder the rapid scaling of electric transport solutions. While Kenya has made progress with policies such as the National Climate Change Action Plan and the formation of the E-Mobility Taskforce, a comprehensive regulatory framework that specifically addresses the needs of e-mobility is still lacking. This includes important areas such as safety standards, vehicle certifications, and charging infrastructure regulations [82].

Moreover, the current legal framework is not fully equipped to incentivize the mass adoption of electric vehicles or support innovative business models such as electric vehicle leasing or shared mobility platforms [83]. For example, there are no clear policies on integrating renewable energy with charging infrastructure or on electrifying public transport systems such as matatus, which remain predominantly fossil-fuelled [84]. Without targeted policies, the transition to e-mobility risks stagnating on old successes.

Support for e-mobility policies in Kenya has been inconsistent, characterized by delays in implementing critical policies such as tax exemptions on electric vehicle imports. The lack of a clear, well-enforced regulatory environment reduces investor confidence and limits the potential for large-scale adoption of e-mobility technologies [85].

Energy supply and grid challenges

Despite being heavily reliant on renewable energy sources, Kenya's electricity's grid still faces challenges that delay the expansion of e-mobility. Grid stability remains a concern in rural and peri-urban areas where power outages are frequent [86]. The national grid needs substantial upgrades to handle the additional load from widespread EV charging, especially if electric public transport systems are to be implemented on large scale [87].

Another challenge lies in the uneven distribution of electricity access across the country. While urban areas like Nairobi have relatively stable access to electricity, many rural and peri-urban areas still lack reliable connections to the grid, limiting the feasibility of e-mobility in these regions [88]. Addressing these grid challenges will require investment in both physical infrastructure and smart grid technologies that can manage fluctuating energy demands and optimize the integration of renewable energy sources into the transport system [89].

Public awareness and social acceptance

A low level of public awareness and societal acceptance of electric vehicles is a hindrance. Consumers are generally unaware of the advantages that EVs offer over traditional vehicles which include lower operating costs and decreased environmental harm, while the broader belief is that EVs are less reliable as compared to conventional cars [90]. The informal transport sector operators (boda-boda and matatu drivers) who rely on fuel-powered vehicles for their livelihood remain unsure of how reliable electric vehicles performance is or if they are cost-effective [91].

There also exists a low level of public understanding of the health benefits of e-mobility especially from air quality improvements and consequent health outcomes [92]. The public has not been sensitized on the public health case for e-mobility, which in turn has limited the appetite for cleaner transport options. Persistent sales of EVs will need to be supported by comprehensive public education campaigns and pilot projects to demonstrate the viability of EVs. Additionally, greater involvement of informal transport operators to help build trust in electric mobility solutions is necessary [23].

Inadequate private sector investment

While private sector investment in e-mobility exists, it is still insufficient, Other than a few substantial investments from companies like Roam (formerly Opibus), EkoRent, and Ampersand, the level of investment in the sector is relatively low as compared to other countries globally [93]. High entry costs, combined with regulatory uncertainties and infrastructure gaps, have deterred many private investors from fully committing to the e-mobility space in Kenya [94].

A key factor limiting private sector involvement is the absence of clear financial incentives or risk-sharing mechanisms that could de-risk investments in electric mobility infrastructure and vehicles [95]. Public-private partnerships (PPPs) could play a crucial role in overcoming this barrier, but so far, there has been limited engagement between the government and private investors to co-develop the necessary infrastructure and services that would enable the growth of Kenya's e-mobility ecosystem [96].

The need to understand e-mobility impacts in Kenya

It is evident that the journey towards e-mobility in Kenya has been shaped by both opportunities and challenges. Kenya having huge renewable energy resources and growing private sector investments with government policy support has the potential for fast-tracking e-mobility, especially in the public transport space and electrification of boda-bodas [97, 98]. However, many barriers such as the absence of charging infrastructure, high upfront costs, and regulatory gaps continue to inhibit faster adoption of electric vehicles [99]. Nonetheless, many initiatives continue being rolled out in the major urban centres in Kenya namely Nairobi, Mombasa and Kisumu [100–102]. Are there any visible impacts on urban development?

While most recent research has focussed mainly on the e-mobility development in the capital city, Nairobi, the scale of complexities in the city given its scale make it challenging to attribute direct impacts to e-mobility alone [103]. Perhaps a smaller scale could be more instrumental in providing meaningful insights. Kenya's third-largest city and one of the fastest-growing urban areas, Kisumu is an ideal site for monitoring how e-mobility interacts with urban development because while it has attained city status, it is still 'small' enough to possess more manageable complexities [104].

Fast-paced urbanization in the city is accelerating issues surrounding transport emissions, energy infrastructure, and urban sprawl [105]. However, Kisumu remains an interesting choice for leading e-mobility solutions given its importance as a transportation hub, located in the western part of Kenya and ongoing efforts to integrate the use of renewable energy into regional development plans [106]. This research asserts that an analysis of selected e-mobility initiatives in Kisumu could generate local insights into how e-mobility impacts sustainable urban development in African secondary cities that are often neglected while attention is paid to megacities such as Nairobi [64, 107]. Taking Kisumu as a case study, what can we learn from e-mobility initiatives in the city to understand broader strategies for electrifying transport across Kenya? Kisumu makes for a valuable local case for how e-mobility powered by renewable energy impacts urban development in the context of fast urbanizing cities in Africa.

A case study of Kisumu

This section focusses on Kisumu's e-mobility experience and the impacts observed. By studying selected local initiatives and projects, it evaluates Kisumu's unique context for e-mobility adoption, and how they have impacted the city's urban development from an environmental, economic, and social perspective.

