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Review

The Role of Internet of Things on Electric Vehicle Charging Infrastructure and Consumer Experience

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Abstract: The drive for net-zero emission and global decarbonization spurred the need for a worldwide transition towards cleaner energy options. The fossil-fuel-dominated global transportation system is a target for these initiatives, accounting for 37% of recent carbon emissions. This has accelerated the adoption of electric vehicles (EVs) into the global market to cut down carbon emissions and improve efficiency in the transportation sector. In the face of this growth, limitations in EV charging infrastructure still loom large amongst EV consumers. Resolving this bottleneck requires systematic approaches to ensure seamless operation and integration into the existing transport systems. This study examines the critical role of IoT in addressing the challenges of EV public charging through reviewing the literature to understand the inter-relation and highlighting its attendant impact on consumer experience. Findings show that while IoT serves as a strong tool to foster public interest through favorable public policy, its novel and innovative nature faces developmental challenges based on existing government policies that could hinder the interest of potential investors. Therefore, governments should consider evaluating existing policies and practices to ascertain their suitability for IoT adoption in EVs, ensuring that they do not constitute unintentional barriers.

Keywords: internet of things; electric vehicle; transportation; EV charging infrastructure; energy transition

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1. Introduction

The current global transportation system is dominated by fossil fuels, which account for roughly 37% of carbon dioxide (CO_2) emissions from end-use sectors [1]. Consequently, there is now worldwide support for cleaner transportation options in a direct bid to mitigate climate change. This shift has accelerated the adoption of electric vehicles (EVs) into the global market with the promise of achieving low-carbon transportation, high efficiency, and consequent flexibility in grid operation and integration. It is no surprise to witness the recent year-on-year growth of EVs, which peaked at 6.6 million sales in 2021, compared to 12,000 units in 2012, with approximately 10% of current global car sales being electric vehicles. Following projections from the 2022 Global EV Outlook published by the International Energy Agency (IEA), EVs are expected to account for more than 30% of vehicle sales across all modes in 2030 (excluding two- and three-wheelers) [2]. While these statistics, coupled with advantageous government incentives and financial subsidies, point towards a bright future for EVs, there are attendant drawbacks, especially regarding the charging experience of EV consumers.

Despite the apparent decline in EV prices and expansion in driving range, one bottleneck still lingers amongst current EV consumers: charging infrastructure. A recent study conducted by McKinsey and Company estimates that China, Europe, and the United States could witness a drastic rise in total charging demand across their EV consumer populations from around 20 billion kWh in 2020 to roughly 280 billion kWh in 2030 [3]. To put that into perspective, this figure represents an estimated 14-fold increase in EV consumer charging demand in 10 years. This prediction has led to marked growth in the rate of fast charger installations, which increased by 48% in 2021 compared to 2020, with 500,000 charging points installed in the same year [4]. Albeit these numbers look promising, current consumer charging experiences still point to dissatisfaction with EV charging infrastructure. From limited information hindering timely accessibility to nearby public charging points to charging interruptions and slow charging time [5], EV consumers cite negative charging experiences as a major concern hindering EV adoption [6]. EV consumers also lament the proliferation of multiple charging app and payment options, which mean EV drivers looking for charging stations at different locations will need to download multiple apps on their mobile phone as well as add numerous payment options. This issue introduced unnecessary complexity as compared to traditional filling up at the pump, which offers a simpler user experience.

These drawbacks are evident in the apparent disparity in the number of EV charging stations compared to that of petrol stations. Although investment in petrol stations declined in recent years, there are still more petrol stations compared to EV charging points [7]. This issue resulted in clustered charging stations at peak periods of the day, consequently placing a strain on the power grid owing to overloading [4]. Additionally, while it usually takes minimal time to fill up internal combustion engines (ICEs) at petrol stations, EVs often require extended charging duration spanning to hours with exact charing times being primarily dependent on the model of the vehicle and throughput of the charger [8]. Despite the undeniable benefits that are certain to come with the increased adoption of EVs across the transport sector, there are evident shortfalls in charging experiences that may dampen the progress of this initiative. This issue hastens the need to automate charging technologies with a drive toward a positive consumer experience [9,10]. One instrumental mechanism for achieving this development is the Internet of Things (IoT) [10].

The nature of the current day-to-day activities around the globe shows the need to automate charging technologies to efficiently manage available limited resources, particularly in developing countries where issues such as poverty, education, and health disparities remain center stage in policy discourse [11]. This fact is evident in the heightened transition from the era of conventional data to the "Big Data" age [12]. Not only does this underscore the importance of real-time information to the success of any industry, but it also evidently portrays the crucial role that smart technology plays in revolutionizing data storage and transmission. There is little wonder as to why the IoT is becoming a cutting-edge technology that enables businesses to analyze and process large data sets while providing maximum control [13]. However, what charging experience does this so-called smart technology entail for the average EV consumer?

When viewing IoT, one must be aware that this term can be viewed by different people to mean different concepts for different applications [14,15]. In simple terms, the IoT can be viewed as a convergence of OT (Operational Technology) and IT (Information Technology). While OT deals with the operations of physical properties, such as devices, sensors, and connectivity, IT focuses on the digital transformation aspects [16]. However, IoT more intricately portrays a global infrastructure for the information society, enabling advanced services through interconnecting (physical and virtual) things based on existing and evolving interoperable information and communication technologies [17]. As a smart technology tool, IoT is fundamental to solving the complex structure of EV charging stations and its decentralized nature through providing a more seamless maintenance and management process. Additionally, IoT can empower consumers to easily locate charging stations, schedule charging times for their vehicles, pinpoint the appropriate time of charging, and provide information about those factors that can potentially affect charging time [18]. The availability of information about a nearby charging port on the internet helps consumers to plan and organize their EV charging experiences, enabling them to feel empowered by their ability to impact and have effects on modern technology products [13].

In the literature, there are several studies centered around IoT as it relates to consumer experience and EV charging infrastructure around the globe. Some studies have investigated the impact of IoT-based EV charging and parking systems [15], while others present an approach for EV charge scheduling in smart distribution systems [14]. There is also research centered around charging stations with IoT and the nature of charging techniques used in these stations. These studies compare each type against the energy sources for these stations, such as whether it is renewable or non-renewable [17]. Other broad-based studies were previously initiated that provided an overview of the status of IoT-based EV charging stations. For example, a comparative study between IoT charging stations and the type of charging is carried out in [19], in which it was found that IoT-based charging simplifies user access to charging stations. In [17], the Internet of Vehicles (IoV), which is another coinage describing the integration and communication of EVs, modern power utilities, and users in conjunction with IoT, is highlighted as a critical infrastructure for driving large-scale EV charging networks based on blockchain technology, transactive energy, artificial intelligence, and cloud computing, among others. Moreover, digital twin technology is identified as a resourceful tool for efficiently and cost-effectively predicting the lifecycle of EVs based on intelligent charging systems [20]. On the other hand, it was identified that the infrastructural requirements for enabling IoT-based EV charging stations are not fully developed [21]. Other aspects of the EV charging imbroglio are data security and privacy threats, which were comprehensively analyzed in [22] and for which federated learning and blockchain technology are advanced as two emerging solutions to address these concerns. In [23], an in-depth analysis of EV charging station infrastructure is conducted, in which the optimal charging scheduling techniques are proposed as a viable solution for EV charging infrastructure planning, location, and management.

So far, the state-of-the-art studies on IoT-based EV charging highlighted the different impacts of intelligent technologies and smart systems but fall short of fully appraising EV adoption and usage. In this study, an overview of the role IoT plays in EV public charging experience, consumer behaviour, and, by extension, EV adoption and consumer acceptability is undertaken. This study dissects the nuances around EV public charging and its role in customer satisfaction and subsequent EV growth. It goes without saying that in a transport sector dominated by heavy-emitting ICEs, there is a need for a paradigm shift towards cleaner and more affordable transport options. The pace of adoption of EVs is dependent on many factors, with public charging experience being a clear hindrance [6]. Addressing this shortcoming requires systematic approaches and methodologies to ensure that EVs are properly integrated into the transport systems in a manner that seamlessly eases daily operations. This begs the following question: to what extent does IoT play a critical role in curtailing bottlenecks peculiar to EV public charging and EV end-user and consumer experience? To address this question, we reviewed the literature to understand the inter-relation between IoTs and EV public charging, highlighting its attendant impact on consumer experience.

Articles were retrieved for the literature using the following search engines: Google Scholar, Scopus, and Web of Science. The keyword search included internet of things, IoTs, electric vehicles, public charging, consumer experience, and charging infrastructure. We also supplemented our search with the snowballing technique and limited our article search to papers published from January 2010 to February 2023 to align with global trends in electric vehicle development. Article selection was based on their relevance to the research aim and objectives. Our interest is in the role of IoTs in EVs and how to improve public charging experiences for EV consumers. The ensuing subsections discuss this subject through exploring the smart EV ecosystem and highlighting the need for synergy between IoTs and EV public charging. The subsections also put in perspective the key technical aspects, emerging challenges, and social and safety impacts relevant to this concept. Finally, the study postulates recommendations that can be adopted by relevant stakeholders in ensuring a seamless transition to improved EV public charging services.

