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Future Trends in Smart Green IoV: Vehicle-to-Everything in the Era of Electric Vehicles

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ABSTRACT The electrification of the transportation sector is a pivotal stride towards ensuring sustainability in our systems. This paradigm offers a promising solution to multiple challenges, including reducing oil consumption, lowering Greenhouse Gas (GHG) emissions, enhancing air quality, improving the efficiency of the transportation sector, and facilitating the integration of renewable energy resources into the electric grid. Despite its potential, the electrification of vehicles encounters a major bottleneck-the need for diverse charging infrastructure options. Three groundbreaking technologies, including Dynamic Wireless Charging (DWC), Battery Swapping Stations, and Fast Charging Stations (FCSs), have emerged, holding the promise to accelerate the adoption of Electric Vehicles (EVs). These technologies address critical challenges such as range anxiety and charging downtime, contributing to a seamless experience for EV users. This work primarily delves into the realm of FCS, recognized as one of the most readily available options in the current market. Optimizing the utilization of charging infrastructure hinges on tackling challenges related to routing EVs to the nearest FCS capable of meeting specific charging requirements. These requirements encompass factors such as wait time, charging duration, and charging cost. In addition to the integration of Vehicle-to-Everything (V2X) communications for enhancing EV routing to FCS, coordinated management of EV charging demand becomes imperative for achieving grid load balancing and preventing grid overload. This paper aims to present the vision and future trends of Smart Green Internet of Vehicles (IoV) in the era of EVs. The focus extends beyond mere vehicular connectivity, delving into sustainable V2X connectivity, grid integration, vehicular networking, data security, and associated services.

INDEX TERMS Internet of Vehicles, plug-in charging, wireless charging, electric vehicles, battery swapping stations, V2X technology, machine learning, power grids, sustainability.

I. INTRODUCTION

As the world accelerates towards a zero-emissions future, the imperative of developing sustainable transportation has never been more apparent. The transportation sector shoulders a significant burden, accounting for approximately 62.3% of global fuel consumption [1] and contributing to around one-quarter of worldwide greenhouse gas emissions [2]. Decarbonizing the transportation sector stands as a vital piece of the climate action puzzle. Sustainable transport promises universal access, improved safety, reduced climate and environmental impacts, enhanced resilience, and significantly heightened efficiency. Urgent steps must be taken to embrace alternative fuels and advanced technologies, including EVs, while also promoting greater reliance on public transportation.

EVs hold immense importance in our efforts to fight climate change and reduce our dependence on fossil fuels. They offer a cleaner and more sustainable mode of transportation, contributing to reduced greenhouse gas emissions and air pollution. Fig. 1 identify four aspects trends in this area which are focused on achieving net zero emissions, enhance the EV charging infrastructure, as well as manage the smart charging of the EV. Additionally, intelligent method of routing EV

