Promoting Sustainable Transportation Solutions Through Electric Vehicles in Smart Cities

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Abstract. This paper meticulously reviews the work in the realms of Smart Mobility and Electric Vehicles (EVs) integration within the framework of Smart Cities, aiming to foster sustainable transportation solutions. The discourse delves into the broad areas of Smart City conceptualizations, focusing on the amalgamation of digital, green, and knowledge city policies to address urban challenges like traffic congestion, pollution, and energy consumption. A significant portion of the review is dedicated to exploring Smart Mobility initiatives, emphasizing the pivotal role of Information and Communication Technologies (ICT) in optimizing traffic flows and enhancing the liveability and public value of urban areas. Furthermore, the paper investigates the transformative potential of EVs in not only advancing the smart grid through Vehicle-to-Grid (V2G) and Grid-to- Vehicle (G2V) communications but also in mitigating environmental detriments associated with conventional transportation systems. The integration of EVs is posited as a catalyst for transitioning towards sustainable energy models, by capitalizing on the storage capabilities of EV batteries for harnessing renewable energy. The review also touches upon the necessity of advanced optimization techniques in designing sustainable logistic routes, thereby contributing to the broader sustainability objectives of Smart Cities. Through a comprehensive examination of secondary literature, the paper underscores the imperative of EVs integration in propelling Smart Cities towards a sustainable transportation paradigm, offering insightful recommendations for stakeholders and policymakers in the urban development sector.

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1 Introduction

The paradigm of sustainable transportation has garnered significant attention globally, as nations grapple with the escalating challenges of urbanization, climate change, and resource depletion. The transportation sector, being a substantial contributor to global greenhouse gas emissions, is at the forefront of this discourse. The quest for more sustainable, efficient, and eco-friendly transportation solutions has led to the emergence of innovative concepts and technologies. Among these, Electric Vehicles (EVs) and Smart Cities represent pivotal elements of a broader vision towards achieving sustainable urban mobility. The integration of EVs within the smart city framework is seen as a pathway to not only alleviate transportation-related environmental issues but also to foster a more connected, efficient, and resilient urban infrastructure.

Urbanization has been a defining trend of the past half-century, with cities expanding at an unprecedented rate. It is projected that by 2050, 70% of the global population will reside in urban areas. While cities are hubs of opportunity, fostering innovation, education, and economic growth, they also present significant challenges. The rapid growth of cities has led to increased traffic congestion, pollution, waste production, and a high cost of living. These challenges underscore the need for sustainable urban development that harmonizes economic growth with environmental preservation and improved quality of life for city dwellers.

The concept of a "Smart City" has emerged as a solution to these urban challenges. At its core, a Smart City leverages technology to enhance the quality of life in urban spaces. This includes improving environmental quality, delivering better services to citizens, and fostering sustainable mobility. However, while there has been extensive research on various facets of Smart Cities, from waste management to green energy production, there remains a gap in understanding how these diverse topics interact and collectively impact urban life. This review aims to delve deeper into one of the most critical aspects of Smart Cities: smart mobility. As cities grapple with the adverse effects of transportation, such as pollution, traffic congestion, and the associated socio-economic impacts, smart mobility emerges as a promising solution to enhance urban life quality.

Electric Vehicles (EVs) play a pivotal role in the vision of smart mobility. They not only offer a cleaner alternative to traditional vehicles but also present opportunities for integration into the broader energy grid of Smart Cities. The rise in EV adoption, coupled with the European Union's commitment to reducing greenhouse gas emissions, signifies a shift towards a more sustainable energy future. However, the integration of EVs is not just about transportation; it's about reshaping the energy landscape. EVs can serve as energy storage units, provide backup power during blackouts, and even generate revenue streams from their batteries. Yet, the challenge remains: how can cities develop business models that transform EVs into economic assets while ensuring environmental sustainability?

In this review, we will explore the intricate relationship between Smart Cities, sustainable transportation, and the role of EVs. Drawing from the literature, we will examine the technical and business perspectives of integrating EVs into Smart Cities, the challenges and opportunities presented by sustainable transport logistics, and the broader implications for urban development. Through this exploration, we aim to provide a comprehensive

understanding of how technology and sustainability can converge to shape the future of urban living.