2. Smart EV Charging Ecosystem

The promise of smart cities has been discussed for decades. The prospect of interconnected devices and systems sharing real-time data and, in the process, optimizing and improving use cases, thereby improving the quality of life for citizens, is a key driver for proponents of smart cities. Technological advancements in sensor technology, data collection, mining and analysis, communication technologies, and cloud computing platforms facilitated the rise of the Internet of Things (IoT), which is a key enabler in smart city ecosystems. Connected vehicles are envisioned to play a key role in the smart cities' ecosystem.

As the transition to electric mobility gathers momentum, modern electric vehicles, which tend to be more connected when compared with the older generation internal combustion vehicles, are, therefore, set to be a key pillar in the smart cities' ecosystems from a mobility, infrastructure, and an electricity grid/network point of view. This fact means that the growth of the electric vehicle's market share and the electric vehicle charging ecosystem will be one of the key drivers toward mass adoption of IOT along the journey to full smart cities. Public smart electric vehicle charging ecosystems can be described by three main layers, as shown in Figure 1. These layers are the Energy and Power Infrastructure Layer, the IOT and Communications Network Layer and the Application Layer.

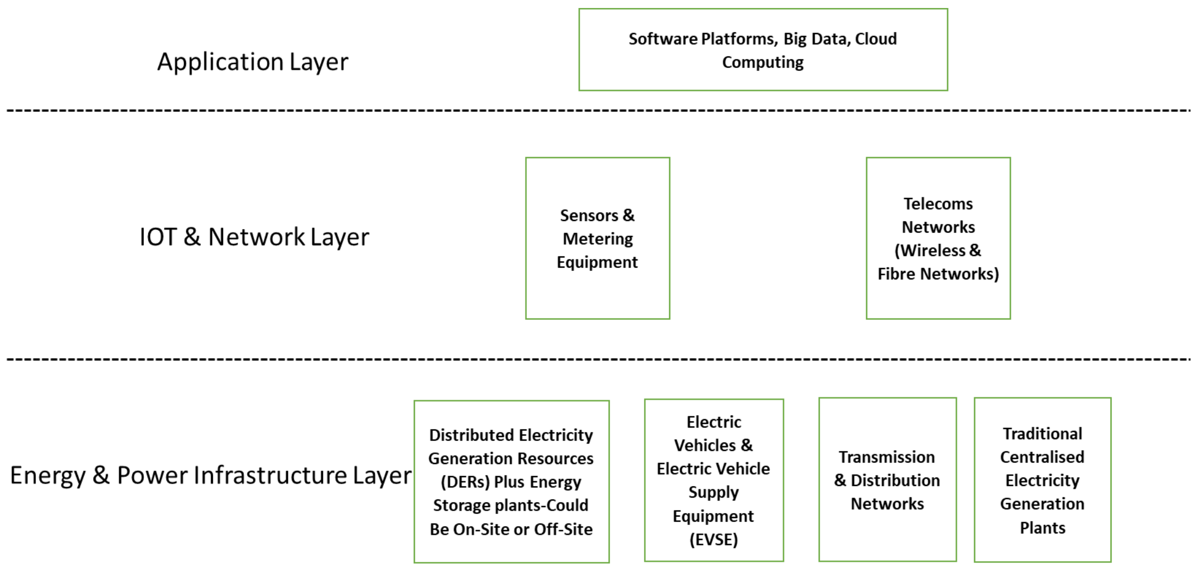

Figure 1. Smart Electric Vehicle Charging Ecosystem, adapted from ITU-T L.1380 (11/2019) [24].

As the penetration of electric vehicles and distributed energy resources grows, the grid will become increasingly decentralized, bi-directional, decarbonized, and digitized, as well as coupled with the need to balance supply and demand to avoid grid constraints, IOT-facilitated real-time information is critical. Preferential charging aligned to periods when the carbon intensity of the grid is low, periods of cheaper grid tariffs, and the need to maximize self-consumption of on-site renewable energy, will become progressively more prominent. An enormous amount of data will be gathered and exchanged between the millions of connected devices in this ecosystem. Involved actors will include vehicles, charge points, charge point operators, DERs, utility companies, and fintech and payment platform companies, as well as aggregators, such as those firms involved in the aggregation of electric vehicle traction batteries and turning the meter stationary storage into virtual power plants across the three layers. Data quality and data consistency will be crucial for an efficient and resilient smart public charging ecosystem. IoT will play a crucial role in this regard.

3. IoT—Public Smart Charging, Consumer Experience and Setbacks

3.1. Elements in Public Smart Charging Limitations

In this modern era of accelerated technological uptake, the ability to maximize time is the primary need of consumers. The frustration and stress that occurs in the face of delay—no matter how slight—negatively impact consumer experience, which in turn hinders drivers' receptibility to EVs as a means of transportation [25]. Combating this experience requires the existence of public smart charging infrastructure to increase EV desirability, resulting in extended driving days and electrified mileage [26]. To understand the need to integrate IoT into Public Smart Charging and its long-term benefits on the EV consumer experience, one must first understand the adverse effects of uncontrolled charging. EV charging has marked consequences on the distribution, transmission, and generation of electricity [27]. Uncontrolled charging can result in peak demand and transformer overloading, worsening power quality, overload transmission lines, or prompt system upgrades [28–31]. However, EVs can also provide value to the grid through providing services of frequency regulation and real-time ramping [27], which is where Public Smart Charging plays a major role.

In the purview of EV smart charging, IoT comprises three major elements: charging equipment, mobile apps, and charging management platforms [16,31,32]. Smart charging depicts a cloud-based automated and intelligent process for charging EVs, functioning in a manner that ensures EVs and charging devices are interconnected while sharing data on the same network [33]. This method of charging guarantees (to a reasonable extent) efficient energy utilization. Through ensuring consumers can make informed charging choices on public charging infrastructure, public smart charging addresses the scepticism surrounding range anxiety for EV drivers and allows for optimum utilization of battery range. IoT provides an enabling system for EV smart charging in terms of continuous monitoring and data presentation in the form of reports and dashboards. It also helps in notifying users in the event of critical failures or important updates. For example, EV drivers can be informed via a mobile app about charging time and costs. Charge point operators can remotely troubleshoot devices without a physical visit. Network operators can enhance roaming services for their charging network [16]. Smart charging stations facilitate communication between the charging grid and EV through data connections. Where applicable, certain limits on energy consumption are defined by utility companies to enable them to manage energy supply and demand [34]. Figure 2 illustrates a snapshot of this public smart charging ecosystem [33].

The benefits of public smart charging transcend the interests of EV consumers and charging station service providers through generating a vast amount of data upon which important decisions can be made by both parties [10]. Through using vehicle–grid integration (VGI), it permits charging operators (either consumers or service providers) to manage the amount of energy dissipated to EVs plugged-in at any time. This result can be achieved in either of two ways: customers respond to price signals from the electric vehicle supply equipment's (EVSE) automated response to control signals that either react to the grid and market situations, or through a combination of the two while respecting customers' needs for vehicle availability [35]. This approach allows regulation of electricity consumption, thereby managing EV loads and, consequently, limiting pressure on the power grid. As such, charging operators are curtailed from exceeding the maximum energy capacity of the charging station, as defined through their chosen energy tariff and local grid capacities [36]. When compared to conventional charging methods, this system has the laudable advantage of providing a seamless experience for EV consumers, while also minimizing grid damage [31].