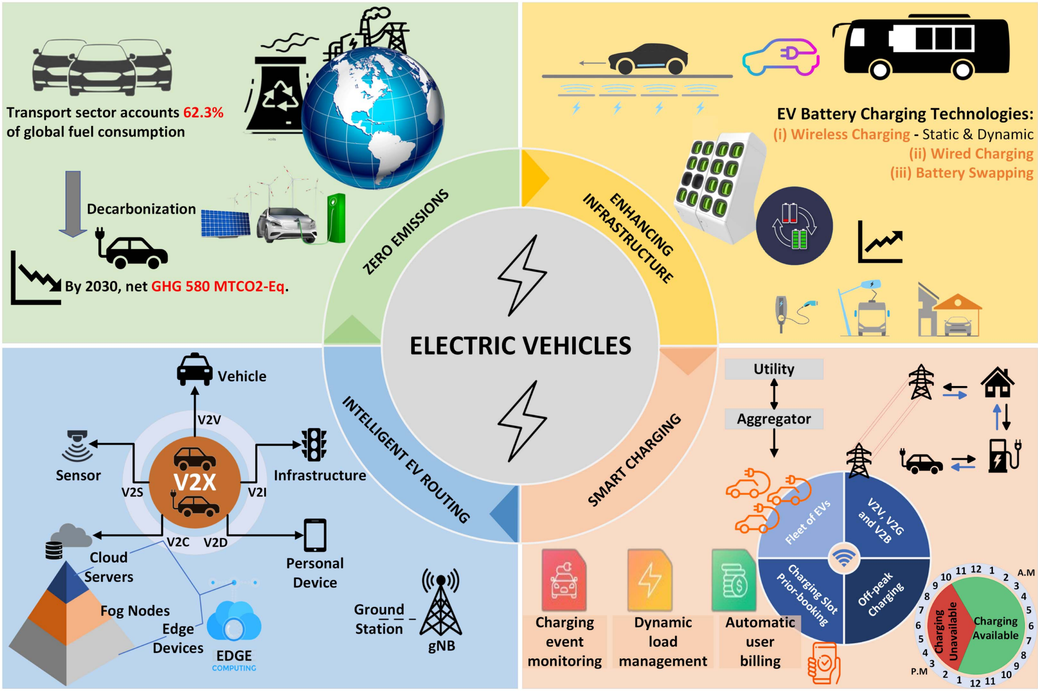

FIGURE 1. **Electric vehicle (EV) growing demand and trends.**

while utilizing the V2X capabilities where explored to support the growing demand for EVs and to assess the overall environmental impact of their widespread adoption. These aspects will be discussed further in this paper.

EVs have surged in popularity, owing to their cleaner and more efficient attributes when compared to Internal Combustion Engine Vehicles (ICEVs). According to a report by the International Energy Agency [2], it is anticipated that the number of EVs will reach 70 million by 2025 and will constitute 30% of the transportation system by 2030. With this burgeoning demand for EVs, it becomes imperative to ensure that the infrastructure is capable of accommodating the increasing number of these vehicles. Moreover, addressing the challenges faced by EV owners is of paramount importance to facilitate a seamless transition. Challenges such as range anxiety, battery degradation, and energy availability require focused attention and solutions.

One promising solution to extend the driving range of EVs and alleviate range anxiety is the implementation of DWC systems infrastructure, which delivers energy to EVs while they are in motion [3]. The adoption of DWC is expected to increase EV adoption by at least 15% while greatly enhancing drivers' convenience and the overall Quality of Experience (QoE) [4]. In addition to DWC, battery swapping stations are gaining popularity, effectively reducing charging downtime for EV owners. However, clear ownership policies for these stations need to be established. It's worth noting that these stations can integrate more renewable energy into the grid, provide support to utilities, and serve as Distributed Generation (DG) sources. To further promote the widespread adoption of EV technology, it is crucial to ensure the availability and accessibility of fast-charging stations, while also standardizing EV chargers. A variety of wired charging solutions are now available in homes, workplaces, and public areas. By strategically planning a network of EV charging solutions that encompasses both stationary and dynamic options, as well as wired and wireless alternatives, we can offer extensive charging opportunities to EV drivers. This addresses their range concerns and incentivizes greater EV adoption, driven by the long-term cost savings associated with EV. These endeavors align with user-centered strategies aimed at promoting large-scale EV adoption [5].

While improving the infrastructure for EVs is crucial, it's equally important to anticipate the impact that a high penetration level of EVs will have on the electrical grid. Such a penetration is expected to significantly affect the grid's performance and efficiency. It will necessitate additional investments in both generation and transmission capacity, mainly due to the increased peak loads resulting from a straightforward charging strategy. The introduction of EVs into the grid also raises concerns about power quality, transformer and line saturation's, and a rise in electrical losses. To effectively and safely integrate a large number of EVs into the grid, several measures become imperative. These include network reinforcements, embedded generation, and the implementation of EV charge management strategies [6].

As we progress toward an era of increased intelligence and connectivity, innovations have the potential to significantly enhance the EV owner's experience while simultaneously ensuring the accessibility of charging infrastructure. An integral aspect of this enhancement involves optimizing the routing of EVs to the nearest charging station, battery swapping facilities, or DWC lanes, all with shorter waiting times and competitive pricing, thus becoming increasingly vital. These measures serve to minimize the distances EVs need to travel to reach charging stations, reduce waiting times, and streamline the entire charging process. Such routing improvements can be achieved by harnessing the capabilities of the IoV, which empowers vehicles to communicate with each other, pedestrian and with infrastructure. This allows for the collection and secure processing of data, facilitated by low-latency and high-reliability V2X communication [5]. The convergence of V2X, which is subset of IoV technologies holds the potential to revolutionize the landscape of EV charging. These advancements infuse intelligence and efficiency into the system, alleviating range anxiety, optimizing energy utilization, mitigating congestion at charging stations, and contributing to the development of a more sustainable transportation ecosystem [7].