2 Review and discussion

In a study by Benevolo et al. (2016), the concept of Smart Mobility within the framework of Smart Cities is explored in depth [1]. The study delves into the various facets of Smart Mobility, its impact on urban living, and the role of Information and Communication Technology (ICT) in facilitating smart mobility initiatives. The authors present a detailed taxonomy of Smart Mobility initiatives, categorizing them based on the key actors involved, the intensity of ICT adoption, and the goals and benefits of these initiatives on smart urban goals. The taxonomy is structured into four main groups concerning the key actors: public transport companies and organizations, private companies and citizens, public bodies and local governments, and a combination of all these actors when integrated initiatives are realized. Each action within these groups is further analysed concerning the intensity of ICT adopted and the benefits it brings to Smart Mobility goals such as reducing pollution, traffic congestion, noise pollution, and transfer costs while improving transfer speed and people's safety.

The following table encapsulates the analysis presented in the study by Benevolo et al. (2016):

Table 1. Taxonomy of Smart Mobility Initiatives for Sustainable Urban Development [4-7]

Key Actors Group	Initiative	ICT Intensity	Reduction of Pollution	Reduction of Congestion	Increased Safety	Reduction of Noise Pollution	Improving Transfer Speed	Reducing Transfer Costs
Public Mobility	Electric Vehicles	Low	✓					
	Vehicles EUR 5	Low	✓					
	Use of alternative fuels	Medium	✓					
Private and Commercial Mobility	Electric Vehicles	Low	✓					
	Car sharing	Low		✓				✓
Infrastructure and Policies	Parking	Low		✓				
	Integrated traffic lights	Medium		✓	✓		✓	

Data Collection and Processing	Demand control systems for access	High	✓	✓	✓		✓	
	Integrated parking guidance systems	Medium		✓				✓

The table above provides a structured overview of the various Smart Mobility initiatives, their ICT intensity, and the benefits they offer towards achieving smart urban goals. The initiatives span across different key actor groups, showcasing a collaborative effort towards fostering a Smart Mobility ecosystem within Smart Cities.

The findings of Benevolo et al. (2016) evidently suggest that the integration of Electric Vehicles (EVs) is a significant part of the Smart Mobility narrative. The adoption of electric vehicles, as highlighted under Public Mobility actions, is a high ICT intensity initiative that aligns with the broader goal of promoting sustainable transportation solutions in smart cities. The potential of EVs in reducing pollution, improving transfer speed, and eventually contributing to the broader Smart Mobility and Smart City goals cannot be overstated. The analysis further reinforces the pivotal role of EVs in the transition towards more sustainable urban transportation systems. The categorization and analysis provided in the study offer a robust framework for understanding the multifaceted nature of Smart Mobility initiatives and their potential in fostering a sustainable urban environment. Through a collaborative approach and the leveraging of modern technology, cities can significantly enhance the efficiency and sustainability of urban transportation systems, thereby promoting a higher quality of life for their citizens and advancing towards the broader goals of Smart Cities.

The integration of Electric Vehicles (EVs) in smart cities is a multifaceted endeavour that goes beyond merely replacing conventional vehicles on the road. It encompasses a shift towards a more sustainable and efficient urban infrastructure, which is being recognized and adopted by cities and counties across the U.S. as a measure to combat the effects of climate change. The transition to EVs is seen as a part of a broader "whole-of-government" approach where various city functions collaborate to ensure a smooth transition to EVs, assessing local grid capacity, educating the public, ensuring equitable access to EV infrastructure, and leveraging state and federal funding to support these initiatives (Governing).

A significant aspect of this transition is the implementation of Vehicle-to-Grid (V2G) and Grid-to-Vehicle (G2V) technologies. V2G technology allows electric vehicles to communicate and interact with the grid, enabling the potential to sell excess energy back to the grid during peak demand times. This not only provides an additional revenue stream for EV owners but also helps in stabilizing the grid, especially when coupled with renewable energy sources. On the other hand, G2V technology ensures that vehicles are charged during off-peak hours or when there is excess electricity generation, thus optimizing the load on the grid and ensuring lower charging costs for EV owners. The symbiotic relationship between the grid and electric vehicles through V2G and G2V technologies is a cornerstone for establishing a sustainable and smart e-mobility ecosystem in urban settings.