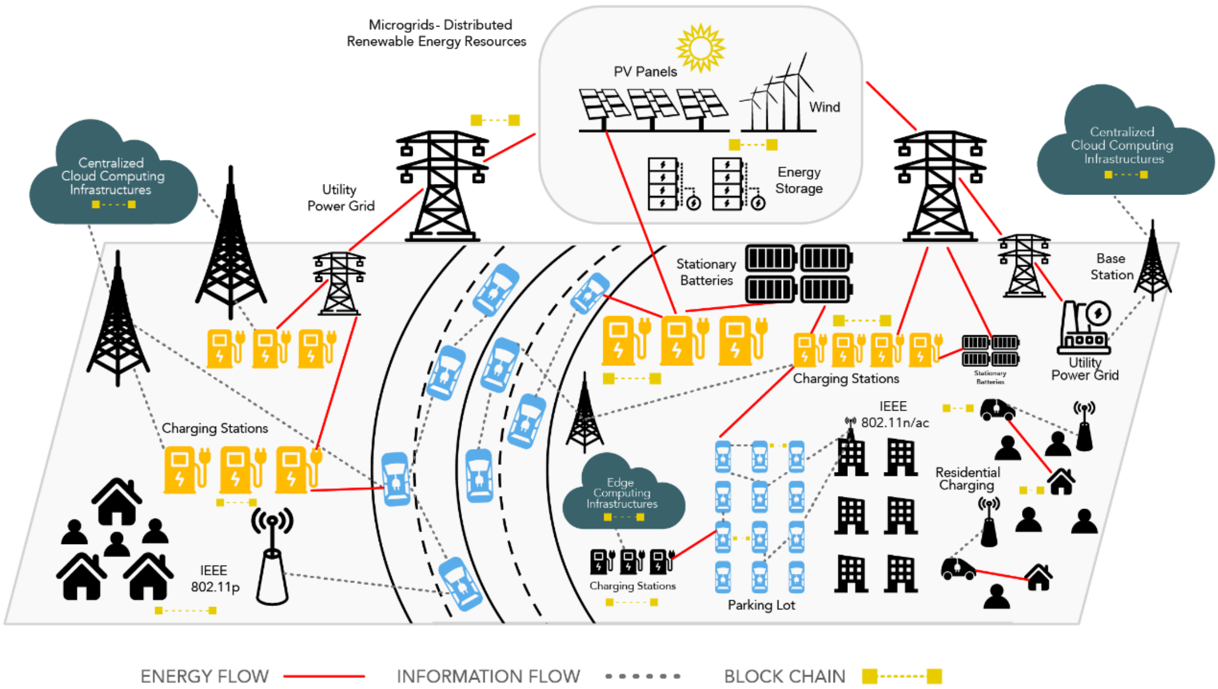

Figure 2. Public smart charging ecosystem consisting of fleets of electric vehicles, utilities, and power grids, including both centralized generation and distributed renewable energy generation and distributed storage, peer-to-peer (P2P) transactions, as well as control, communications, and computing and cloud computing infrastructures. Redrawn from [33].

3.2. Setbacks in Operations, Management, and Payment Features

As earlier stated, EVs are a major advancement towards a sustainable future for transportation. Like every functional system, EV charging systems require a fluid operations interface. Operations are required to facilitate easy control and management. It is a two-way process in public smart charging. Firstly, it involves consumers searching for a public charging station and subsequently scheduling a time to charge their vehicles. Secondly, the system requires that the service or network provider confirms the charging point and time [20]. Operations also come with other features, such as power boost and dynamic power sharing, which require effective management. With this, IoT can be useful for the smart management of EV public charging stations. For power sharing management, power sharing or load balancing (or leveling) is performed through distributing equal energy to all EV charging stations belonging to a business company or network operator, while management can be performed more effectively with the real-time processing of information [37]. In a situation where there is a power outage or fault, operations make it possible for alternative charging stations to be easily located [38,39].

With the growing adoption of EVs, the management of charging infrastructure will continue to dominate the frontline. In an era of Big Data, connectivity and real-time information play major roles in advancing technology solutions. Smart devices are required to be on par with digitalization enterprises and serve as a catalyst for business innovations to enable organizations to stay competitive. IoT can serve as a tool to enable effective and efficient management and monitoring of EV charging stations, enabling them to become more convenient for both drivers and service workers. Given that the EV market is expected to expand significantly in the next decade [4], it is expected that the number of EV charging stations will also increase significantly to meet increasing consumer demand. Presently, the charge points for EVs are decentralized, creating significant problems for management and maintenance by on-site personnel due to the complex nature of this setup. IoT, on the other hand, generates enormous data in huge amounts, which will be a major driver for processing and analyzing large data sets from numerous embedded sensors. This serves to centralize the EV charging system, making it easy for Charging Point Operators (CPOs) to monitor and manage this data within one platform. This enables EV public charging stations to become connected and smarter, making them more accessible for remote maintenance, control, and support.

The payment feature is another potentially beneficial aspect of IoT for EV public charging because it provides consumers with the exact information as it relates to charging time and cost [40]. Publicly operated charging stations imply that they are available for public use at commercially billed rates. These public sites are readily available for residents in a high-rise or city apartments since house owners can afford residential charging options. There are numerous nations where regulations are not stringently implemented to forestall misrepresentation in instalment frameworks [41]. This situation raises issues of trust and straightforwardness. Although in its nascent stage, the blockchain platform is a potential tool to mitigate the drawbacks associated with consumer trust and reliability within the purview of EV charging payment. Blockchain is a cutting-edge technology that is currently being explored as it mitigates trust and protection issues. This technology was previously proposed as a shared energy exchanging and charging instalment framework for electric vehicles [13,14].

In such a framework, clients, so-called prosumers, who have excess power can offer it to the charging stations while taking care of the charging bills through electronic wallets. Such a peer-to-peer (P2P) energy trading plan affords certain consumers the right to maintain the energy demand–supply balance via an integrated IoT network. The proposed framework decreases human collaboration and increases trust, straightforwardness, and data protection for EV clients [42]. Moreover, it can be very useful in urban areas. This system also allows clients to pay from their mobile phone app directly upon charging, saves time and energy, and can provide information regarding tariff management. Digital currency, notably cryptocurrency, has evolved and grown on such a global level that consumers perceive easy cash flow as a fundamental way to reflect on their user experience. Partly due to this reason, EV consumers in India, China, the USA, and Japan perceive this automated and accelerated form of monetary transaction as a convincing factor in pointing to the effectiveness of the system [42].

3.3. The Interplay of Optimal Scheduling-Based EV Charging System

Another critical index to consider in an IoT-based EV system is optimal charging scheduling, which includes battery swapping, charging station location, the quantity of spare or backup batteries, the number of charging points per station, and routes and schedules. To be considered are the critical aspects of EV charging in terms of both battery- and non-battery-based optimal scheduling constraints.

3.3.1. Battery-Based

The main EV charging architecture, otherwise known as EV supply equipment (EVSE), involves a panel connected to the service line, conducting lines connecting the panel to the charger, and EV charging equipment. The optimal charging scheduling for EVs was previously studied in different contexts e.g., its integration with emerging distributed generation grids [43], its operations considering traffic patterns and travel distance [44], its efficiency in terms of reducing charging and operational costs [45], its participation in a vehicle-to-grid (V2G) routine for electricity bills savings at an office building [46], and its convergence towards EV user satisfaction and charging convenience [47]. Thus, the different charging technologies for EVs can be broadly grouped into conventional and emerging battery charging configurations.

Conventional Battery Charging

- Slow Charging: This conventional EV charging technology is time-consuming and, thus, increases turnaround time.
- Night Charging: This is also a conventional way of charging batteries overnight at a slow pace and at low-peak energy rates, leading to extended battery life.
- Battery Swapping: This charging technology is as old as EV technology itself. This technology allows continuity of service for EV users through simply replacing drained batteries with fully charged ones at charging stations. Charging stations could be either centrally or locally sited. Although this technology improves scheduling with minimum delays, the major challenges are high costs, which result from duplicated hardware, and high land usage, especially where local charging stations are deployed. The important design indices to consider in battery swapping include battery property, battery size, charging location, battery swapping location, the quantity of spare backup batteries, the number of charging points per station, and routes and scheduling [48,49].

Emerging Battery Charging

- Dynamic Wireless Power Transfer (DWPT): DWPT, also known as inductive charging, is an emerging technology that promises to eliminate the range limitation in EVs. The technology, which employs wireless inductive power transfer pads, ensures that EVs can be charged while in motion. One big advantage of this DWPT charging is that it cuts down on the size of on-board battery capacity, which translates to more affordable EVs [50]. However, a major challenge of this charging technology is poor efficiency because of the conceivable distance separating the primary sending coil and the secondary pickup coil. Three main types of DWPT charging for EV buses were identified:
    - stationary: when the EV bus is parked and standing over the charger;
    - quasi-dynamic: when the EV bus is forced to drive at low speed while charging;
    - dynamic (on-route or opportunity charging): when the EV bus is charged instantaneously under normal operation.
- Fast Charging: This usually goes together with DWPT-inductive charging. With fast charging for EVs, operational efficiency and driving range can be improved drastically, among other things. Existing fast charging technologies can cut down charging timed to less than a quarter of current times, though this could also mean that battery life and travel range are shortened over time [51]. Concerns about ultra-fast charging degrading battery performance over time compared to extended normal repeated charging exist [52]. Furthermore, ultra-fast charging in frequent but short duration was previously identified as a critical factor in reducing battery capacity and service interruptions.

3.3.2. Non-Battery-Based

This subsection touches on critical aspects of EV charging that are not directly linked to the battery. They are critical because ignoring them would mean that battery charging and life are negatively impacted in the long run. The categorization of these optimal scheduling constraints, as inspired by [53], is illustrated in Figure 3.

