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Perspective

Mobile-Energy-as-a-Service (MEaaS): Sustainable Electromobility via Integrated Energy–Transport–Urban Infrastructure

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Abstract: The transport sector is one of the leading contributors of anthropogenic climate change. Particularly, internal combustion engine (ICE) dominancy coupled with heavy private motor vehicle dependency are among the main issues that need to be addressed immediately to mitigate climate change and to avoid consequential catastrophes. As a potential solution to this issue, electric vehicle (EV) technology has been put forward and is expected to replace a sizable portion of ICE vehicles in the coming decades. Provided that the source of electricity is renewable energy resources, it is expected that the wider uptake of EVs will positively contribute to the efforts in climate change mitigation. Nonetheless, wider EV uptake also comes with important issues that could challenge urban power systems. This perspective paper advocates system-level thinking to pinpoint and address the undesired externalities of EVs on our power grids. Given that it is possible to mobilize EV batteries to act as a source of mobile-energy supporting the power grid and the paper coins, and conceptualize a novel concept of Mobile-Energy-as-a-Service (MEaaS) for system-wide integration of energy, transport, and urban infrastructures for sustainable electromobility in cities. The results of this perspective include a discussion around the issues of measuring optimal real-time power grid operability for MEaaS, transport, power, and urban engineering aspects of MEaaS, flexible incentive-based price mechanisms for MEaaS, gauging the public acceptability of MEaaS based on its desired attributes, and directions for prospective research.

Keywords: mobile-energy-as-a-service (MEaaS); mobile energy; urban electromobility; electric vehicle; renewable energy resource; bidirectional electric vehicle charging

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1. Introduction

The climate change crisis arising from increasing greenhouse gas (GHG) emissions from all sectors of the economy, including energy and transport, demand decisive action towards sustainability and smooth transition to cleaner energy sources [1,2]. After the recent UN Climate Change Conference (COP-26), several governments and businesses in the industrialized countries are beginning to show a paradigm shift in addressing these challenges [3]. As road transport is a significant contributor to GHG emissions [4,5], the uptake of electric vehicles (EV) in large numbers has been touted as one of the pathways to lower the carbon footprint from the transport sector [6]. Accordingly, the world's major automotive industries have pledged to phase out internal combustion engines (ICEs) and replace them with the EV technology. For example, the designated timelines for this conversion are Volvo in 2030, Mazda in 2030, GM in 2035, and Nissan in the early 2030s [7].

EVs form the spine of electromobility [8], where the term electromobility is defined as "a set of activities related to the use of EVs, as well as technical and operational EV solutions, technologies and charging infrastructure, as well as social, economic and legal issues pertaining to the designing, manufacturing, purchasing and using EVs" [9] (p. 1). There are many challenges in establishing electromobility in cities. These range from EV costs and charging station availability and accessibility, from charging speed and battery capacity and cost to purchasing power and government incentives, from cost of electricity to vehicle to grid adoption and consumer awareness on green technologies [10–13].

In many countries, EVs are expected to proliferate over the coming decade [14]. Based on Bloomberg New Energy Financial predictions, after a tipping point in ICE/EV comparative costs in the coming years, 60% of the cars will be fully electric, and the rest of them will have the plug-in capacity by 2040. Globally, more than seven million EVs are sold in 2021 alone, indicating the serious market penetration [7]. Although EVs have significant environmental benefits, given the potential to use renewable power for charging purposes, widespread adoption is limited due to the lack of available charging infrastructure and the capability of the existing electricity distribution network to handle cumulative peak demand [15–17]. In developing a comprehensive EV charging regime, the locations, including customer premises, workplaces, public stations, online charging on-route and car parks, are critical [18,19].

In the absence of any smart charging facilities, uncoordinated and erratic bidirectional charging (charge and discharge) of EVs will hamper the stability of the electricity grid. Based on [20], most customers tend to connect their EVs to the grid immediately after returning home from work between 6:00 p.m. and 10:00 p.m. For instance, a study in the Netherlands reports uncoordinated charging with just 30% EVs penetration, leading to a 54% increase in peak demand [21]. A similar study in Western Australia reports that a 62% EV penetration rate will result in a 2.57 time increase in electricity loading [22]. Hence, large-scale uncoordinated EV penetration will lead to excessive feeder overloading and poor power quality [23,24]. The existing power quality issues, which are primarily over-voltage problems, owing to the large numbers of rooftop photovoltaics (PVs) in the distribution grids [25–28], will become worse due to the uncoordinated integration of EVs.

Therefore, there is a need to develop an intelligent scheduling and control mechanism that encourages EV owners to relieve the overloading issue in the electricity grid. In addition, optimal placements of EV charging infrastructures considering transport and urban real-estate constraints are paramount to alleviate the electricity loading constraints. Moreover, an incentive-based market mechanism where EV owners are rewarded for their bidirectional charging behavior between EVs and grid (vehicle-to-grid (V2G) and grid-to-vehicle (G2V)) helping the electricity grid is necessary. Additionally, the bidirectional power flow can also be used to provide high-quality ancillary services such as voltage and frequency regulation, peak power management and improvement to the load factor [29–32]. This should be combined with appropriate market research where the public acceptability of this mechanism is evaluated. Furthermore, treating EVs as mobile energy sources has created the concept of the mobile energy internet [33].