Overview of Kisumu's urbanization and transport challenges

The rapid urbanization of Kisumu has altered its landscape with urban and peri-urban areas expanding to accommodate the rising population [108]. This rising population has led to an increased demand for affordable and cost-effective transport solutions. The city, like other cities in the country, heavily depends on unregulated transport modes such as matatus (minibuses) and boda-bodas (motorcycle taxis) for urban-peri-urban connections [109]. While these vehicles are indispensable to the daily commuting and freight needs of urban residents and their peri-urban neighbours [110], they are also major emitters of the city's transport-related greenhouse gas emissions. This has public health consequences for the city and its population [111]. Older adults, children and persons with compromised health are more likely to suffer from respiratory diseases, such as asthma and bronchitis, or other chronic conditions due to these pollutants [112].

Boda-bodas specifically are found in large numbers in Kisumu, given their ability to manoeuvre through traffic and narrow paths, with over 130,000 riders registered.[2] Their growing numbers have already contributed to increased air pollution, noise pollution, and traffic congestion. Recent studies indicate that boda-bodas are a major source of urban air pollution due to the high emission rates of particulate matter (PM) and nitrogen oxides (NOx) [113].

This gravitation towards boda-boda use, coupled with a growing fleet of other forms of vehicles in the city, leads to a higher energy dependence on fossil fuel in the city, putting more pressure on the environment and energy systems [114]. In addition, the informality of the sector poses a challenge for developing emission reduction policies primarily targeting this indispensable mode of transport [115]. The introduction of electric motorcycles within Kisumu's mobility ecosystem is thus a suitable entry point for addressing negative environmental and public health outcomes from these vehicles [116].

E-Mobility initiatives in Kisumu and environs

Several e-mobility initiatives have been recorded in Kisumu targeting motorcycles. This paper focusses on three main projects that have demonstrated potential for impact in the five key themes of *environmental sustainability, economic development, infrastructure, policy action, and community participation.* The projects analysed were the WeMobility, SESA, and Energica projects [117]. Alongside these projects, private company initiatives by Roam and Ampersand have also contributed to the entry of e-mobility initiatives in the region and will be highlighted. These initiatives collectively have been directed toward the improvement of the city's mobility through electric motorcycles and in turn, its wider urban development [118].

[2] http://chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.lawyershub.org/Digital%20Resources/Reports/BodaBoda%20Law%20Project%20Report.pdf

WeMobility project

The WeMobility Project, established in 2019 and run by WeTu, is a social enterprise project committed to collaboratively improving the living standards of the communities in which they operate. The project's e-mobility work covers multiple sites in Western Kenya, Kisumu included. Through the concept of circular economy hubs dubbed 'WeHubs' (see Fig. 1), WeTu assembles and leases out electric boda-bodas to registered riders who use them for their livelihood, charge them at the hub and participate in other productive uses such as clean water pumping, cargo deliveries and waste management [119, 120].

In connection to 14 solar-powered energy hubs, over 30 solar-powered charging stations have been established, 40 electric motorcycles and three-wheelers have been introduced and 2 battery swapping stations [121] [119]. The solar charging stations provide clean energy to power the electric motorcycle ensuring that the whole system is truly sustainable. Electric motorcycles powered by clean energy have close to zero emissions and are cheaper to run and maintain in comparison to their fossil fuel counterparts [122]. Creating a network of hubs and charging stations enables community acceptance as it meets the demand for clean energy access with a variety of productive uses including mobility. In addition, the project has generated over 60 full-time jobs in the area, mainly set up as vehicle maintenance and solar charging activities [121].

Smart Energy Solutions for Africa (SESA) project

The SESA Project is a collaborative project between the European Union and nine African countries aimed at providing sustainable energy access technologies and business models with a replicability, scalability and social cohesion focus. In Kenya, the project is being implemented in Kisumu's peri urban site, Katito and surrounding areas where it aims to deploy solar power hubs for e-mobility and other productive uses such as solar pumping of clean water [123]. The site was selected based on its peri-urban dynamics, in which public transportation is essential for everyday living and where fossil fuel-based motorcycles have caused significant pollution [124].

SESA has established one solar living lab in Katito and a solar-powered charging hub for electric boda-bodas, that are under progressive testing and monitoring to record performance, challenges and observable impacts at the site and its environs. This solar-powered living lab hubs facilitates the charging of electric motorcycle batteries and enables local businesses to transition to green energy through access to productive uses at the hubs such as water pumping. The hub also mitigates additional burden on the national grid while promoting Kisumu's renewable energy transformation. The hub has already saved an estimated 1.17 million kWh of solar energy, a fundamental part of lowering emissions and the city's average carbon footprint [125]. With the deployment of electric vehicles, an estimated 12,053 metric tons less CO_2 annually is being emitted through the electrification of two-wheelers such as boda-bodas, and projections show that this will increase with growing electric vehicle adoption [125].