- Routes: The travel range to a large extent determines the amount of discharging on battery life. Shorter routes mean prolonged battery life, and vice versa. The condition of roads and traffic are factors that affect EV bus driving cycles and, by extension, battery life. Inductive charging solutions were previously suggested as means of addressing routes with dense traffic and extensive public transport networks [54], while accurate navigation and range prediction is useful in promoting strategies to address EV range anxiety [55]. In [53], DWPT charging is recommended for extended integrated network routes, while for smaller condensed network routes, static wireless power transfer (WPT) can suffice [56]. Other critical factors to consider on EV travel routes are the number and length of bus stops, road texture, overlapping bus lines, average speed, climate, and available time per stop [57].

- Operation: Planning and scheduling is the ability to operate EVs in continuous service along planned routes. They are very important factors to consider because EVs cannot continue a trip if the battery life drops below a minimum threshold. If charging is required, it results in schedule interruptions, delays, and commuter anxiety if the bus needs to be parked until recharging is completed. Hence, to maintain schedule reliability, proper planning and periodic scheduling of transit routes need to be integrated into EV public charging to minimize or eliminate interruptions. In [58], robust scheduling and integrated planning are recognized as critical areas of research for addressing limited driving range and long charging hours for EV transport systems.
- Support Infrastructure: The integration of the emerging renewable energy power system, battery storage, and EVs under an optimal energy management system (EMS) result in optimal power dispatch in terms of reduced energy consumption, reduced energy and operational cost, and reduced greenhouse gas (GHG) emissions [59,60].

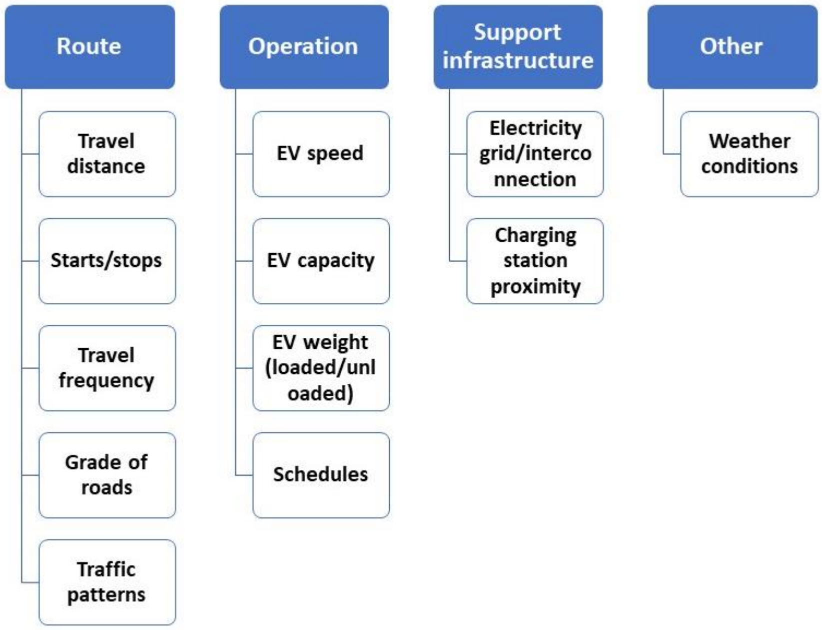

Figure 3. Optimal scheduling constraints for EV public charging.

3.4. Technology Challenges and Opportunities

Several challenges hindering IoT adoption concern EV public charging infrastructure. These drawbacks include the susceptibility of these systems to cyber-attacks, regulatory deficiencies, and compatibility issues [61]. Governments around the world are pushing for a green technology transition to tackle climate change and reduce reliance on hydrocarbons. Norway already has a network of 17,000 charging points for electric vehicles, and the U.S. Department of Transportation recently announced it would spend 5 billion dollars on a new network of charging stations for electric vehicles [62,63]. By 2021, the number of new energy vehicles in China has reached 7.84 million, representing a year-on-year increase of 59.3%. It is estimated that in 2025, the number of new energy vehicles in China will reach 26.72 million, and the number of pure electric vehicles will reach 23.24 million [64]. To meet the demand for safe charging of electric vehicles, the state has made it clear that by the end of the 14th Five-Year Plan, China's charging infrastructure system will be able to meet the charging demand of more than 20 million electric vehicles, while the number of charging piles is expected to reach 6.543 million in 2025 [65–67].

While car companies are dramatically ramping up the production of electric vehicles, the industry has not made sufficient progress to deal with cybersecurity issues related to the Internet of Things devices. Advances in technology witnessed advances in techniques used to breach the safety walls of the systems. Consequently, there is always a risk of a breach in the security of IoT systems [68]. IoT puts EVs at the risk of cyber-attack and data theft because several devices are connected to the internet, with a high amount of data being constantly transmitted. This situation could result in hackers attempting to access the system in a bid to steal personal information, which could be misused. Fundamentally, EV consumers could become sceptical about adopting this technology, given the nature of this apparent flaw. Figure 4 shows a summary of some of the potential targets of cyber-attacks.

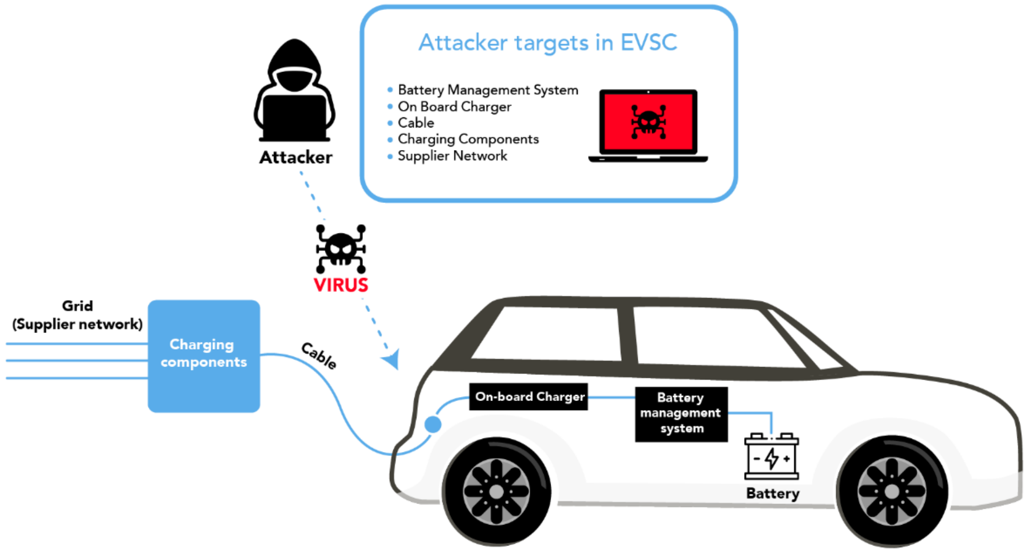

Figure 4. Potential targets of cyber-attacks. Image Redrawn from [17].

The V2G process makes the EV ecosystem a typical Internet of Things (IoT) ecosystem, which inevitably poses an additional cyber-attack threat to the power system from the demand side. While such cyberattacks against electric power systems have not yet been conducted in practice, similar attacks were previously reported in other IoT ecosystems. As an example, in Mirai Botnet [69], which was a cyber-attack against IoT devices, the attackers compromised more than 600,000 IoT devices and launched a DDoS cyber-attack against Dyn domain service providers. Cyberattacks from the demand side are more threatening than the previously widely studied cyberattacks from the operational side of the power system, because there are more access points for attacks from the demand side than from the utility side due to its complex cyberspace and multiple roles.

Considering the huge potential threat of EV attacks on the power system, several works in the literature were discussed to explore the impact of the attacks. Saber et al. [41] demonstrated that inappropriate charging behavior will lead to peak loads, voltage violations, and degraded grid performance. Following this idea, Acharya et al. [42] show that through collecting information from publicly accessible sources and combining it with vulnerabilities in EV charging stations, an attacker can manipulate a large number of EV charges simultaneously, causing frequency instability and disrupting the automatic generation control system of the transmission grid. Manhattan was used as a case study in this paper. Sayed et al. [61] analyze vulnerabilities in communication protocols, IoT, and firmware for EVs, and demonstrate that even if only 2.5% of EVs are manipulated, an attacker can still cause huge voltage violations with high penetration of EVs.

Another team of researchers led by Elia Bou-Harb [62], Director of the Center for Cybersecurity and Analysis at the University of Texas, explored the real-world impact of cyber-attacks on electric vehicle charging systems and how cybersecurity countermeasures could be used to mitigate these attacks. With this goal in mind, the researchers evaluated 16 electric vehicle charging station management systems (EVCSMS), including systems developed by well-known global suppliers. Their assessment identified 13 of the most serious vulnerabilities in EVCSMS firmware, mobile, and web applications that could lead to 11 types of cyber-attacks. The team divided cyber-attacks into three distinct categories: (i) attacks against EVCS, (ii) attacks on users, and (iii) attacks on the power grid.