This perspective paper introduces a novel concept of Mobile-Energy-as-a-Service (MEaaS), a well-planned mechanism incorporating transport, power, and urban infrastructure aspects of mobile energy for EVs and the flexible incentive-based pricing schemes to handle challenges introduced by the upcoming wave of EVs. Provided that this mechanism is planned well, challenges due to widespread EV uptake on urban power systems could be handled via rapidly advancing mobile energy technology [34–37]. In other words, EV batteries could serve as mobile energy sources to compensate the pressures on the grid during peak times. Nevertheless, this requires a careful system design for large metropolitan cities that can accommodate an MEaaS system.

One of the attractive features is that MEaaS creates a platform for EV users to trade energy in an established market which can be operated via an app in smartphones. Using the arbitrage market (i.e., power price differential during peak and off-peak hours), EV owners could cover not only the costs of running their vehicles but even profit from it. The other advantage is convenience, timesaving, reliability of electricity supply to EVs and the opportunity to be connected to a market on a 24/7 basis. Therefore, this new technology adds extra value to the rapidly emerging process of prosumaging—Prosumage is a term used for PROroduction, conSUMption, and storAGE [38]. The rollout of MEaaS should further accelerate the uptake of EVs, increase the number of prosumagers, lead to an increase in renewable energy driven by market forces [39], lower prices and a reduction in GHG emissions from the transport sector. In this sense, MEaaS provides an opportunity where large numbers of EVs, with their batteries, form a giant battery when aggregated. The batteries not only will take the pressure off the grid, but their mobility provides an opportunity for energy to be delivered to consumers on-demand, both to households as well as EV users in a certain area where shortages exist.

In this perspective paper, we introduce a novel MEaaS system approach and offer a discussion around the issues of: (a) Measuring optimal real-time power grid operability; (b) Utilizing transport, power, and urban infrastructures; (c) Establishing a flexible incentive-based price mechanisms, and (d) Gauging the public acceptability of MEaaS based on its desired attributes. All statements in this perspective paper are based on a thorough review of the current literature, research, developments, trends, and applications.

It should be noted that this paper is written in the form of a perspective piece, where the authors express their personal experiences and opinions on a new perspective about emerging research and development (i.e., MEaaS) on a particular topic (i.e., urban electro-mobility). After this introduction, the rest of the paper is structured as follows. Section 2 introduces the state-of-the-art in mobile energy and transport. Section 3 presents the key aspects of MEaaS as the future of urban mobile-energy. Section 4 concludes the paper by presenting remarks on the future research directions.

2. Mobile Energy and Transport: The State-of-the-Art

Smart bidirectional EV chargers can regulate the grid frequency by charging and discharging the EV batteries [40]. Using the arbitrage market, EVs can be financially attractive to potential owners, covering EVs' running costs to make a profit. For example, one study reports that the EV-owner can gain between $3777 to $4000 per year for sharing an EV's power reserve with the power grid with a regulating power of 10–15 kW [41].

Load-levelling and peak-shaving are other potential benefits of G2V and V2G applications [42,43]. With the help of V2G, it is possible to discharge the extra power of EV batteries to the grid during daily peak demand (peak-shaving). On the other hand, with the help of G2V, EVs can be charged during off-peak hours, improving the load profile during the day (load-levelling). According to [44], if New York City's EV population is approximately 100,000, representing a 50% penetration level, up to 10% of the peak power can be provided by EV batteries—valued at $110 million per year.

In addition, the renewable energy sector can benefit from the presence of G2V and V2G charging. Due to the intermittent nature of RERs, it is possible to use EV batteries as storage units during periods of high peak generation and discharge them during peak demand. Such a market will lead to an inevitable further increase in the uptake of rooftop PVs, EVs and, at the same time, reduce the stress on the grid. Increasing amounts of renewable energy generated, through an increased number of PVs, will eventually lead to lower electricity prices even during peak hours, replacing fossil fuel-based generation, leading to an eventual decrease in GHG emissions.

On the other hand, smart bidirectional charging makes it possible to determine the charging time. This coordinated system can help decrease daily electricity costs, transformer and conductor current ratings and flatten the power profile of the grid. Authors in [45] report that a 50% peak load increase can be avoided at a 10% EV penetration rate with a coordinated bidirectional charging strategy for the US power grid. Adopting a coordinated mechanism requires specialized equipment such as sensors and communication devices and related policies that can encourage customers to adopt EVs and adhere to associated bi-directional charging protocols. Some policies incentivize customers to purchase EVs in tax credits/rebates and subsidize charging installation or discount in-building parking [46].

For instance, in the case of Australia, limited policies that exist at the state level look surprisingly more proactive than those at the federal level. For example, the states of Queensland and South Australia offer up-front financial incentive programs for EV buyers and subsidies for EV bidirectional charging stations. On the other hand, some policies involve bidirectional charging scheduling strategies. In the context of coordinated bidirectional charging algorithms, most policies are based on multi-level pricing that are established using power demand and RER generation to encourage customers to shift to off-peak power demand. Several countries are lagging other developed countries in terms of coordinated scheduling with no clear framework in place to set state and federal initiatives [7]. Policymakers need to consider numerous local and national factors, including the existing infrastructure; types of bidirectional charging stations and their locations; the EV penetration rate, customer mobility profiles, convenience, preferences and acceptability.