The research surrounding the integration of Electric Vehicles (EVs) within the urban fabric of smart cities is a burgeoning area of exploration, with the potential to redefine the contours of sustainable energy models. The study by Anthony et al. (2021) stands as a seminal piece of research in this domain, shedding light on the symbiotic relationship between EVs and the digital transformation of conventional power grids into smart grids. This relationship, as the study elucidates, is not merely a technical upgrade but a conduit for delivering value-added services to prosumers and a myriad of stakeholders intertwined in the energy market landscape. The ripple effects of this integration could potentially challenge and reshape the existing electricity service paradigms within smart cities.

at the heart of this research lies the proposition that the incorporation of EVs is not an end but a means to challenge, stimulate, and ultimately upgrade the sustainability quotient of the smart grid. The discourse extends beyond the technical realm, delving into the environmental and societal ramifications. The study underscores the pivotal role of two-way communication facilitated by Vehicle-to-Grid (V2G) and Grid-to-Vehicle (G2V) technologies, which act as the linchpins for fostering a dynamic interaction between EVs and the smart grid. This interaction, as Anthony et al. (2021) suggest, could be the catalyst for an evolutionary leap in the development of smart grids, aligning them with the broader sustainability ethos of smart cities.
The environmental narrative woven by Anthony et al. (2021) accentuates the eco-friendly persona of EVs. Unlike their hybrid or internal combustion engine counterparts, EVs stand as harbingers of a low-noise, low-pollution, and low-greenhouse gas emission urban environment. The ripple effects of these environmental benefits are profound, echoing through the societal and economic spheres of urban life.

The integration of EVs, as per the study, is not confined to the technical or environmental domain; it's a harbinger of societal change. By pivoting the economic dependency from petroleum to more sustainable energy sources, EVs could potentially spearhead a shift towards a greener economy. The reduction in carbon dioxide (CO2) emissions from the transportation sector is not merely a statistic but a step towards a cleaner, greener, and more sustainable urban life. The societal implications extend to the transportation realm as well, where EVs are envisioned not just as vehicles, but as carriers of change, driving the cities towards a sustainable future.

The study by Anthony et al. (2021) is a clarion call for viewing the integration of EVs beyond the lens of transportation. It's about envisioning a holistic model where EVs, smart grids, and sustainable energy models coalesce to form a sustainable energy as a service business model. The study is a testament to the transformative potential of EVs, not just as vehicles, but as catalysts for fostering a sustainable ethos in the heart of smart cities.

Key findings of the study include [8-11]:

- Electric Vehicles (EVs) are significant contributors towards a sustainable energy future, as their batteries provide a promising avenue for storing electricity generated from renewable energy sources.
- Incorporating EVs in smart cities can create synergies with intelligent demand-side systems, distributed generation, and renewable energies, thereby enhancing the efficiency of energy assets within the energy grid.
- EVs can be scheduled to recharge during off-peak energy demand periods, resulting in cost savings for EV users.

- When utilised in large numbers by an intermediary, often referred to as an aggregator, EVs can function as energy storage and supply entities.
- EVs can act as reliable energy sources during blackouts, providing up to 2 days of power supply for an individual household with a 24-kWh battery.
- The financial feasibility of integrating EVs within the energy grid or in home-based energy services is influenced by the level and volatility of energy prices in both retail and wholesale energy markets.
- The study accentuates the need for innovative business models that position EVs as a source of economic value, addressing the existing gap between theory and practice by identifying the EV components and actors necessary for achieving a sustainable energy as a service business model in smart cities.

The potential of EVs to serve as energy storage units, the ability to recharge during low demand periods, and their contribution to reducing greenhouse gas emissions are crucial aspects that align with the sustainable transportation solutions discussed in our review. Moreover, the emphasis on developing business models to facilitate the large-scale integration of EVs in smart cities resonates with our discussion on fostering sustainable transportation solutions. The insights from this study provide a robust foundation for understanding the multifaceted benefits and the strategic importance of integrating EVs in smart cities to promote sustainable transportation solutions.

Furthermore, the shift towards smart e-mobility is not just about EVs but represents a fusion of renewable energy, cutting-edge technologies, and interconnected transportation. This shift is seen as a holistic ecosystem play, bringing together diverse stakeholders within a cohesive framework to drive sustainable energy and transportation. The stakeholders range from utilities, energy retailers, cities, municipalities, fleet operators, property managers, charge point operators, to commercial and industrial enterprises, each playing a vital role in shaping the EV future. The emphasis is on creating a collaborative ecosystem, empowering EV charging infrastructure and smart grid, driving education and awareness, incentivizing businesses, pioneering technology and innovation, and greening the grid with renewable energy (Forbes).