In the first case, the EVCS may be compromised, causing it to charge reduced or no fees and show customers manipulated fees or disabled features. In the second scenario, an attacker could access a user's billing records and personal information. That means their data can be used for surveillance, extortion, identity theft, and payment fraud. In the third scenario, an attacker could use a large number of infected EVCSMS to initiate synchronous charging operations or reverse the flow of current back into the grid through increasing the discharge supply. Both attacks destabilize the power grid, which can lead to cascading failures. In this project, the research team developed countermeasures to fix each vulnerability they found. They also made recommendations on appropriate security measures, guidelines, and best practices that developers can follow to mitigate attacks. When it comes to preventing large-scale attacks on the power grid, the researchers suggest that patching existing vulnerabilities is not enough. They stress that developers also need to incorporate initial safety measures into the manufacturing of charging stations.

On the issue of regulations, given that IoT is relatively new and its advancement is a continuous process, designing favorable government regulations toward its implementation could become difficult. There are no such regulations available to which the technology can become a subject worldwide, thereby placing the rights and duties of both service providers and consumers in an uncertain position [40]. Additionally, compatibility is another hindrance to IoT adoption. There are currently no set standards available for the IoT industry, which has resulted in blockage of communications, sometimes between devices [63].

Despite these challenges, there are several opportunities that IoT technology provides for EV users. Connecting devices and systems enables IoT to optimize operations in EV charging stations, thereby improving user experience. It can provide EV consumers with a seamless and swift source of connectivity with public charging stations [64]. It can also eliminate range anxiety via giving proper information about established public charging stations [9]. Additionally, the business application opportunities of IoT for service providers are limitless in terms of operations and management. It provides an opportunity for service providers to connect with their clients. The progress in EV transport requires frameworks that highlight their superior capabilities, such as eco-friendliness (with regards to MPGe, i.e., miles per gallon of fuel equivalent), widening range, and quick charging choices [65]. To speed up the reception of EV transportation, innovative patterns for IoT-integrated public charging systems with economically accessible arrangements are key considerations for consumers.

4. Potential Impacts on Consumer Behaviour and Implications

The potential impact on consumer behavior of IoT in the public charging of EVs is eliminating consumer range anxiety to some extent owing to real-time information and accessibility of charging portals. Range anxiety is currently one of the significantly limiting challenges related to EV adoption [66].

Figure 5 depicts the consequent impact of range anxiety on the behavioural travel patterns of EV consumers. From an online survey conducted on 500 EV consumers in the United States, over two-thirds of consumers reported that range anxiety frequently deterred them from taking a trip or caused them to rearrange their travel plans. Around one-fourth of these consumers confirmed that they are always deterred from embarking on trips due to the anxiety centered around the travel range of EVs. In contrast, only about one-tenth of these EV consumers were never deterred from traveling due to range anxiety. These results highlight range anxiety as a significant challenge amongst EV consumers, owing to the obvious limitations in driving range of EVs [66]. Thus, a potential solution to this would be the incorporation of IoT into the public smart charging systems of EVs.

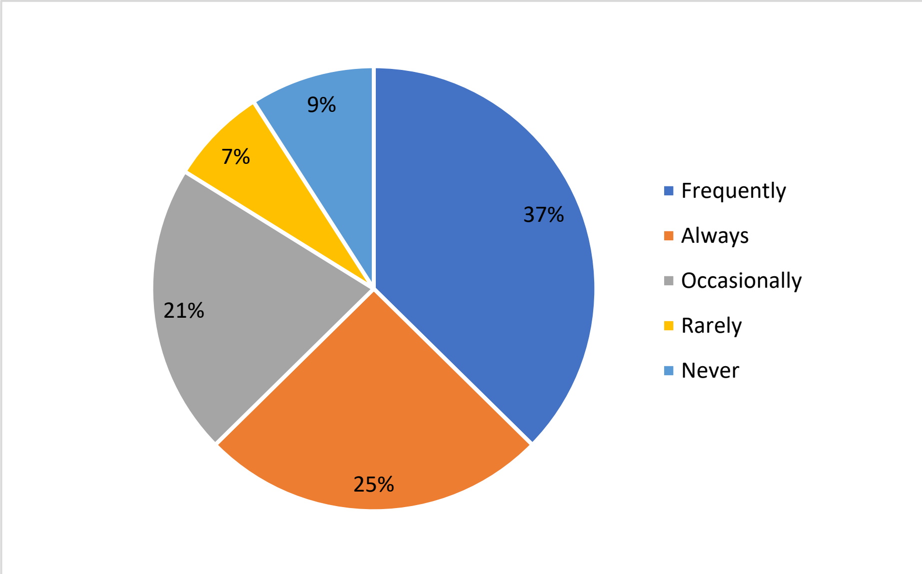

Figure 5. Impact of range anxiety on EV consumer behavior: From a survey of 500 electric vehicle consumers in United States conducted by Forbes Wheel, statistical plot depicting variation in consumer behaviour because of range anxiety is displayed. Survey is centered around assessing EV consumers who were forced to cancel a trip or reschedule travel plans owing to worrisome shortcomings in driving range of their EVs. Consumer responses range from consumers who have never cancelled or rescheduled a trip—identified as "never"—to those who always cancel trips owing to range anxiety of their EVs—identified as "always" [66].

Moreover, consumers' perspectives are greatly influenced based on tariff management and costs [41]. IoT will also play a key role in tackling the previously stated interoperability issues, with EV drivers currently faced with the challenge of having to download and use multiple spps from different charge point operators and payment platforms. In addition, consumer satisfaction means a sense of belonging, familiarity, security, gratitude, and user feedback. However, it is also important to note that although IoT technology is advancing positively, industrial uptake will continue to suffer if consumers experience negative interaction with the technology, such as insecurity shortcomings and regulation challenges. The trust and confidence of consumers are assets to any organization, which are usually earned through paying active consideration to the needs and requirements of these clients. Thus, positive experiences of consumers will result in high demand for EVs, while negative experiences may decrease demand.

In a design thinking framework, the impact of the opinion and preferences of consumers build the fundamental structure of businesses, as the products are developed and changed according to the needs of the consumers [67]. The implication of the consumer attitude towards EVs is as important as the evolution of the industry when compared to that of combustible engine vehicles. Consumer perception of EVs is that they preserve the environment and employ the use the smart technologies (such as digital twins) to improve lifestyle, all of which determine the attitude and behavior of the consumers towards the EV industry [68]. The underlying factor is to affirm a customer's choice model and reduce conflict in terms of innovation reception, which can be more efficiently assessed through investigating customer convictions and post-buy outcomes. Such outcomes provide insights for firms to incorporate future innovations that will continually foster user acceptability and satisfaction [69].

5. Discussion

The EV ecosystem requires proper maintenance and management of its various elements, such as charging stations, payment features, and maintenance systems. In light of the current challenges in developing the EV ecosystem, such as infrastructure management, negative consumer experiences, energy management, and profitability, there is a need to create a system that universally works for everyone. Addressing this shortcoming is tied to consumer perception of EVs, which is in great part dependent on the charging experiences of these consumers. The charging experiences of these consumers are determined through both the rational and emotional attachments of consumers to the product, with public charging infrastructure and tariff designs also playing a huge role in these sentiments.

Potential EV consumers are often reluctant to adopt EV technology owing to range anxiety, which is partly tied to limited public charging infrastructure [69,70]. Despite public charging being the most popular charging option, consumers are more inclined to use home charging than public charging infrastructure [71]. To a large extent, embracing public charging infrastructure depends on the availability of charging service points and charging speeds [72]. Indeed, public charging infrastructure provides a flexible and cheaper option for EV consumers. Although the potential future market of EVs is predicted to be huge, it will depend on how the industry handles the current challenges regarding public charging systems, while also overcoming the price disparities between EVs and conventional ICEs.

The deployment of IoT technology is instrumental to fostering EV growth and promoting positive consumer experience. Its potential benefits cut across all stakeholder groups in the value chain, encompassing the consumers, network operators, and Charge Point Operators (CPOs). The various elements of EV charging each work to ease public smart charging experiences. For instance, the hardware unit is furnished with several charging protocols, connectivity options, sensors, and power electronics to provide a physical connection between the EV and the power grid. The internet-based application (typically smartphones) plays the role of connecting EV consumers with the charging network, in addition to providing a seamless user authentication process and improved charging function management. The third element—the cloud-based management platform—collects data from the IoT sensors and conducts data analytics for managing remote monitoring by consumers and network operators, load balancing, and other smart features peculiar to public smart charging infrastructure. All these elements harmonize to make IoT a powerful tool for improving consumer charging experience.