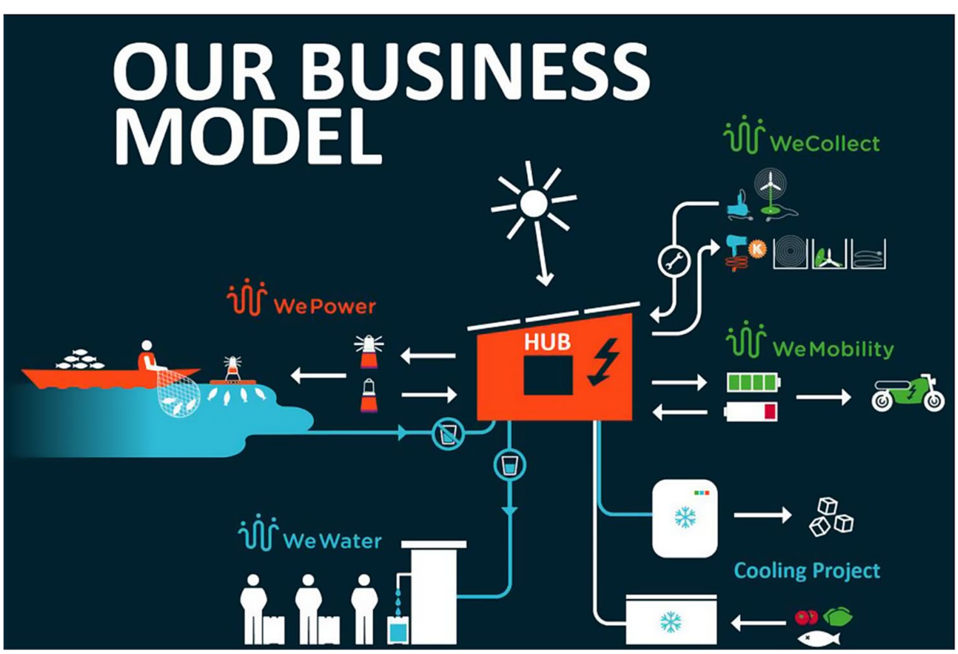

Fig. 1 WeTu project business model concept [119]

The work being carried out in Katito builds up on previous efforts by WeTu in WeMobility as discussed above. This approach exemplifies how productive uses can be coupled with renewable energy and e-Mobility solutions in peri-urban contexts [126, 127]. Figure 2 below presents a visual layout of the Katito hub linking e-mobility powered by renewable energy to productive uses.

Energica

Energica, a parallel project to SESA, has shifted its focus towards the electrification of the Kisumu boda-boda sector in both the urban and surrounding regions like Nyakach and Muhoroni [128]. This initiative has introduced electric motorcycles that run on stored solar energy assisting the local community by reducing fuel costs and emissions [129]. Electrifying motorcycles is being worked on hand in hand with local boda-boda operations which is a critical component of the overall transportation system in Kisumu. The project aims to make sure affordable electric motorcycles reach every boda-boda operator [130].

The efforts of the Energica project not only work towards speeding up the electrification of local mobility but also in building up the crucial infrastructure required for a sustainable transition into electric mobility [131]. The missions in Nyakach and Muhoroni will demonstrate the potential of e-mobility solutions for pollution mitigation in peri-urban and rural areas, ahead of larger electrification efforts that can be scaled to cover even the city outskirts surrounding Kisumu [130]. Figure 3 summarizes Energica's project concept in Kenya.

Contributions by Roam and Ampersand

Private companies such as Roam and Ampersand are also contributing to Kisumu's e-mobility transition, with a particular focus on supporting boda-boda riders in urban and peri-urban areas [82].

Roam has rolled out electric motorcycles and is working on converting traditional fossil fuel-powered motorcycles into electric ones in Kisumu's central business district and surrounding urban areas. The company's ongoing work is centred around providing affordable conversion kits and offering training to local mechanics, ensuring that the benefits of electric mobility are accessible to boda-boda operators [58]. Roam designs and manufactures an electric motorcycle called the Roam Air which is specifically designed for the African market bearing interchangeable batteries as well as a portable charger. Detailed adaptations and design of the Roam Air is targeted towards rugged terrains while affordability, functional design and performance are also of importance. The electric motorcycle features a unique design with a frame that supports two batteries at a time and can hold 220 kg load, a detail that is important for boda-bodas riders who ferry both people and heavy goods [132]. Roam is a contributing partner to the Energica project mentioned above.

On the other hand, Ampersand is implementing a battery-swapping model for boda-boda riders in Awasi and Maseno to replace drained batteries with freshly charged ones. This system reduces downtime, allowing riders to keep on working without the wait times of conventional charging [133]. The model has worked quite well given

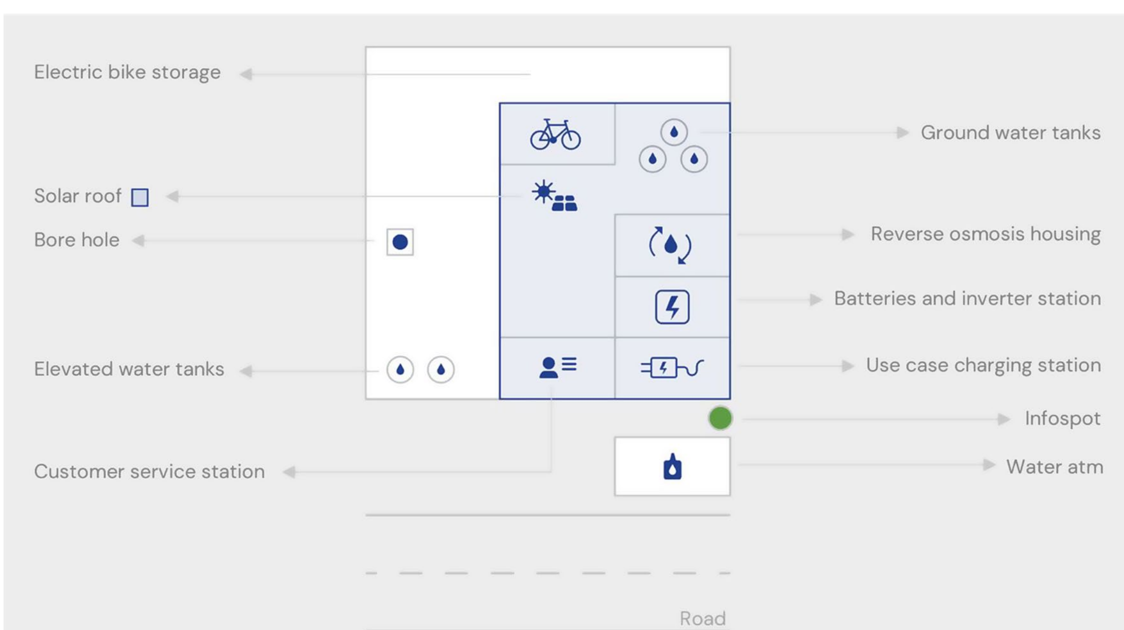

Fig. 2 Layout of the SESA living lab in Katito, Kisumu County [124]