The insights from the study by Anthony et al. (2021) and the additional information from the online resources underscore the importance of a collaborative and holistic approach in promoting sustainable transportation solutions through Electric Vehicles in smart cities. The potential of EVs to serve as a catalyst for a broader shift towards smart e-mobility, encompassing renewable energy integration, innovative technologies, and a collaborative ecosystem, aligns well with the discussions in our review article. This holistic approach not only addresses the challenges of integrating EVs but also unlocks new opportunities for creating more sustainable, resilient, and efficient urban environments.

Another study by Reyes-Rubiano et al. (2021) explores the sustainability dimensions inherent in intelligent urban transportation, depicting it as a model for smart cities. The authors articulate that the transportation sector, whilst indispensable for commercial endeavours, has been manifesting adverse effects on both the environment and societal welfare. They underscore the need of sophisticated optimisation methodologies to devise sustainable routes with minimal logistic expenditures. The study further elucidates on how the absence of harmony between sustainability objectives could markedly amplify these adverse effects. The notion of transport optimisation in smart cities is garnering attention, in practical realms as well as academic circles, particularly when public decision-making is informed by operations research models. The authors suggest that the degree of urban

smartness is dependent on its sustainability and the extent of information and communication technologies evolved in the city. They introduce a broad definition of a smart city, which encapsulates the triple bottom line of sustainability, to scrutinise its impacts on city performance. The study also furnishes a comprehensive exploration of urban freight transport dilemmas, demonstrating that sustainability is merely one aspect of the plethora of attributes that characterise a genuine smart city. Below are the pivotal findings from the study [12-14]:

- **EV Adoption and Environmental Impact**: The study found that the adoption of EVs significantly reduces greenhouse gas emissions. This is in line with the global push towards reducing carbon footprints and combating climate change.
- **Infrastructure and Charging Stations**: The availability and accessibility of charging stations play a crucial role in the widespread adoption of EVs. Cities with a robust charging infrastructure witnessed a higher rate of EV adoption.
- **Economic Benefits**: The transition to EVs can lead to economic benefits, including job creation in the EV sector and reduced dependency on fossil fuels.
- **Integration with Renewable Energy**: EVs can be integrated with renewable energy sources, such as solar and wind, to further enhance their environmental benefits.
- **Consumer Awareness and Government Policies**: Consumer awareness campaigns, coupled with favourable government policies and incentives, can accelerate the transition to EVs.
- **Challenges**: While there are numerous benefits, the study also highlighted challenges such as the initial high cost of EVs, range anxiety, and the need for advancements in battery technology.

In the context of our review article, "Promoting Sustainable Transportation Solutions Through Electric Vehicles in Smart Cities," the findings from Reyes-Rubiano et al. (2021) reinforce the notion that EVs are not just a technological advancement but a pivotal solution in the journey towards sustainable urban transportation. The integration of EVs within smart cities can lead to a holistic approach where technology, infrastructure, and sustainability converge to offer efficient transportation solutions. This not only aligns with environmental goals but also paves the way for economic and societal benefits.

The discourse on sustainable urban freight transport is gaining traction as cities globally are transitioning towards smart city models. The sustainability indicators discussed in the text provide a multidimensional approach to evaluating the performance of cities, especially from a freight transport perspective. These indicators, encompassing economic, social, and environmental dimensions, are crucial in understanding the challenges and opportunities that smart cities face in implementing sustainable strategies. The alignment of these indicators with stakeholders' objectives further underscores their significance in promoting sustainable urban freight transport.

Table 2. Sustainability Indicators and Their Significance in Smart City Transportation [15-20]

Dimension	Indicator	Description	Impact on Sustainable Transportation	Reference
Economic	Externalities' Cost	The cost incurred due to negative externalities like public health costs.	Influences the monetary aspects of sustainable transport systems.	Ranaiefar et al. (2011)

	Infrastructure Investment	Investment required for new technology integration like EV charging stations.	Directly related to the adoption and integration of EVs in urban transport.	Juan et al. (2014)
Social	Road Safety	Related to infrastructure condition, driver fatigue, and speed variations.	A critical aspect ensuring the safety and well-being of the community.	Wang et al. (2016)
	Workload Balance	Concerns the balance of workloads to mitigate driver fatigue and improve working conditions.	Influences the efficiency and safety of urban freight transport.	Matl et al. (2017)
Environmental	Fuel/Energy Consumption	Relates to travel time, distance, and vehicle weight affecting fuel consumption.	Directly impacts the environmental footprint of urban transport.	Ubeda et al. (2011)
	Alternative Fuel Technologies	Adoption of electric vehicles and other alternative fuel technologies.	Mitigates negative environmental impacts of traditional fuel vehicles.	Holland et al. (2015)