Ensuring a seamless smart charging experience is an important reason for incorporating IoT in the EV charging system. The tariff design and structure have evident impacts on consumer behavior toward EV utilization. Consumer behavior, in relation to tariff design and structures, varies from country to country due to the different policies implemented by governments and rates of energy consumption per hour [41]. The more economical the country's tariff design, the more positive consumer response and behavior. Tariff design also helps in managing demand for energy in one specific area and is important for enhancing the consumer experience of public charging [73]. With the integration of IoT, there are additional benefits of enhanced trust, cost management, and operational efficiency [16]. To this end, public charging is considered resourceful in areas where the utilization rate is low, with IoT then serving as a tool for subsidizing infrastructure and tackling excessive charging costs.

The benefits of IoT in EV public smart charging are numerous. Foremostly, public charging systems cannot quite boast a structured user identification and payment handling system. However, this problem is ameliorated through integrating IoT into the public charging sphere. Consumers can tag in their Radio Frequency Identity (RFID) cards or connect with a smartphone to enable access, prompting the EVSE to transmit this data to the IoT cloud-based platform. The platform performs authentication processes on the consumer's profile, proceeding to grant authorization and complete secure billing transactions if affirmative. This process guarantees seamlessness in transaction operations, improving payment systems and assuring consumers of a near-autonomous experience.

Slow-charging infrastructure has a time constraint and range limitation, while fast-charging infrastructure takes less time and offers an extended driving range. The experience of consumers towards public charging will entail a timely rate of charging, a real-time network on the availability of charging stations, and secure and convenient payment methods. Usually considered the most valuable factors of interest for EV users, improving drivers' confidence and reducing range anxiety can be addressed through fast public charging infrastructure [20], especially IoT-integrated charging stations [74]. EV charging mobile applications aid in searching for nearby fast-rated charge points, checking the availability of these stations, and reserving slots for the next available timeline for EV consumers based on battery capacity. IoT ensures these apps can indicate the various charging rates via suggesting off-peak hours inclined towards low-cost charging. This function helps in decreasing grid load via providing information to regulate the flow of power. In this regard, EV adoption is fostered while stabilizing the power grid.

Charging location is one of the factors that contributes negatively to consumer experience due to unavailable information regarding the availability the charging stations. Spatial coverage in most countries is very weak, which increases range anxiety in consumers. Where available, it is found that most consumers do not have information about public charging stations [75]. This issue can be primarily attributed to the huge initial capital cost of EV charging infrastructure and stakeholders implementing it based on available demand and potential consumers [76]. To this end, most of the charging events are privately run. However, to address the issue of range anxiety regarding EV charging, countries across the world can push for the proliferation of public charging stations. In both scenarios, IoT can be deployed to monitor charging stations, given that these charge points are geographically dispersed and can be quite challenging to manage. This bottleneck for CPOs could result in negative feedback from consumers. Using IoT, CPOs can monitor and manage charge operations remotely, enabling them to timely resolve consumer charging problems in real time as they relate to EV usage and performance. This approach subsequently reduces downtime and fosters predictive maintenance. In the event of an expansion in charging stations, data on existing charging points will aid CPOs in effectively planning geographically favorable locations for new stations, with the existing data enabling optimized utilization of chargers. These data can also be used to track trends over time and provide a basis for identifying potential areas of improvement.

Remote management is another plus side of adopting IoT technology for EVs. It enables CPOs to manage operations remotely, resulting in the timely resolution of issues. IoT provides real-time metrics and usage insights, as well as data on device performance. The cloud-based platform collects and stores data from different sensory nodes, upon which it analyses vital metrics, such as energy tariffs, grid limit, charging state, and EV battery capacity. Using this data, it becomes easier to manage charging infrastructure in large fleets. Information depicting troubleshooting, charger availability, and fault monitoring also aids in reducing downtime and easing predictive maintenance.

Although the adoption of IoT technology in public charging infrastructure gives an inclination of positive consumer experience towards promoting EV adoption, like every other technology, it comes with its attendant bottlenecks. The current data available is still insufficient to draw firm conclusions as to the extent to which consumers' expectations are met. For example, there are also problems with the IoT technology in terms of gaining the trust of the consumers for it to potentially solve problems associated with the public charging infrastructure, such as low charging station coverage, tariff problems, and payment difficulties. However, the potential impacts of IoT technology outweigh these drawbacks, as it can change the complete course of the EV industry and the associated problems of consumers with EV charging experiences. It remains the best possible option to tackle consumer range anxiety, which is one of the biggest problems of the EV industry right now [6].

6. Conclusions

EVs are likely to gain mainstream acceptance in the coming years, following recent improvements in driving range, optimized battery costs, and the increasing variety of options being made available. However, the charging infrastructure still suffers from setbacks. Establishing reliable charging infrastructures will help to complement this positive trajectory in EV growth through positively influencing consumer behaviour. This study reviewed the emergence of IoT as a cutting-edge technology for enhancing EV public charging systems and, by extension, consumer experiences. Although public smart charging is a more robust low-cost charging option that also promotes equitable use of infrastructure, faster charging and reduced concerns regarding range anxiety, this framework also raises the issue of a lack of trust, reduced privacy, data insecurity, and operational and regulatory bottlenecks. The potential industrial uptake of EV technology is hugely dependent on how these challenges are tackled, as well as on the integrated technology solution of IoT-based public charging networks. IoT systems were previously identified as potentially addressing these gaps through employing blockchain technology, cryptocurrency, machine learning, big data, and digital twin to offer network solutions that improve transparency, consumer trust, and data security and ensure a positive consumer experience. However, overall consumer behavior toward EV charging is determined largely based on the ubiquity of charging points and the relative speed of the charging infrastructure, as well as affordability.

In terms of improving the consumer experience of EV public charging infrastructure, it is recommended to consider developing and integrating public charging infrastructure with IoT to boost charging timed, reduce installation costs, increase geographic penetration, and ensure ease of consumer access. This approach would also require an increase in the number of charging stations installed at prime locations, such as near residential areas, schools, markets, and subways. The proximity of these routes and their real-time information on the internet need to be easily accessible to consumers. Encouraging private sector innovation can help to foster this action and improve user experience in the integration of IoT across EV charging systems.

Governments and policymakers should also consider evaluating existing policies and practices to ascertain their suitability for IoT adoption in EVs, ensuring that they do not constitute unintentional barriers to the adoption of EVs. Although IoT serves as a strong tool to foster public interest through favourable public policy, its novel and innovative nature faces developmental challenges based on existing governmental policies, which could hinder the interest of potential investors. As such, governments and policymakers should provide incentives and subsidies to encourage industries, consumers, and service providers to enter the EV market and encourage green technology. Green technology makes a major contribution to the sustainability of the natural environment.

Introducing IoT services nationwide will come with its bottlenecks in terms of conflicting regulations, with regulatory uncertainty being a huge barrier. However, IoT as a target area for research and innovation will serve to encourage all stakeholders to participate in and fully contribute to IoT deployment in an enabling environment. An example can be drawn from the European Union's (EU) Digital Agenda for Europe 2020 initiative, which focuses on research, applications, and an innovative policy environment for IoT integration. Participation and encouragement by the government to promote EVs, alongside the adoption and use of Global Technical Standards, will positively induce public concern towards the environment, while cost-effective designs and increased production will add business value for relevant stakeholders.