Urban planning is another aspect that can be significantly affected by integrating EVs to the power grid [47–49]. Public bidirectional charging stations that are optimally located and easily accessible are critical in boosting the adoption of EVs. Moreover, range anxiety is a prohibitive concern for the rapid growth of EVs. Many studies have been dedicated to maximizing the satisfaction level with respect to charging demand and limited budgets [50,51]. Nevertheless, optimization of EV bidirectional charging locations must be expanded to encompass traffic concerns, equitable distribution of stations, the capacity of roads/cities and existing infrastructure limitations. Furthermore, the current public charger locating strategies do not consider the impact of having household chargers, which may lead to the excessive location of the public charger in residential areas.

The increasing number of studies indicates that the number of EVs on our roads will rise as they are preferred as personalized transport given the environmentally friendly benefits and the acceptance of autonomous driving technology [52]. The uptake of autonomous driving will also be revolutionizing smart urban mobility, where electrification of such vehicles is also a desired outcome [53]. The levels of EVs on roads and their changing environmental roles globally in recent years indicate that EVs will be the future of personalized transport, especially when autonomous EV technology is concerned [54,55].

Although it is expected that 28% of total sold vehicles will be battery-powered by 2030, little work has been done to estimate the required infrastructure and the corresponding budget to meet this growing demand. The practicability of constructing a complex infrastructure across the country requires time, deep analysis of the issues and considerable financial expenditure. Since the rapid growth of EV numbers has already started, the analysis of the current grid system is essential to ensure that grid resilience is not jeopardized. Although extra headroom for facilities is considered when the power grid is constructed to account for future power demand increases, it is unlikely to be sufficient once the EV fleet is integrated into the transport system. Thus, system augmentation is inevitable, and potential flaws must be identified.

In addition, the increasing number of EVs as public transport necessitates the new bidirectional charging stations with appropriate technologies for public stations, which is different from the household stations. A substantial investment is required to develop the needed technology, and significant financing is necessary to install and operate these stations. Due to the complexity of the cost estimation and its dependency on the local and national parameters, so far, no comprehensive analysis has been carried out to estimate the expected investment and the gained profit for many countries. Internationally, only two scenarios have been widely investigated for charging infrastructure requirements [56].

The first one is based on bulky battery packages that can guarantee the daily driven distance of an ordinary individual. The EV is charged at night using a moderate power transmission rate in this strategy. From an investment perspective, this approach requires a low investment cost at the household level since most installed infrastructures in houses can tolerate the required power transmission based on existing ratings of the installed wires. However, the main concerns of this approach are the lack of providing the required ancillary services during the daytime and the increasing power demand across residential area feeders at night [57].

The second strategy is based on the constant charging and discharging of the EVs with a small battery-package volume that would be feasible with the help of new emerging charging technologies such as 'wireless power transfer systems' (WPTS), which can charge EVs on-road. Although the continuous drive option might be an ambitious and appealing target, it requires a significant modification in both electrical and roadway infrastructures and, therefore, an unjustifiable expense, particularly for low population density regions. In general, commercialized bidirectional chargers can be classified as Level 2 chargers (~5–10 kW) and Level 3 chargers (fast chargers, ~50 kW) [58]. The former suffers from slow bidirectional charging time, making it more suitable for household applications. Level 3 charges can substantially increase power flows during peak power usage periods, making it more convenient for public stations.

Ideally, the adopted bidirectional charging facilities should not be restricted to a single technology. Thus, analyses related to EV infrastructure and corresponding impacts need to be expanded to encompass various bidirectional charging options. For example, so far, the investigated business models of bidirectional charger stations have been focused only on a single technology across a system (i.e., only Level 2 or only Level 3 is adopted), while the cost optimization of hybrid bidirectional charging facilities (including Level 2, Level 3, and on-route bidirectional chargers) has not been investigated (Figure 1). Furthermore, how EVs as mobile energy carriers would affect the electricity grid power quality and stability and the way the electricity and transport networks are interwound have not been comprehensively investigated.