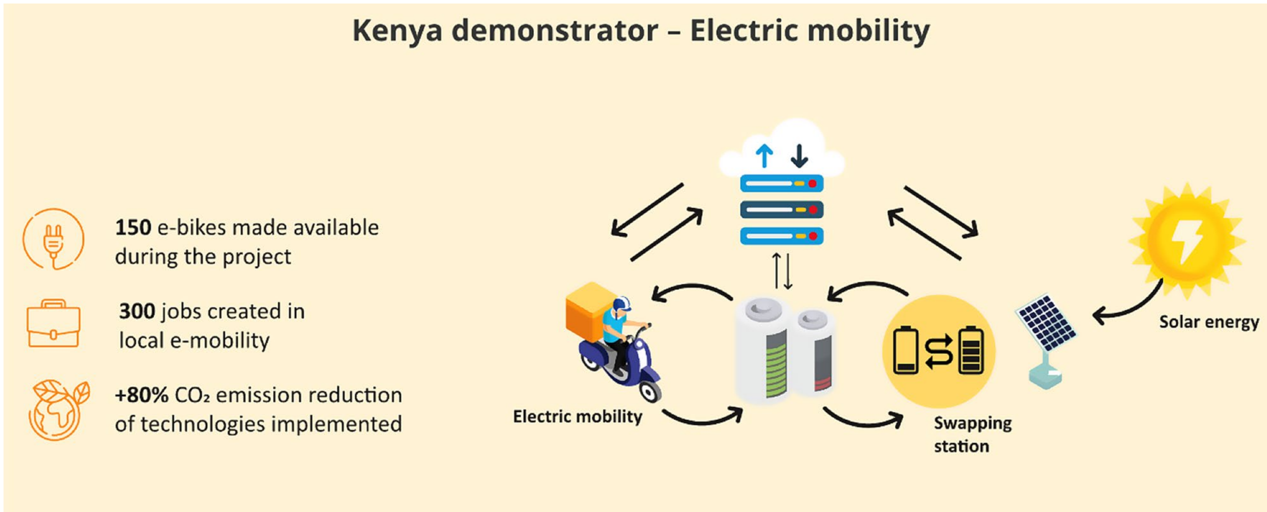

Fig. 3 Energica's project concept covering Nairobi and Kisumu, Kenya [130]

the high demand for accessible boda-boda services. Ampersand aims at integrating its business model and technology within the scope of riders' activities. Riders borrow smart, on-demand batteries from the accompanying network of Ampersand swap stations. With their solution, the riders realize the benefits of e-mobility without incurring the initial expense or risk in the acquisition of a lithium battery pack or incurring longer downtimes in the wait of battery recharge. Renting a charged battery from Ampersand helps drivers reduce costs by about 45% as compared to fuel and oil changes. Each battery lasts for around 350,000 km but delivers depending on the nature of work done, the roads used, and the weight carried about 50–110 km per swap. This means that there is less of a requirement for drivers to swap out as they would otherwise have done with petrol fuelled vehicles [134].

Summary

The WeMobility Project, SESA, and Energica are changing Kisumu's transportation scenario by focusing on sustainable and renewable energy electric mobility solutions. These activities around the Lake Victoria Basin development are lowering emissions while assisting local livelihoods. Roam and Ampersand have also contributed to these efforts by introducing low-cost electric motorcycles with their battery swapping services within urban/ peri-urban areas of Kisumu. Collectively, these initiatives are laying a foundation for future upscaling and establishing a cleaner and environmentally sustainable transport system for Kisumu.

Impact of e-mobility initiatives in Kisumu and its environs

The e-mobility projects in Kisumu and its surroundings are having marked and continuously enduring effects on the environmental, economic, and societal aspects of urban development. The projects are transforming the face of transport in Kisumu and the benefits are vast. This is largely influenced by their role in vehicle electrification and its impact on renewable-energy-powered ecosystems beyond transportation [135]. This section presents the resultant outcomes from these initiatives based on the five key themes of *environmental sustainability, economic development, infrastructure, policy action, and community participation (see* Table 2). It is important to acknowledge that this review is solely based on literature review and controlled surveys. A more comprehensive evaluation may be needed for additional insight.

Environmental impacts

As highlighted in Table 2, the collective environmental gains from the initiatives of WeMobility, SESA, Energica, Ampersand and Roam in Kisumu are immense and varied. These projects in combination assist in the overall carbon mitigation of the transport sector in Kisumu through the adoption of electric and sustainable mobility solutions [130]. This mitigation of greenhouse gases is commendable as it helps to reverse climate change impacts and assists Kisumu in its task of lowering urban carbon emissions [119, 124, 126].