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References

1. IEA. Improving the Sustainability of Passenger and Freight Transport. Available online: https://www.iea.org/topics/transport (accessed on 25 November 2022).
2. IEA. Global EV Outlook 2022. Available online: https://www.iea.org/reports/global-ev-outlook-2022 (accessed on 25 November 2022).
3. Engel, H.; Hensley, R.; Knupfer, S.; Sahdev, S. The Basics of Electric-Vehicle Charging Infrastructure | McKinsey. Available online: https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/charging-ahead-electric-vehicle-infrastructure-demand (accessed on 3 March 2023).
4. IEA. Electric Vehicles—Analysis—IEA. Available online: https://www.iea.org/reports/electric-vehicles (accessed on 3 March 2023).
5. Wang, Y.; Chi, Y.; Xu, J.H.; Yuan, Y. Consumers' Attitudes and Their Effects on Electric Vehicle Sales and Charging Infrastructure Construction: An Empirical Study in China. *Energy Policy* **2022**, *165*, 112983. [CrossRef]
6. Hardman, S.; Jenn, A.; Tal, G.; Axsen, J.; Beard, G.; Daina, N.; Figenbaum, E.; Jakobsson, N.; Jochem, P.; Kinnear, N.; et al. A Review of Consumer Preferences of and Interactions with Electric Vehicle Charging Infrastructure. *Transp. Res. D Transp. Environ.* **2018**, *62*, 508–523. [CrossRef]
7. Adoba, P.O.; Dioha, M. Strategic Development of Electric Vehicles in Canada. In *IAEE Energy Forum First Quarter*; International Association for Energy Economics: Cleveland, OH, USA, 2021; pp. 26–31.
8. Ernst & Young LLP. *EY Strategy Canadian Electric Vehicle Transition-the Difference between Evolution and Revolution EY Strategy*; Ernst & Young LLP: Sydney, Australia, 2020.
9. Savari, G.F.; Krishnasamy, V.; Sathik, J.; Ali, Z.M.; Abdel Aleem, S.H.E. Internet of Things Based Real-Time Electric Vehicle Load Forecasting and Charging Station Recommendation. *ISA Trans.* **2020**, *97*, 431–447. [CrossRef] [PubMed]
10. Hoque, A.H.E.; Ahmed, M.R.; Barber, A.; Rizqullah, A.; Iqbal, A.; Khandakar, A. Internet of Things Applications in Electric Vehicles—A Review. *Lect. Notes Electr. Eng.* **2021**, *723*, 315–322.
11. Arif, S.M.; Lie, T.T.; Seet, B.C.; Ayyadi, S.; Jensen, K. Review of Electric Vehicle Technologies, Charging Methods, Standards and Optimization Techniques. *Electronics* **2021**, *10*, 1910. [CrossRef]
12. Divyapriya, S.; Emayavaramban, G.; Amudha, A.; Ramkumar, M.S.; Nagaveni, P.; Mansoor, V.M. Internet of Things Enabled Plug in Electrical Vehicle Based Self Maximum Demand Controller for Shopping Mall. *Mater. Today Proc.* **2020**, *37*, 2567–2571. [CrossRef]
13. Sestino, A.; Prete, M.I.; Piper, L.; Guido, G. Internet of Things and Big Data as Enablers for Business Digitalization Strategies. *Technovation* **2020**, *98*, 102173. [CrossRef]
14. Kiran, D.R. Internet of Things. In *Production Planning and Control*; Butterworth-Heinemann: Oxford, UK, 2019; pp. 495–513. [CrossRef]
15. Phadtare, K.; Wadkar, S.; Thorat, S.; Ghorpade, A.; Jadav, A. A Review on IoT Based Electric Vehicle Charging and Parking System. *Int. J. Eng. Res.* **2020**, *V9*, 831–835. [CrossRef]
16. Bhagora, D. Role of IoT in Fueling EV Charging Future Growth. Available online: https://www.einfochips.com/blog/role-of-iot-in-fueling-ev-charging-future-growth/ (accessed on 3 March 2023).
17. ITU-T. Internet of Things Global Standards Initiative. Available online: https://www.itu.int/en/ITU-T/gsi/iot/Pages/default.aspx (accessed on 3 March 2023).
18. Harris, B. Data-Driven Internet of Things Systems and Urban Sensing Technologies in Integrated Smart City Planning and Management. *Geopolit. Hist. Int. Relat.* **2021**, *13*, 53–63. [CrossRef]
19. Qahtan, M.H.; Mohammed, E.A.; Ali, A.J. Charging Station of Electric Vehicle Based on IoT: A Review. *Open Access Libr. J.* **2022**, *9*, e8791. [CrossRef]
20. Bhatti, G.; Mohan, H.; Singh, R.R. Towards the future of smart electric vehicles: Digital twin technology. *Renew. Sustain. Energy Rev.* **2021**, *141*, 110801. [CrossRef]
21. Savari, G.F.; Sathik, M.J.; Raman, L.A.; El-Shahat, A.; Hasanien, H.M.; Almakhles, D.; Aleem, S.H.A.; Omar, A.I. Assessment of charging technologies, infrastructure and charging station recommendation schemes of electric vehicles: A review. *Ain Shams Eng. J.* **2022**, *14*, 101938. [CrossRef]
22. Teimoori, Z.; Yassine, A. A Review on Intelligent Charging Management System for Future Electric Vehicle Transportation. *Sustainability* **2022**, *14*, 14100. [CrossRef]
23. Mastoi, M.S.; Zhuang, S.; Munir, H.M.; Haris, M.; Hassan, M.; Usman, M.; Bukhari, S.S.H.; Ro, J.-S. An in-depth analysis of electric vehicle charging station infrastructure, policy implications, and future trends. *Energy Rep.* **2022**, *8*, 11504–11529. [CrossRef]
24. Rimal, B.P.; Kong, C.; Poudel, B.; Wang, Y.; Shahi, P. Smart Electric Vehicle Charging in the Era of Internet of Vehicles, Emerging Trends, and Open Issues. *Energies* **2022**, *15*, 1908. [CrossRef]
25. Efthymiou, M.; Njoya, E.T.; Lo, P.L.; Papatheodorou, A.; Randall, D. The Impact of Delays on Customers' Satisfaction: An Empirical Analysis of the British Airways On-Time Performance at Heathrow Airport. *J. Aerosp. Technol. Manag.* **2018**, *11*, e0219. [CrossRef]
26. Levinson, R.S.; West, T.H. Impact of Public Electric Vehicle Charging Infrastructure. *Transp. Res. D Transp. Environ.* **2018**, *64*, 158–177. [CrossRef]

27. Anwar, M.B.; Muratori, M.; Jadun, P.; Hale, E.; Bush, B.; Denholm, P.; Ma, O.; Podkaminer, K. Assessing the Value of Electric Vehicle Managed Charging: A Review of Methodologies and Results. *Energy Environ. Sci.* **2022**, *15*, 466–498. [CrossRef]
28. California Air Resources Board. *CARB Draft 2020 Mobile Source Strategy*; California Air Resources Board: Sacramento, CA, USA, 2020.
29. Borlaug, B.; Muratori, M.; Gilleran, M.; Woody, D.; Muston, W.; Canada, T.; Ingram, A.; Gresham, H.; McQueen, C. Heavy-Duty Truck Electrification and the Impacts of Depot Charging on Electricity Distribution Systems. *Nat. Energy* **2021**, *6*, 673–682. [CrossRef]
30. Muratori, M. Impact of Uncoordinated Plug-in Electric Vehicle Charging on Residential Power Demand. *Nat. Energy* **2018**, *3*, 193–201. [CrossRef]
31. Coignard, J.; Saxena, S.; Greenblatt, J.; Wang, D. Clean Vehicles as an Enabler for a Clean Electricity Grid. *Environ. Res. Lett.* **2018**, *13*, 054031. [CrossRef]
32. PsiBorg Technologies Pvt. Ltd. IoT for Electric Vehicle Monitoring & Management. Available online: https://www.iotforall.com/iot-for-electric-vehicle-monitoring-and-management (accessed on 3 March 2023).
33. Virta Smart Charging of Electric Vehicles: The Ultimate Guide. Available online: https://www.virta.global/smart-charging (accessed on 3 March 2023).
34. Gibson, P. Internet of Things Sensing Infrastructures and Urban Big Data Analytics in Smart Sustainable City Governance and Management. *Geopolit. Hist. Int. Relat.* **2021**, *13*, 42–52. [CrossRef]
35. IRENA Innovation Outlook. *Smart Charging for Electric Vehicles*; International Renewable Energy Agency: Masdar City, Abu Dhabi, 2019.
36. Carey, N.; Anthony, D. Smart Charging May Be Key to Saving Power Grid in World of EVs | Reuters. Available online: https://www.reuters.com/markets/europe/smart-charging-may-be-key-saving-power-grid-world-evs-2022-02-14/ (accessed on 3 March 2023).
37. Ecocharge. How Electric Vehicle Charging Load Management Works. Available online: https://evocharge.com/resources/how-electric-vehicle-charging-load-management-works/ (accessed on 20 March 2023).
38. ChargePoint Power Management FAQ. Available online: https://www.chargepoint.com/products/power-management-faq (accessed on 13 April 2023).
39. Abo-Khalil, A.G.; Abdelkareem, M.A.; Sayed, E.T.; Maghrabie, H.M.; Radwan, A.; Rezk, H.; Olabi, A.G. Electric vehicle impact on energy industry, policy, technical barriers, and power systems. *Int. J. Thermofluids* **2022**, *13*, 100134. [CrossRef]
40. Johnson, J.; Berg, T.; Anderson, B.; Wright, B. Review of electric vehicle charger cybersecurity vulnerabilities, potential impacts, and defenses. *Energies* **2022**, *15*, 3931. [CrossRef]
41. Saber, A.Y.; Venayagamoorthy, G.K. Intelligent unit commitment with vehicle-to-grid—A cost-emission optimization. *J. Power Sources* **2010**, *195*, 898–911. [CrossRef]
42. Acharya, S.; Mieth, R.; Karri, R.; Dvorkin, Y. False data injection attacks on data markets for electric vehicle charging stations. *Adv. Appl. Energy* **2022**, *7*, 100098. [CrossRef]
43. Wu, J.; Jia, Q.S. On optimal charging scheduling for electric vehicles with wind power generation. *Fundam. Res.* 2022, *in press*. [CrossRef]
44. An, Y.; Gao, Y.; Wu, N.; Zhu, J.; Li, H.; Yang, J. Optimal scheduling of electric vehicle charging operations considering real-time traffic condition and travel distance. *Expert Syst. Appl.* **2023**, *213*, 118941. [CrossRef]
45. Sadeghian, O.; Oshnoei, A.; Mohammadi-Ivatloo, B.; Vahidinasab, V.; Anvari-Moghaddam, A. A comprehensive review on electric vehicles smart charging: Solutions, strategies, technologies, and challenges. *J. Energy Storage* **2022**, *54*, 105241. [CrossRef]
46. Chai, Y.T.; Che, H.S.; Tan, C.; Tan, W.-N.; Yip, S.-C.; Gan, M.-T. A two-stage optimization method for Vehicle to Grid coordination considering building and Electric Vehicle user expectations. *Int. J. Electr. Power Energy Syst.* **2023**, *148*, 108984. [CrossRef]
47. Xu, D.; Pei, W.; Zhang, Q. Optimal Planning of Electric Vehicle Charging Stations Considering User Satisfaction and Charging Convenience. *Energies* **2022**, *15*, 5027. [CrossRef]
48. You, P.; Yang, Z.; Zhang, Y.; Low, S.H.; Sun, Y. Optimal charging schedule for a battery switching station serving electric buses. *IEEE Trans. Power Syst.* **2016**, *31*, 3473–3483. [CrossRef]
49. Liu, Z.C.; Song, Z.Q. Robust planning of dynamic wireless charging infrastructure for battery electric buses. *Transp. Res. Part C Emerg. Technol.* **2017**, *83*, 77–103. [CrossRef]
50. Bi, Z.; Song, L.; De Kleine, R.; Mi, C.C.; Keoleian, G.A. Plug-in vs. wireless charging: Life cycle energy and greenhouse gas emissions for an electric bus system. *Appl. Energy* **2015**, *146*, 11–19. [CrossRef]
51. An, K.; Jing, W.; Kim, I. Battery-swapping facility planning for electric buses with local charging systems. *Int. J. Sustain. Transp.* **2019**, *14*, 489–502. [CrossRef]
52. Gao, Z.; Lin, Z.; LaClair, T.J.; Liu, C.; Li, J.-M.; Birky, A.K.; Ward, J. Battery capacity and recharging needs for electric buses in city transit service. *Energy* **2017**, *122*, 588–600. [CrossRef]
53. Aamodt, A.; Cory, K.; Coney, K. *Electrifying Transit: A Guidebook for Implementing Battery Electric Buses*; National Renewable Energy Laboratory: Golden, CO, USA, 2021. Available online: https://www.nrel.gov/docs/fy21osti/76932.pdf (accessed on 14 March 2023).
54. Xylia, M.; Silveira, S. The role of charging technologies in upscaling the use of electric buses in public transport: Experiences from demonstration projects. *Transp. Res. Part A* **2018**, *118*, 399–415. [CrossRef]