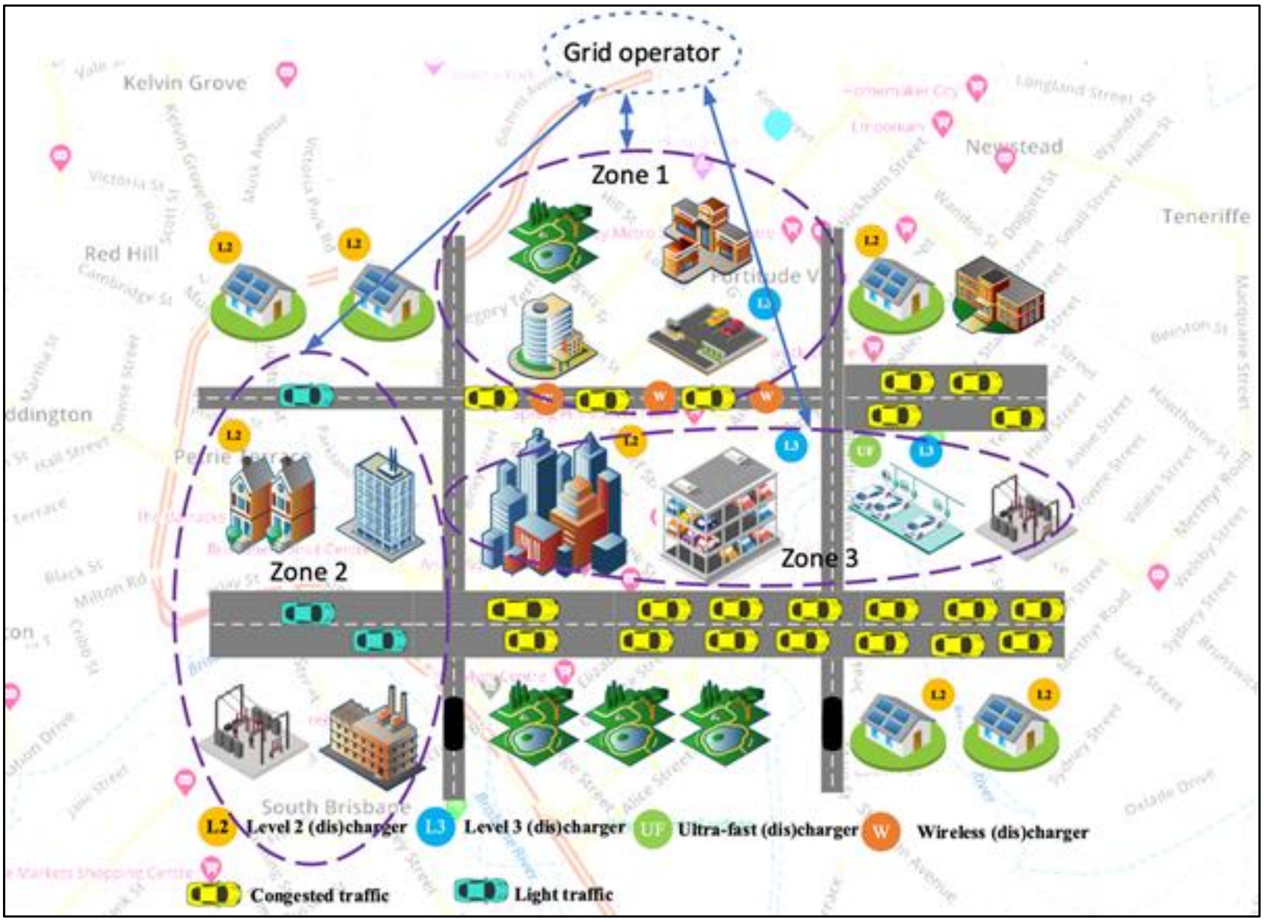

Figure 1. Bidirectional EV charging technologies and their interactions with power and transport grids.

Thus, this perspective paper is concerned with how the variability of electricity unit price from RERs will influence the state-of-the-art stationery and dynamic bidirectional charging costs and related operating expenses. In this way, a generic model for large metropolitan cities can be developed to offer the optimal combination of bidirectional chargers for the public (including on-route and stationary chargers) and household applications.

From an urban planning perspective, there are limited but growing studies concerning the location of EV charging stations [59]. In the urban planning literature, integration of land use and transport has been widely covered [60], whereas the inclusion of power infrastructure is rather new. The existing literature on the location of charging stations does not adequately factor in power, transport and urban planning aspects [61–63]. Moreover, while there are studies on wireless power transfer with one-directional charging consideration [64–66], there are, to our knowledge, no comprehensive studies conducted to determine the optimal location of bidirectional charging stations or infrastructure.

So far, accessibility has been the main factor in determining public EVs' location bidirectional chargers. As a result, parking lots are assumed to be a reasonable location for the installation of such stations [67–69]. Nevertheless, factors such as balancing the power generation from RER and EV charging power demand at each urban locality (e.g., suburbs or neighborhoods); system augmentation; the impact of household chargers; traffic-related concerns; the capacity of the civil infrastructure and the change in the behavior of drivers on the face of potential charging/discharging incentivizing schemes have not been covered systematically in the literature [70].

Despite a growing literature in this domain, it only covers limited aspects in identifying optimal locations for bidirectional charging infrastructure [71]. Additionally, while MEaaS provides a system approach to urban mobility including EVs [72], there is no comprehensive and system-level approach to EVs and bidirectional charging infrastructure in the context of metropolitan cities.

Against this backdrop, this perspective paper advocates a system thinking to pinpoint and address the negative externalities of EVs on the power grid of our cities. Hence, in the next section, the paper coins and conceptualizes a novel concept of MEaaS to operationalize energy, transport and urban infrastructures for establishing sustainable electromobility in large metropolitan cities.

3. Mobile-Energy-as-a-Service (MEaaS): The Future of Urban Mobile-Energy

Accordingly, this paper aims to provide a multidisciplinary perspective—of power and transport engineering, urban planning, and social science—for the smooth transition from the grid in its present form to a network that can support a dominance of EVs on roads via an MEaaS. Furthermore, this research intends to analyze the effect of the power system when EVs act as sources of mobile energy. Such mobile energy sources can be utilized to supply energy to specific areas that experience energy deprivation at any given time or absorb energy from certain areas that experience energy surplus. Thus, with proper forecasting of the mobility over the transport network, EVs can be used as dynamic energy sources to alleviate power system operational issues using bidirectional charging. This shows the symbiotic relationship between transport and energy networks that can be managed to be economically optimized.