By incorporating solar energy use in their operations, there is a lessened dependence on non-renewable sources for urban-peri urban transportation purposes. Electric motorcycles recharged using solar energy, increases the sustainability of the whole system. Such applications of solar energy use enhance the energy self-sufficiency and resilience of Kisumu and by so doing, sets the city as a champion of sustainable urbanization and renewable energy use [132, 134].

Table 2 E-Mobility initiatives in Kisumu and Environs and Thematic Impacts

	WeMobility	SESA	Energica	Others: Roam, Ampersand
Environmental sustainability	-Transitions fossil motorcycles to electric power -Powered by renewable energy, solar -Establishes circular-economy hubs	-Introduces electric motorcycles from the onset -Powered by renewable energy, solar -Establishes economy hubs called living labs	-Introduces electric motorcycles from the onset -Powered by renewable energy, solar -Establishes solar energy swapping stations	- Introduce electric motorcycles into Kisumu -Transition fossil-based motorcycles to electric power
Economic development	-Develops new skills through workshops and trainings -Creates jobs for motorcycle operators and those working at the hubs -Saves costs through renewable energy use, rental models and sustainable waste management	-Develops new skills through workshops and trainings -Creates jobs for motorcycle operators and those working at the hubs -Saves costs through renewable energy use -Tests and validates various business models for productive use of solar energy	- Creates jobs for motorcycle operators through the deployment of electric motorcycles -Saves cost through battery-swapping and renting models	- Create jobs for motorcycle operators through the deployment of electric motorcycles -Save cost through battery-swapping and renting models
Infrastructure	-Impacts infrastructure by setting up solar energy hubs -Creates a network of charging stations -Establishes battery swapping stations	-Impacts infrastructure by setting up solar energy hubs -Creates a network of charging stations	-Impacts infrastructure by creating a network of battery-swapping stations	-Both establish battery swapping stations
Policy action	-Responds to the government policy provisions discussed in section "Government policy support" and "Progress in public-private-partnerships (PPPs)" -Works closely with the County Government(s)	Responds to the government policy provisions discussed in section "Government policy support" and "Progress in public-private-partnerships (PPPs)" -Works closely with the County Government(s)	Responds to the government policy provisions discussed in section "Government policy support" and "Progress in public-private-partnerships (PPPs)" -Works closely with the County Government(s)	Respond to the government policy provisions discussed in section "Government policy support" and "Progress in public-private-partnerships (PPPs)" -Work closely with the County Government(s)
Community participation	-Works with the wider community through participatory training workshops at the hubs	-Works with the wider community through participatory training workshops at the living labs	-Work with local boda-boda riders	-Work with local boda-boda riders

Improvements in air quality benefit public health. As electric mobility solutions are adopted by more people, the reduction of nitrogen oxides and particulate matter will mean less respiratory and cardiovascular diseases in the population (Schöne, Dumitrescu, & Heinz, 2023). Overall, these interventions are gradually contributing to better air quality in Kisumu, especially within urban centres that have been characterized by elevated levels of the pollutant particulate matter and nitrogen oxides stemming primarily from fossil-fuel-energies [136].

Economic impacts

These projects have generated various employment opportunities in the production, maintenance, and deployment of electric vehicles and renewable energy infrastructure. For example, Ampersand and Roam's focus on local manufacturing and assembly mean less imports and more economic value within the community through localization of production. This strengthening of local market capabilities and skills of the populace contributes to future sustainability of the economy in Kisumu [132, 134].

The provision of cheap and effective electric vehicles expands the transportation market, leading to increased economic activity since majority of boda-boda riders belong to the lower income segment of society. Reducing the expenses of this group gives them more resources to exploit in other sectors of the local economy such as buying food, water etc. Better mobility and increased economic capability are the foundation upon which markets, education and health can be expanded thus resulting in higher economic output and social welfare [137].

Since these projects decrease dependence on fossil fuels, they also reduce energy expenditures as well as increase energy reliability. The construction of solar energy installations generates new businesses and draws funds both locally and internationally, promoting economic growth. The SESA and Energica projects for instance have both been funded by the European Union's Horizon 2020 research and innovation programme which has enabled the activities implemented on the ground [124, 130].

Thus, the synergetic effect of these contribute to tangible growth in the economy. They promote employment opportunities, protect local economies, decrease traffic and energy costs, and expand outreach to basic services improving the overall economic status of the population (See Table 2).

The high upfront cost of electric vehicles, particularly motorcycles, remains one of the biggest challenges to their widespread adoption in Kisumu. While projects like SESA, WeMobility, and Ampersand have introduced leasing and battery-swapping models that reduce some of the financial burden, many boda-boda operators still struggle to afford electric motorcycles [138]. These operators, who are often from low-income backgrounds, rely heavily on daily earnings and are risk-averse when it comes to high-capital investments.

Although electric motorcycles offer significant savings in fuel and maintenance costs over time, the initial purchase price is still a major deterrent. Electric motorcycles are typically 30–40% more expensive than their gasoline-powered counterparts, making it difficult for operators to fully switch without accessible financing options [139]. Government subsidies, grants, and low-interest loans will be essential in lowering this financial barrier and encouraging more widespread adoption of electric vehicles.

Finally, while e-mobility initiatives have shown promise, additional investment is needed to maximize their advantages. To make e-mobility a scalable option, the investment needed for setting up charging infrastructure must be established, particularly in urban and peri-urban areas. Without such investments, the progress to date may stall and prevent a wider shift to electric mobility in Kisumu and surrounding areas.

Infrastructural impacts

The implementation of solar charging stations and energy hubs (Table 2) are one of the more significant infrastructural impacts of these projects. Such infrastructure not only accelerates the shift to electric mobility but also fosters a cultural shift to productive use of renewable energy sources [44]. The projects are pushing the limits by establishing new infrastructure thereby creating real and tangible change in Kisumu [36].