55. Thitacharee, T.; Sripakagorn, A. Electrification of Public Transport with Fast Charging in Traffic Congested Cities. SAE Technical Paper 2016-01-1718. In Proceedings of the 12th International Conference on Automotive Engineering, Hong Kong, China, 9–11 December 2016. [CrossRef]
56. Iliopoulou, C.; Kepaptsoglou, K. Integrated transit route network design and infrastructure planning for on-line electric vehicles. *Transp. Res. Part D Transp. Environ.* **2019**, *77*, 178–197. [CrossRef]
57. Carrilero, I.; González, M.; Anseán, D.; Viera, J.C.; Chacón, J.; Pereirinha, P.G. Redesigning European public transport: Impact of new battery technologies in the design of electric bus fleets. *Transp. Res. Procedia* **2018**, *33*, 195–202. [CrossRef]
58. Perumal, S.S.; Lusby, R.M.; Larsen, J. Electric bus planning & scheduling: A review of related problems and methodologies. *Eur. J. Oper. Res.* **2022**, *301*, 395–413.
59. Nasir, T.; Raza, S.; Abrar, M.; Muqeet, H.A.; Jamil, H.; Qayyum, F.; Cheikhrouhou, O.; Alassery, F.; Hamam, H. Optimal Scheduling of Campus Microgrid Considering the Electric Vehicle Integration in Smart Grid. *Sensors* **2021**, *21*, 7133. [CrossRef] [PubMed]
60. Fei, L.; Shahzad, M.; Abbas, F.; Muqeet, H.A.; Hussain, M.M.; Bin, L. Optimal Energy Management System of IoT-Enabled Large Building Considering Electric Vehicle Scheduling, Distributed Resources, and Demand Response Schemes. *Sensors* **2022**, *22*, 7448. [CrossRef] [PubMed]
61. Sayed, M.A.; Atallah, R.; Assi, C.; Debbabi, M. Electric vehicle attack impact on power grid operation. *Int. J. Electr. Power Energy Syst.* **2022**, *137*, 107784. [CrossRef]
62. Nasr, T.; Torabi, S.; Bou-Harb, E.; Fachkha, C.; Assi, C. Power jacking your station: In-depth security analysis of electric vehi-cle charging station management systems. *Comput. Secur.* **2022**, *112*, 102511. [CrossRef]
63. Newburger, E. Biden Rolls Out $5 Billion to States for Electric Vehicle Chargers. Available online: https://www.cnbc.com/2022/02/10/biden-rolls-out-5-billion-to-states-for-electric-vehicle-chargers.html (accessed on 5 April 2023).
64. Caixin. China's New-Energy Vehicles Reach a Turning Point. Available online: https://asia.nikkei.com/Spotlight/Caixin/China-s-new-energy-vehicles-reach-a-turning-point (accessed on 5 April 2023).
65. Yang, Z. China Is Building Charging Stations for 20 Million EVs. Available online: https://www.protocol.com/bulletins/china-infrastructure-plan-ev (accessed on 5 April 2023).
66. Lekach, S.; Kwanten, A. EV Survey Shows Range Anxiety High While Charging Costs Remain Low—Forbes Wheels. Available online: https://www.forbes.com/wheels/features/ev-range-cost-confidence-survey/ (accessed on 5 April 2023).
67. Statista Electric Vehicle Charging Infrastructure in China—Statistics & Facts. Available online: https://www.statista.com/topics/10465/electric-vehicle-charging-infrastructure-in-china/#topicOverview (accessed on 5 April 2023).
68. Andrade, R.; Ortiz-Garcés, I.; Tintin, X.; Llumiquinga, G. Factors of Risk Analysis for IoT Systems. *Risks* **2022**, *10*, 162. [CrossRef]
69. Antonakakis, M.; April, T.; Bailey, M.; Bernhard, M.; Bursztein, E.; Cochran, J.; Durumeric, Z.; Halderman, J.A.; Invernizzi, L.; Kallitsis, M.; et al. Understanding the mirai botnet. In Proceedings of the 26th USENIX Security Symposium (USENIX Security 17), Vancouver, BC, Canada, 16–18 August 2017; pp. 1093–1110.
70. Mohd Aman, A.H.; Shaari, N.; Ibrahim, R. Internet of Things Energy System: Smart Applications, Technology Advancement, and Open Issues. *Int. J. Energy Res.* **2021**, *45*, 8389–8419. [CrossRef]
71. Haustein, S.; Jensen, A.F.; Cherchi, E. General Rights Battery Electric Vehicle Adoption in Denmark and Sweden: Recent Changes, Related Factors and Policy Implications. *Energy Policy* **2021**, *149*, 112096. [CrossRef]
72. McLane, R.; Liu, Q. A Look inside China's Timely Charging Infrastructure Plan. Available online: https://www.greenbiz.com/article/look-inside-chinas-timely-charging-infrastructure-plan (accessed on 5 April 2023).
73. Emodi, N.V.; Dwyer, S.; Nagrath, K.; Alabi, J. Electromobility in Australia: Tariff design structure and consumer preferences for mobile distributed energy storage. *Sustainability* **2022**, *14*, 6631. [CrossRef]
74. Kühnbach, M.; Stute, J.; Klingler, A.L. Impacts of Avalanche Effects of Price-Optimized Electric Vehicle Charging—Does Demand Response Make It Worse? *Energy Strategy Rev.* **2021**, *34*, 100608. [CrossRef]
75. Gao, H.; Zang, B.; Sun, L.; Chen, L. Evaluation of Electric Vehicle Integrated Charging Safety State Based on Fuzzy Neural Network. *Appl. Sci.* **2022**, *12*, 461. [CrossRef]
76. Rezvani, Z.; Jansson, J.; Bodin, J. Advances in Consumer Electric Vehicle Adoption Research: A Review and Research Agenda. *Transp. Res. D Transp. Environ.* **2015**, *34*, 122–136. [CrossRef]

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