In essence, MEaaS presents how an operational framework can manage such mobile energy sources to benefit EV owners and urban transport and energy networks, particularly in large metropolitan cities. As the geographical context of MEaaS, the primary implementation target is naturally the large metropolitan cities (cities offering increased urban socioeconomic activities, density and population, and diverse and advanced infrastructure and smart mobility options) [73–75]. Moreover, urban administrations of some global cities (also branded as knowledge or smart cities), particularly in developed nations, have the capability and interest to be the leader in urban innovation [76].

This perspective paper advocates the identification of appropriate charging systems for domestic requirements and for addressing some of the current shortcomings of systems.

Such broad scope and the multidisciplinary research perspective also include a public preference/acceptability study to assist researchers in comprehensively investigating and developing a charging system that tracks the influence of optimization in one aspect over the other (Figure 2).

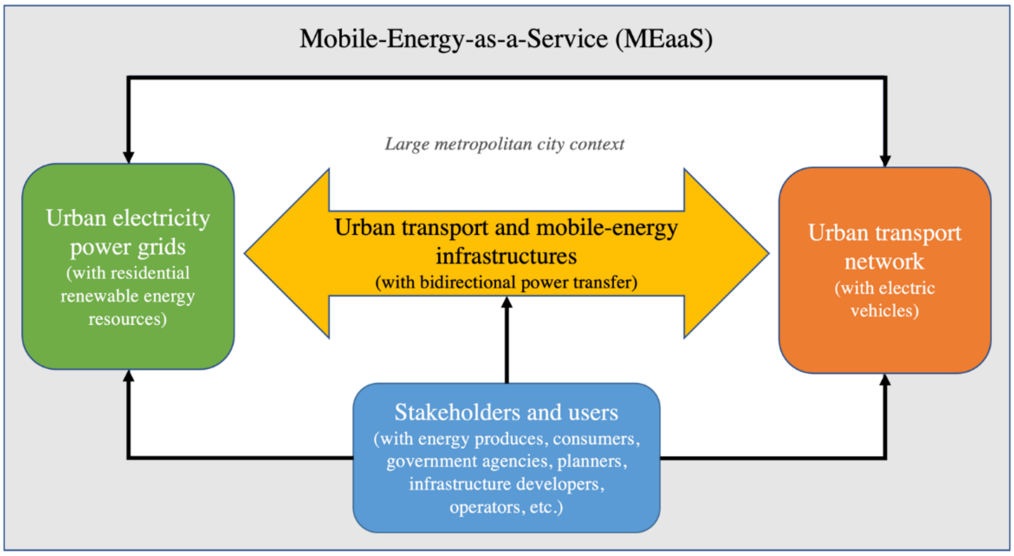

Figure 2. Conceptual framework of MEaaS.

This paper proposes MEaaS as a novel concept to address some of the undesired externalities that EVs will create on urban electricity power grids. Turning the MEaaS concept into reality will require thorough investigations despite this benefit. Four critical ones are listed below and elaborated in the following subsections:

- Identification of optimal real-time power grid operationality when incorporating MEaaS (where this involves, inter alia, a reliability analysis of the existing urban power grid with respect to the future uptake of EVs and RERs) (further details are presented in Section 3.1);
- Determination of the structure of MEaaS in the large metropolitan city context through smart urban infrastructure design guidelines encompassing transport, power and civil engineering aspects (where this involves analysis of the urban topography and urban form and designating the optimal locations for public charging stations) (further details are presented in Section 3.2);
- Development of the flexible incentive-based pricing mechanisms for MEaaS (where this involves optimal bidirectional charging through V2X/X2V of mobile/stationary EVs) (further details are presented in Section 3.3);
- Assessment of public acceptability of MEaaS and identifying its salient attributes under which the system could be widely deployed (where this involves public technology adoption surveys and interviews) (further details are presented in Section 3.4).

3.1. *Measuring Optimal Real-Time Power Grid Operationality for MEaaS*

The impact of EVs on the operations of electricity network utilities must be investigated to avoid imposing an unprecedented burden leading to the degradation of power quality, high-stress levels on local transformers or cables and poor system reliability. This involves identifying optimal real-time power grid power flows incorporating MEaaS—that is, a reliability analysis of the existing power grid with respect to the future uptake of EVs and RERs. Researchers have investigated the impact on electricity grid power flows from EV charging purely from a supply point of view [77]. However, the dynamic spatio-temporal electricity demand distribution and its interaction with RERs have been overlooked. A recent report from Energeia [78] indicates the likely significant variance in cumulative EV uptake over the next decade with respect to the government intervention level and how it can significantly impact the power grid performance in large metropolitan cities.

We suggest the following procedures to measure optimal real-time power grid operationality for MEaaS involving EVs and the advanced bidirectional charging infrastructures. First, the electricity network should be categorized into several modelling zones, which in turn are defined in terms of the electricity distribution system and the local statistical areas. Electricity grids are represented by several substation zones based on local statistical areas, whereas transport networks consider several statistical areas based on socioeconomic characteristics. This needs to be amalgamated to determine the impact of EVs on the power grid. The worst-case condition in each zone, in terms of the required power consumption, can be estimated as Equation (1):

$$P_{tot,EV} = \sum N_i \, P_{nom,i} \tag{1}$$

where the subscript "*i*" designates the adopted bidirectional charging technology, N_i is the number of users of the *i*-th technology in each zone, $P_{nom,€}$ is the nominal power of the bidirectional charger, which is a known value for different technologies (the influence of private and public charging stations is accounted here). N_i represents private users which can be approximated from the historical census records of each zone ($N_i = \alpha_i * N_h$, where N_h is the number of houses in each zone, and α_i is the penetration rate of EV in each zone). Poisson distribution can be used to estimate the worst-case scenario of the number of public station users at a specific timeslot [20].