A renewable and off-grid energy core integration, as seen in the SESA project, enhances the overall resilience of e-mobility infrastructure in Kisumu [137]. Solar off-grid systems offer grid reliability and capacity as a dependable energy source for domestic and commercial activities. It is not affected by national or sub-national power outages, relies on an unlimited energy source and has a controlled complexity since it is housed in a community-managed living lab [140, 141].

Additionally, the increased effort towards sustainable mobility have enabled enhancements in the digital landscape. Ampersand and Roam, for instance, use cloud-based technologies to manage their battery systems. SESA uses InfoSpots to sensitize and educate the local community on the benefits of renewable energy. These ideas are novel in the context of Kisumu and have thus contributed to the growth of the digital infrastructure sphere of the city [4]. Looking further ahead, there will continue to be a need for the integration of smart city technologies such as traffic management systems, ride-sharing services, integrated mobility applications to enhance the functionality and user experience scaled up transport systems in the region [132, 134].

Although progress has been made, e-mobility infrastructure in Kisumu remains in the early stages of development and is yet to achieve the much-needed comprehensive framework [142]. Operators in more remote areas still lack easy access to charging facilities, which hinders the broader adoption of electric vehicles in these regions [28]. The need for widespread, reliable charging stations is particularly urgent given the ongoing expansion of electric motorcycles and public transport vehicles in Kisumu. Additionally, investments in grid stability and further expansion of off-grid solar hubs will be necessary to create a reliable and scalable charging infrastructure. Without addressing these gaps, the risk of limited scalability for e-mobility remains a significant concern.

Policy impacts

The policy impact synthesis of the WeMobility, SESA, Energica, Ampersand and Roam projects in Kisumu (See Table 2) illustrate how these projects are consistent with the existing policy framework in the country while also identifying the policy gaps. These projects respond well to the goals of Kenya's Vision 2030 and the Sustainable Development Goals of the United Nations by assisting in the provision of clean energy sources, reduction of emissions and improvement of urban transport [3, 143]. They also draw from the Energy Act 2019, with its provisions for renewable energy, and the National Climate Change Action Plan (NCCAP) which pursues goals for a reduction of greenhouse gas emissions, as examples of these National frameworks in action [61].

However, they also point to deficiencies in implementation of policies and provide avenues for improvement. Improved tax rebates and other subsidies for electric vehicles would speed up the process of rapid emergence of electric mobility [34]. There should be more emphasis on the provision of more integrated sustainable transport solutions that will include simple, off-grid EV charging structures, bicycle paths, footpaths and mass transit. Improved mechanisms for participation of the private sector such as faster procedures for project sanctioning and co-funding as well as sharing of experiences can also improve collaboration [119, 126, 130].

Further improvement in regulatory structure is required to facilitate better adoption of distributed renewable energy sources particularly solar energy [94]. The simplification of procedures for the issuance of licenses, grid connection requirements as well as the provision of subsidies to the operators of small renewable energy plants will enhance the deployment of clean energy [127]. Policies enhancing the role of new technologies in urban transportation, such as real-time data flows in traffic management or the development of smart cities, may increase the efficiency and quality of urban transport systems [70].

Shortly, whereas these projects make good use of Kenya's current policy provisions, they also bring to the fore the need for policy strengthening to improve urban sustainability. By doing so, the country will be better placed to strengthen its policies to promote localized urban improvement that is sustainable, resilient and efficient in its cities, including Kisumu.

Community impacts

The collective community impact of WeMobility, SESA, Energica, Ampersand, and Roam Projects is from the perspective of improved quality of living and social welfare (Table 2). First, these projects lead to better health outcomes for the people by facilitating electric mobility instead of the use of fossil fuel-powered motorcycles helping to combat air pollution. The lowered air pollution contributes to less respiratory and cardiovascular illnesses, which means an improved health level in the society in the long run [144].

Participatory processes such as community participation help to sensitize and develop the appreciation of the need for sustainable mobility and clean energy [145]. Kisumu residents have received knowledge and training opportunities through the hubs as well as through digital channels such as Infospots and cloud-based applications [113]. A more informed society is a better society as they can make knowledge-based decisions in improving their immediate environment. Communities need to be empowered to drive their own development even after such projects have come to a closure [146].

These projects have also established a gender and youth component whereby women and young people have been active participants in the day-to-day running of various aspects of the projects, particularly in the energy hubs and living labs. This inclusive approach makes for a better society where economic power plays are lessened and vulnerable groups of the population are empowered, albeit to varying extents [125]. Overall, these projects contribute collectively to the climate change awareness in Kisumu [126].

Reports from these projects however indicate that there is still need for further sensitization work. There remain questions about electric motorcycles' durability and safety performance as well as the battery life concerns by many operators [146]. These concerns are magnified by the fear of the unknown which surrounds change, particularly in the case of daily incremental earnings on vehicle performance as it applies to informal transport [147]. To overcome this challenge, more robust public education and awareness campaigns are essential. To help reduce resistance and build confidence in the technology, more pilot programs could allow boda-boda riders to try electric vehicles before purchasing them. In addition, partnering with boda-boda associations can help spread the message and drive deeper usage across operators.

Lessons learned and policy recommendations

As seen in the selected case studies, the experience of transitioning to e-mobility in Kisumu has brought important lessons on how to start restructuring and electrifying transport systems in secondary cities of sub-Saharan Africa. These highlights emphasize renewable energy integration, public-private partnerships, financial accessibilities, and education campaigns to make widespread adoptions of electric mobility solutions. This section draws on the key lessons learned to propose focused policy recommendations that may inform future undertakings in Kisumu and similar urban settings across the region.