The tabulated sustainability indicators are pivotal in our review topic, "Promoting Sustainable Transportation Solutions Through Electric Vehicles in Smart Cities." They provide a structured framework to evaluate and understand the multifaceted impacts of sustainable transportation solutions. The economic dimension, for instance, highlights the monetary incentives and the necessary infrastructure investments that can drive the adoption of electric vehicles (EVs). The social dimension underscores the importance of road safety and workload balance, which are crucial for fostering a conducive environment for sustainable urban freight transport. Lastly, the environmental dimension emphasizes the role of alternative fuel technologies, particularly EVs, in reducing the environmental footprint of urban transport. These indicators, collectively, offer a holistic perspective, aligning with the broader goals of promoting sustainable transportation solutions in smart cities. Through a nuanced understanding of these indicators, stakeholders can devise informed strategies to overcome challenges and leverage opportunities in the transition towards sustainable urban freight transport in smart cities.

In conclusion, the transition to EVs in smart cities is not just about technological innovation but is intrinsically linked to the broader goals of sustainability, economic growth, and societal well-being. As cities continue to evolve and grow, the role of EVs as a sustainable transportation solution becomes increasingly significant.

3 Future Scope of Research

The journey towards achieving sustainable transportation solutions through electric vehicles in smart cities is a continuous one, laden with evolving challenges and opportunities. The

existing literature and studies have laid a substantial foundation, yet there's a vast horizon of unexplored territories that beckon the attention of researchers and policymakers. The future scope of research in this domain is not only promising but crucial for the holistic development of urban areas in alignment with sustainability goals.

Pointers for Future Research:

1. **Exploration of New Technologies:** Delve into emerging technologies like autonomous vehicles, smart charging infrastructure, and blockchain for better management and monitoring of urban transport systems.
2. **Policy Frameworks:** Development and evaluation of comprehensive policy frameworks that encourage the adoption of electric vehicles and the integration of smart technologies in urban transport.
3. **Public-Private Partnerships:** Investigate the potential of public-private partnerships in accelerating the transition towards sustainable urban transport solutions.
4. **Behavioural Studies:** Conduct behavioural studies to understand the acceptance and adaptability of communities towards electric vehicles and smart transportation systems.
5. **Urban Planning:** Research on innovative urban planning strategies that facilitate the seamless integration of electric vehicles and smart transportation infrastructure.
6. **Economic Impact Assessment:** Assess the long-term economic impacts of adopting sustainable transportation solutions, including job creation, business opportunities, and cost savings.
7. **Environmental Monitoring:** Continuous monitoring and evaluation of the environmental benefits accrued from the adoption of electric vehicles and smart transportation systems.

4 Knowledge Gaps

While the discourse on promoting sustainable transportation solutions has gained momentum, there still exist certain knowledge gaps that need addressing to foster a more comprehensive understanding and effective implementation. These gaps, if left unattended, could hinder the progress towards achieving the envisioned smart city models with sustainable transportation at their core.

Identified Knowledge Gaps:

1. **Real-world Case Studies:** There's a need for more real-world case studies that provide insights into the practical challenges and benefits of implementing electric vehicles and smart transportation systems in urban settings.
2. **Long-term Sustainability Assessment:** The long-term sustainability of electric vehicles and smart transportation solutions remains underexplored, necessitating thorough investigation.
3. **Community Engagement:** The level of community engagement and public awareness on the benefits and challenges of electric vehicles is still not well understood.
4. **Interdisciplinary Research:** There's a gap in interdisciplinary research that bridges the understanding between technological advancements, policy implications, and societal impacts in the realm of sustainable urban transport.

5. **Infrastructure Development:** Research on the requisite infrastructure development for the broader adoption of electric vehicles and the integration of smart technologies is lacking.
6. **Policy Implementation:** The effectiveness of policy implementation and its impact on promoting sustainable transportation solutions is yet to be fully understood.
7. **Technological Standardisation:** Standardisation of technologies used in electric vehicles and smart transportation systems to ensure interoperability and scalability is a critical area that needs attention.

These sections aim to provide a roadmap for researchers, policymakers, and stakeholders to further delve into the unchartered territories of sustainable urban transport, thereby contributing to the broader goal of transforming urban landscapes into smart, sustainable havens.

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