With the help of Poisson distribution, the probability of the customers of public stations (including the stationary and dynamic bidirectional chargers) can be determined to estimate the corresponding power consumption/generation from Equation (1).

Customer behavior regarding the bidirectional charging operation is influenced by several factors: electricity price, mobility trip purpose (work/recreational/shopping), time (day/week/month) and customer convenience. The different electricity demand scenarios should be modelled considering the aforementioned factors, and Equation (1) should be solved for different times of the day. This analysis adjusts the current/projected daily load curve by incorporating each zone's RER generation distribution and demand scenarios from the available power grid database. It should determine the limitations of the existing power grid in each zone and the need for corresponding network augmentation.

3.2. Transport, Power and Urban Engineering Aspects of MEaaS

Integration of a large EV fleet into the power grid requires a placement strategy that can justify the financial outlay and consideration of urban-related issues such as congestion and social welfare. Moreover, the applications and implications of EVs are overshadowed by the uncertainties and potential consequences for the operation of the existing power grid and urban infrastructures. Regarding the placement strategies for bidirectional chargers, several critical factors such as the travel anxiety level, the required time to charge with respect to the adopted technology, and fair access to these facilities must be considered. The power grid infrastructure limitations such as the power system transformer ratings must also be taken into consideration.

In addition, the advent of modern technologies such as wireless powered bidirectional chargers provides a unique opportunity for on-the-go bidirectional charging to be employed. Although the required technology for on-route bidirectional charging is more expensive than stationary chargers [64], it offers valuable features such as reducing the waiting time in queues and the requirement for the EV battery size [79].

Furthermore, in locations with sufficient traffic, the revenue generated from cars using bidirectional charging on the route can meet the investment expenses. There is limited research on developing frameworks for identifying the most suitable locations for public chargers in locations such as shopping centers and parking lots [50,56,66]. Nonetheless, most drivers were shown to prefer mobility rather than profitability and indicated social welfare, grid augmentation and urban planning-related concerns. Noticeably, the simultaneous impact of more than one technology is not considered [80].

The grid augmentation and economic viability concerns should be conducted in parallel with the grid modelling. In terms of various available bidirectional charging options and topography of the city, there is a clear gap in the quantitative evaluation of the placement of these stations with respect to urban planning and transport operational constraints.

Access to the strategic transport demand model and relevant socioeconomic and land use data is necessary, as this provides an opportunity to demonstrate the applicability of the research on a real network and establish evidence-based findings. The research should consider spatio-temporal travel patterns and the recent advancements in artificial intelligence and machine learning techniques (such as non-negative matrix factorization) on the transport data can be explored for accurate and reliable modelling of base case transport patterns.

Different scenarios specified by MEaaS should be considered to model EV customer profiles with respect to the adoption of EVs. The profiling should consider different types of EV customers and their socioeconomic characteristics. Different modelling scenarios based on technology enthusiastic early adopters should be used to assess the price sensitivity where there is mass ownership of EVs. A structured review of the emerging international findings on EV and similar technology adoptions should provide a strong foundation for the design of scenarios.

Based on the MEaaS scenarios, the charging location of EVs should be optimized considering various factors such as spatio-temporal demand distribution, temporal vehicle trip distribution, driving behavior (on the face of incentivizing schemes), power grid impact and other technical factors related to charging type (e.g., fast/slow, wireless/plug-in, reverse).

Different multi-objective mathematical function formulations (Z) for the objective function should be considered. In general, Z is defined as a function of the traffic delay on the network (Tg) and impact on power grid (Pg) as represented by Equation (2). The sensitivity and stability of the different formulations should be thoroughly tested systematically. The values will be based on the simulation using the strategic transport model and the power grid simulator:

$$Z = f(Tg, Pg, \textit{other constraints}) \quad (2)$$

Potential algorithms that can be considered for optimization include simulated annealing, advanced meta-heuristic algorithms, gradient descent and its variations, evolutionary computation, hybridized algorithms and reinforcement learning.

The optimization protocol should take the following factors (not limited to) into account: (a) Spatio-temporal distribution of mobile energy; (b) Travel patterns; (c) Strategic transport model; (d) Customer profiling with respect to the adoption of EVs; (e) Various urban scenarios; and (f) Optimization for charging infrastructure location with respect to different technology types.

To accomplish a public placement bidirectional charger plan, an MEaaS feasibility/optimization study—looking into transport, power, and urban engineering aspects of MEaaS—should utilize a zone-based geographic partitioning technique to predict electricity generation and demand at each zone. Given the available local data and the type of land used (e.g., residential/commercial/industrial/recreational), one can forecast the behavior and demand of users in each zone. The strategy should be based on optimal placement of the public bidirectional charging stations (Level 3) in areas with the low RER and high-power demand (such as apartment zones), where household bidirectional chargers (Level 2) are more effective. Given the traffic flow at each zone, the modelling should pinpoint those areas where there is potential for application of ultra-fast and wireless bidirectional chargers.