Lessons learned

Integrating renewable energy is essential for sustainable e-mobility

One of the biggest takeaways from the e-mobility projects in Kisumu is the importance of electric mobility being integrated with renewable energy. The success recorded in solar-powered charging hubs, such as **Katito**, demonstrate that a comprehensive solution to addressing sustainability concerns by e-mobility is beneficial [58].

The leasing and battery-swapping models make e-mobility more accessible

The leasing and battery-swapping models show the importance of making electric mobility affordable to low-income groups, especially boda-boda operators. These models reduce the initial purchase price of electric vehicles and e-mobility more accessible [69, 148]

Public-Private-Partnerships are key to scaling e-mobility

These projects have benefitted from Public-Private Partnerships (PPPs) with the County Government of Kisumu to build solar-powered charging infrastructure at three locations in Kisumu City. The importance of promoting future partnerships is underlined by the success associated with such undertakings in advancing e-mobility [149]. Governments could stimulate these partnerships by adopting policy incentive levers as financial incentives and regulatory frameworks to mobilize private sources of international finance for investment in electric mobility.

Education and awareness are crucial for adoption

Electric motorcycles face resistance from many boda-boda operators, who are initially misinformed about their reliability, performance, and true cost [150]. Through pilot programs and public engagement campaigns, operators have been gradually convinced of the long-term financial and environmental benefits of electric vehicles. Public education campaigns, supported by local government and the private sector, will be crucial for further promoting e-mobility. Demonstrating the advantages of electric motorcycles, such as lower fuel costs and reduced maintenance, can help overcome resistance and encourage more widespread adoption [151]. Additionally, collaborating with boda-boda associations to educate riders about the benefits of electric mobility should be scaled up.

Infrastructure expansion must keep pace with demand and context

Although the absence of charging infrastructure poses a major challenge in advancing e-mobility in Kisumu in general, the distinctive features of electric two-wheelers can also counter this problem. Unlike larger electric vehicles which depend on complex and sophisticated charging systems, which are few in number and very specific, motorcycles and tuk-tuks can be charged from normal household electric sockets that are found almost everywhere. Consequently, the arrangement and installation of charging systems can be simplified and made cheaper, leading to faster adoption of e-mobility into the local transport framework [60].

Policy recommendations

The policy landscape for e-mobility in Kenya has made some initial progress, particularly with the introduction of tax incentives and efforts to develop infrastructure. However, there is a need to strengthen these measures to accelerate the adoption of electric vehicles (EVs) and promote the growth of supporting infrastructure. Based on the current policy landscape, the following recommendations aim to address the existing gaps and reinforce Kenya's commitment to sustainable transport solutions.

Strengthen financial incentives for e-mobility adoption

Kenya has already taken important steps to encourage e-mobility by reducing import duties on electric vehicles and offering tax exemptions for electric motorcycles. However, to further stimulate adoption, these incentives need to be expanded. The government should consider:

- **Expanding tax exemptions** to cover more types of electric vehicles which are essential for public transport systems in urban areas like Kisumu [74].
- **Increasing subsidies** for electric vehicle purchases, particularly targeting low-income users such as boda-boda operators. Introducing low-interest loans and financing schemes could make electric motorcycles more affordable, enabling broader access to e-mobility [73].
- **Developing long-term financial incentives** for businesses investing in e-mobility, including tax breaks or grants, to encourage private sector participation [116].

Expand public-private-partnerships (PPPs) for infrastructure development

The success of public-private partnerships (PPPs) in projects like SESA and WeMobility demonstrates the potential for scaling e-mobility infrastructure. To ensure infrastructure development keeps pace with growing demand, the government should:

- **Encourage further private sector investment** in solar-powered off-grid stations, particularly in rural and peri-urban areas where infrastructure is lacking. Expanding the existing partnerships could help provide comprehensive coverage for the charging needs of electric motorcycles, ensuring that rural operators can access the same infrastructure as urban users [152].
- **Create more incentives for private companies** to develop renewable energy-powered infrastructure, such as solar-powered charging hubs, which would reduce pressure on the national grid and promote sustainable energy use [153, 154].

Strengthen regulatory frameworks for e-mobility

Although Kenya's National Climate Change Action Plan and the formation of the E-Mobility Taskforce are positive steps, the regulatory framework needs to be more comprehensive to support widespread e-mobility adoption. Key areas for improvement include:

- **Standardizing charging infrastructure** to ensure compatibility across different regions and vehicle types, simplifying the scaling up of electric two-and-three wheelers [128].
- **Establishing clear regulations for battery disposal and recycling** to minimize environmental risks associated with used batteries. These would involve drafting rules to safely dispose of electric vehicle

Table 3 A summary of policy recommendations

Policy area	Current status	Opportunities for strengthening
Import duties & Taxation	Reduced import duties on electric vehicles; tax exemptions on electric motorcycles [49]	Expand tax exemptions to cover more types of electric vehicles, including electric buses.
Subsidies & incentives	Limited subsidies for electric vehicle purchases; plans to increase financial support [23]	Increase government subsidies, and introduce low-interest loans for operators, particularly boda-boda riders.
Infrastructure development	Solar-powered charging stations in urban and peri-urban areas through partnerships [159]	Expand charging infrastructure to rural areas; increase investment in grid reliability.
Renewable energy integration	Policies promoting the use of renewable energy in e-mobility projects, e.g., solar-powered hubs	Further, integrate solar and other renewables into all e-mobility projects
Public-private partnerships (PPPs)	Encouraged through government policies; and existing collaborations [68]	Increase incentives for private sector involvement, especially in rural areas.
Regulatory frameworks	National Climate Change Action Plan includes targets for e-mobility; an e-mobility task force formed [82]	Develop clearer regulations for battery disposal, recycling, and standardization of infrastructure.
Public awareness & education	Early-stage public awareness campaigns; low engagement with informal transport sectors [46]	Broaden public awareness efforts; target informal transport sectors with education campaigns

batteries and encouraging battery recycling projects [60].