The interaction between the price of electricity for selling or buying, user decision to choose the travel route and the capacity of roads to accommodate the number of EVs generates a coupled equilibrium in power and transportation.

Such optimization study can learn from [50] the interaction between the price of electricity and destination choice of EVs users, the optimized profit for both the stations and users with respect to the optimal location of the stations. To this end, a combined distribution and assignment model should describe the user destination choices based on the price of charging and price paid for the purchase of excess electricity by charging stations. Research can be further extended to model the effect of vehicle discharging on traveler behavior and road capacity, not considered in [50].

3.3. Flexible Incentive-Based Pricing Mechanisms for MEaaS

The EV charging behavior of users can significantly impact the power grid performance [79]. Currently, the charging infrastructure is limited to specific locations such as workplaces, residential, commercial, and recreational premises. The existing charging pattern and its impact on the grid is primarily governed by user convenience and the cost associated with existing tariffs (pay-per-kWh and pay-for-time). Such patterns are not system optimal and significantly impact the power grid.

With the advancement of technologies, users would actively participate in vehicle-to-everything or everything-to-vehicle (V2X/X2V) mechanisms through bidirectional charging and associated Smart/IT/apps/technologically based solutions. Although consequential system augmentation is inevitable to some extent, adopting a reasonable policy or pricing mechanism to incentivize users should result in optimal capital investments in power, transport and urban infrastructures.

Furthermore, due to the high penetration of RERs in some nations, such as Australia, and the lack of synchronous generators (low inertia), as pointed out in the introduction, the grid is prone to instability, and the connection of EVs to the grid can be a beneficial alternative if managed competently. Thus, there is a unique opportunity for many national electricity utilities (grid and retail) and charging station operators to benefit from the optimal integration of EVs. Nevertheless, there are neither mechanisms nor incentives for EV owners at this stage. Several studies offer guidelines for the economic operation of charging stations, ignoring the multiple options for charging EVs. Furthermore, the literature has rarely modelled strategies regarding the discharging process and sharing stored electricity of EVs with the power grid [81].

Therefore, it is imperative to incorporate multiple bidirectional charging technologies connected to the electricity grid, charging stations and other energy storage facilities with a flexible incentive-based pricing scheme for the optimal operation of MEaaS. Such a mechanism should consider many priorities, including the RER generation profile, demand and generation of power (supply) within each geographic zone and capturing the sensitiveness of buyers and sellers of electricity to changes in price to make the market dynamic.

It should be noted here that this system should be highly flexible, incentive-based and entirely dependent on the existing demand and supply of electricity at any given time and location. Strategically, the operating system automatically, for example, increases (decreases) the sale price during peak (off-peak) demand to discourage (encourage) customers to charge (discharge) them to sell (buy) to (from) the grid, charging stations, EVs and other storage devices. In addition, it should be able to provide a travel plan for EV drivers depending on their battery capacity where possible economically beneficial pathways for them can be identified in terms of charging/discharging during travel.

Accordingly, the peak-load demands of the grid can be minimized, leading to more optimal usage of the infrastructure. One potential pricing mechanism that can be considered for the MEaaS is an improvement/variant of, for example, Australia's existing wholesale spot market pricing scheme, which is operated by the Australian Energy Market Operator (AEMO), where the electricity supply and demand is 'matched' simultaneously using real-time spot market dispatched every five minutes [82].

The AEMO operated spot market pricing scheme is not accessible to the public to directly purchase electricity from generators. Nonetheless, given the technology involved with MEaaS and because it operates within defined zones, it is argued here that the spot market for mobile energy should be instantaneous because such pricing could be arranged on a zone-by-zone basis as shown in Figure 1 to reach market equilibrium prices. Markets clear when quantity demanded (Q_d) equals quantity supplied (Q_s), as represented in Equation (3):

$$Q_d = Q_s \tag{3}$$

where Q_d and Q_s are quantities of electricity demanded and supplied, respectively. Using primary and secondary data, it is possible to solve for equilibrium prices and quantities. Once the price is settled in each zone, the price is instantaneously made available to all system users (buyers and sellers) via an app. The main merit of this strategy is that the price of electricity is instantaneously determined locally. Thus, with respect to RER generation, EV users can decide to charge/discharge (bidirectional charging) in a zone based on the prevailing price. Furthermore, since providing the ancillary services is crucial for grid operators, they can offer further incentives for EV users to participate in the market through V2X/X2V mechanisms. It is advocated that a fully flexible, highly incentivized pricing system that affords the opportunity to arbitrage is a key determinant of success for the uptake of the MEaaS system.

3.4. Public Acceptability of and Appropriate Business Models for MEaaS

Creating a dynamic pricing system for arbitrage is one of the key essentials for the success of MEaaS. Another key determinant for the uptake of this emerging technology hinges on the public acceptability of mobile energy as a realistic product with the desired attributes linked to its use. For public acceptability, it is imperative to showcase the key attributes of the technology. They include the costs, monetary gains from the use of the technology, convenience, reliability and the inclusion of renewable energy and uptake of EVs instead of ICEs.