- **Create safety standards for electric vehicles and associated charging stations** to protect operators as well as passengers and the infrastructure in general [77].

Expand public awareness campaigns and capacity building

While some initial awareness campaigns have been initiated, more will be required. The government must continue to collaborate with the private sector to further take action to address these needs.

- **Launch large-scale awareness campaigns** for boda-boda operators and the general public. Such advertising should serve the dual purpose of publicizing the economic and environmental advantages of electric vehicles while proving that their low-cost implications on operational, maintenance, and fuel expenses are false [90].
- **Create training and skills-building opportunities** geared toward local mechanics and technicians to maintain the expanding pool of electric vehicles. For example, in these programs operators can deliver locally accessible vehicle maintenance capabilities to local experts which is essential for the long-term sustainability of e-mobility [80, 155].

Integrate e-mobility into national and local urban planning

To ensure that e-mobility becomes a central part of Kenya's transport future, it should be integrated into both national and local urban planning processes. This would involve:

- **Prioritizing the inclusion of charging infrastructure** in future urban development plans, particularly in rapidly growing cities like Kisumu. By embedding renewable-powered charging stations in these plans, urban areas can accommodate the expected increase in electric motorcycles, three-wheelers and possibly buses [156].
- **Developing electric public transport systems** as part of urban mobility strategies. In cities like Kisumu, transitioning buses and public service vehicles to electric alternatives will be crucial for reducing emissions and improving air quality [157, 158].

The Table 3 below presents a summary of the policy recommendations outlining strategic policy areas, the current status of each and the opportunities for strengthening these policies.

Conclusion

In essence, Kisumu's transition to electric mobility (e-mobility), led by key initiatives such as WeMobility, SESA, and Energica, marks a major advancement toward building a more sustainable, efficient, and equitable urban transport system. These projects showed the significant opportunities to introduce EVs with renewable energy integration, including off-grid solar-powered charging stations for electric boda-bodas. These efforts have shown early promise, but they also provide key lessons learned and showcase some of the obstacles that need to be overcome for e-mobility in Kisumu and other similar areas to gain long-term acceptance.

The environmental benefits of e-mobility are already becoming evident with significant reductions in greenhouse gas (GHG) emissions noted in places like Katito, Nyakach, and Mbita. These initiatives have not only led to cleaner air but also appreciative participation in climate change.

From an economic perspective, e-mobility has created job opportunities and poverty reduction. In some circumstances, battery-swapping stations and leasing models have made it possible for low-income boda-boda operators to transition to electric bikes with minimal costs payable upfront. These initiatives have not only to the costs of transportation getting reduced for operators, but also supported local employment. Nonetheless, further measures need to be taken to address financial barriers through additional and stronger incentives such as increased subsidies or attractive financing options.

From a policy standpoint, Kenya has made some commendable policy moves, with incentives for the adoption of e-mobility, but they now need to be reinforced and broadened. The regulatory architecture needs to be revisited to match the growing requisites of the e-mobility industry including safety standards, infrastructure augmentation, and recycling of used batteries. Unambiguous, supportive policies will draw in a greater share of investment and pave the path for faster electric mobility adoption nationwide.

Limited infrastructure remains a critical challenge. The role of infrastructure as demand for electric vehicles continues to grow is key. Developing a broader network of off-grid solar-powered charging hubs will bridge those gaps. In addition, public awareness needs to be increased through education campaigns which will encourage more uptake of electric mobility, especially from the reluctant boda-boda and other informal transport users at the first stage who may not easily embrace new technologies.

The lessons from Kisumu offer valuable insights for urban mobility policy going forward. For Kisumu, focusing on renewable energy integration, expanding public-private partnerships, and strengthening policy support will enable its legacy of sustainable transport solutions to carry onward. This improvement will not only increase the environmental and economic stimulus in the city but also provide a model for other parts of the region to jumpstart electric transitions and help build more sustainable and resilient urban growth plans. Electrification of Kisumu´s transportation system, starting with boda-bodas, is therefore an initiation point in building a sustainable future. Kisumu's experience with transitioning to e-mobility is likely capable of being replicated by other secondary cities in sub-Saharan Africa.

Acknowledgements
The paper was reviewed by Judith's supervisors namely Prof. Abdellah Abarkan (Blekinge Institute of Technology), Dr. Oliver Lah (SESA, Urban Electric Mobility Initiative) and Associate Professor Henrik Ny (Blekinge Institute of Technology).

Author contributions
J.O.M was the sole author of this paper. She prepared the entire manuscript and edited subsequent drafts. Figs. 1–3 were prepared by the projects evaluated. The paper was reviewed by Judith's supervisors namely Prof. Abdellah Abarkan (Blekinge Institute of Technology), Dr. Oliver Lah (SESA, Urban Electric Mobility Initiative) and Associate Professor Henrik Ny (Blekinge Institute of Technology).

Funding
Open access funding provided by Blekinge Institute of Technology.
This research has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 101037141.

Data availability
Data is provided within the manuscript or supplementary information files.

Declarations

Competing interests
The authors declare no competing interests..

Received: 14 October 2024 / Accepted: 17 February 2025
Published online: 10 March 2025

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