For this purpose, a common approach is to conduct a consumer choice model, where the most desired attributes mentioned above could be tested, and consumer preferences ranked and highlighted. It is also possible to test whether consumers are willing to adopt the change, under what circumstances they would do so or whether they would prefer the status quo. In this case, ICEs or EVs minus the MEaaS system. It is also possible to rank consumers' acceptability for each attribute in monetary terms. The choice modelling is usually embedded in a survey of consumers where the technology is most likely to be adopted.

A consumer choice model assumes that a consumer reveals his/her preference. Here, the consumer selects the alternative that provides the highest utility [83], say between ICE and EV with MEaaS technology. That is, a consumer n selects choice I if $U_i > U_j$, "$_j$ Î $C_{n,}$ $i \neq j$, where U_i is decomposed into a A deterministic (observed), V_{nj}, and random (unobserved) part, ε_{nj}, as represented in Equation (4):

$$U_i = V_i + \varepsilon_i \tag{4}$$

where V_i is a deterministic component, and ε_i is a random error component that captures any influences on individual choices that are unobservable to the researcher. The deterministic component, V_i, is the function of the MEaaS attributes and socioeconomic characteristics of the consumer, and can be expressed as represented in Equation (5):

$$V_i = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots.. + \beta_n X_n + \beta_a S_1 + \beta_b S_2 + \ldots.. \beta_m S_k \tag{5}$$

where β_0 is the alternative specific constant, X_1 to X_n are the attributes, S_1 to S_k are the social, economic and attitudinal characteristics of the consumer and β_1 to β_n and β_a to β_m are attached to the vectors of attributes and vectors of the consumer characteristics, both of which influence utility. Models such as multinomial logit (MNL), random parameter logit (RPL) and other models can be used to analyze the choice data [84,85].

Researchers have used choice experiments to test consumers' acceptability of autonomous vehicles and one of the studies that provide before and after provision of information about the emerging technologies include [86]. These experiments which gather socioeconomic (including income, education and gender) and attitudinal data on surveyed residents provide numerous indications, including which groups are likely to adopt such technology and those who are unlikely. That is to say, identifying key determinants of such technology is vital for technology developers, policy planners and investors. Such modelling can also indicate barriers and identify the most preferred attributes and provides an excellent basis to measure the strengths of these markets and to what extent and under what conditions consumers are likely to embrace such technology.

In summary, choice surveys, if well-executed, could elicit critical data that will enable the planning and execution of a business model that considers customer preferences, costs and benefits. This exercise will also provide valuable insights into the pricing mechanisms (including the development of relevant apps) that need to be put in place and obtain an understanding of the challenges and opportunities that MEaaS provides the various stakeholders.

4. Conclusions: Future Research Directions

Increasing urban population and their energy and mobility needs have created major energy and transport sustainability problems for particularly large metropolitan cities [87–89]. In this perspective paper, we argued for the need for MEaaS to operationalize energy, transport and urban infrastructures for establishing sustainable electromobility in large metropolitan cities to address the energy and transport sustainability problems. Prospective studies on MEaaS are needed as they provide numerous benefits, where some of them are elaborated as below.

Prospective studies on MEaaS will disclose new knowledge and scientific outcomes: The chief specific outcome of prospective research on MEaaS will be new scientific knowledge, as the MEaaS concept is the first comprehensive attempt to investigate future urban energy systems for sustainable electromobility in large metropolitan cities, where many of them today call themselves smart cities. These investigations will generate critical knowledge and an evidence base that will enable government agencies to follow pathways in adopting appropriate urban energy systems for sustainable electromobility.

Prospective studies on MEaaS will generate economic returns flowing from scientific outcomes: There are likely to be significant economic returns flowing from such scientific outcomes. These investigations will be of direct benefit to government agencies, and many others internationally—as these research studies will unveil new knowledge on adopting appropriate urban energy systems for sustainable electromobility. The large-scale commercialization of these MEaaS will generate an economic return.

Prospective studies on MEaaS will provide social and environmental returns flowing from scientific outcomes: The flow-on benefits will not just be economical; there will be significant societal and environmental benefits, as these studies will identify socio-spatial negative externalities of urban mobility and prescribe responsible solutions for government agencies to address the adverse effects on the communities and the environment. The MEaaS system with its financial and other benefits will accelerate the uptake of EVs, thus reducing the use of fossil-based fuels. These investigations will also reduce the strain imposed on the existing power grid.

Prospective studies on MEaaS will support informed urban, transport and energy policy and debate: These studies, throughout their investigation phase, will generate research outcomes, which will be communicated regularly to inform urban, transport and energy policy and debate, thereby raising the awareness of governments and the public regarding the importance of MEaaS solutions.

Future research will inform urban, transport and energy policy circles and the research community by leading a public discourse on urban energy systems that foster sustainable electromobility in large metropolitan cities. Our research team will also continue to embark on different facets of MEaaS and complimentary aspects of future urban, transport and power technologies.

We conclude this perspective piece by quoting [90], "the electricity grid with a high penetration of renewable energy can enable travelers to travel free of emissions using state-of-the-art EVs. Extensive EV demands at the peak-times, and an increase in electricity consumption due to population growth, have led to higher utility infrastructure investments. Mobile energy systems can be used as an innovative demand-side management solution to reduce long-term utility infrastructure investments. They can store and release electricity to the grid based on consumer demand. However, a scientific planning approach for grid integration has been overlooked (p. 1)", and our study in this paper offers a new conceptualization of such a system integration with MEaaS.

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