Numerous contributions have enriched the literature on EV charging, addressing crucial aspects of this evolving field. With the deployment of DWC lanes poised to significantly reduce range anxiety, researchers have introduced innovative solutions. A rule-based EV-to-lane allocation algorithm to effectively coordinate the charging demand within a network of DWC lanes was proposed in [8]. This algorithm aims to achieve load balancing among EV users and prevent delays in addressing their charging needs. In a complementary approach, an IoV-based framework for managing EVs charging was introduced in [9]. This framework encompasses two key facets: the deployment of mobile charging infrastructure and optimization of charging scheduling. Leveraging a branch and bound algorithm, it optimizes charging station placement to minimize installation costs and charging expenses for EV owners. Furthermore, authors in [10] leveraged stochastic geometry to assess the deployment of charging infrastructure in metropolitan settings. This study focuses on two critical performance metrics: (a) the distribution of distances from sources to the nearest charging road and (b) the probability that any given trip will pass through at least one charging road. These insights are invaluable for city planners, policymakers, car manufacturers, and drivers in understanding the potential of DWC. The development of EVs extends beyond infrastructure to offer owners flexibility in charging methods. Various charging mechanisms for Plug-in Electric Vehicles (PEVs) in parking lots, aiming to satisfy PEV owners' charging needs while minimizing costs was presented [11]. Additionally, an algorithm that combines path selection and charging/discharging decisions to maximize EV coalition profits was discussed [12]. It employs a distributed game theory-based approach, considering average EV profit. Recognizing the importance of Machine Learning (ML) in routing and charging EVs, [13] explores the utilization of ML in advanced vehicular communication and networking. The paper reviews diverse techniques, including fog node-assisted traffic management, integrated control and communication, and satellite-assisted and hybrid RF-Visible Light Communication (VLC)-based V2X communications. Various use cases, such as 6G-V2X technology deployment, radio resource management, and ML-based resource allocation, are addressed. Performance metrics like communication quality of experience, reliability, channel state, buffer status, and latency are discussed to evaluate V2X systems. Lastly, another work presents a compelling scenario wherein IoV infrastructure facilitates Vehicle-to-Vehicle (V2V) charging/discharging applications [14]. A model integrating fog and edge intelligence through a double-sided auction mechanism is proposed, maximizing volume with a considerable matching pair and ensuring that EV owners achieve average positive utilities. The model's performance is assessed based on real data, considering average EV costs and utility. The rich and diverse body of literature surrounding EV charging underscores the field's rapid growth and increasing significance in advancing sustainable transportation solutions.

Various aspects of EVs have been explored in the existing literature, as discussed previously. Nevertheless, this field still faces significant limitations that warrant attention. Some of these limitations in the aforementioned literature include the need for improved alignment of EVs in DWC systems. Enhancing the coordination of EV charging demand across energy supply points is paramount. Current research often relies on oversimplified assumptions, including linear models, constant energy consumption rates, and fixed distance thresholds for EVs. To advance this field, it is crucial to consider the integration of coordinated Vehicle-to-Grid (V2G) energy transfer and address assumptions related to electricity supply and communication infrastructure. Moreover, the integration of renewable energy sources holds the potential to yield cost savings and provide utility support. Charging management should be guided by the mobility patterns of EVs, and privacy concerns must be effectively managed. Future research should aim to generalize system settings, incorporate human mobility patterns, and leverage ML for prediction and optimization. Notable challenges include variable electricity prices, State of Charge (SOC) estimation for batteries, and the computational demands of machine learning model training. Additionally, expanding charging infrastructure in specific geographic areas presents ongoing challenges. Furthermore, establishing common standardization practices for electric vehicles remains a persistent issue within the field. Therefore, addressing these limitations through targeted research efforts will play a pivotal role in advancing the electric vehicle field and realizing its full potential.

We summarize the main contributions as follows.

- We provide a comprehensive review of the energy-efficient green IoV architecture and application from the perspectives of EV battery charging technology, V2X communication & Intelligent Transportation Systems (ITS), energy harvesting, and vehicular edge computing.
- Introduce our vision for smart green IoV scenarios towards mobility and sustainability.

- Discuss the EV regulatory frameworks and standardization for IoV systems and possible solutions to privacy and security threats.
- Present the Artificial Intelligence (AI)-enabled technologies that will support the green IoV architecture and applications and provide the potential advantages of grid integration.
- Discuss the current research challenges for green IoV scenarios and address the environmental and economic impacts.
- Envision important future research directions for sustainable V2X connectivity, grid integration, vehicular networking, data security, and services for IoV-related devices.

The rest of this paper is organized as follows. In Section II, we introduce the green IoV architecture for the 6G era and its application to V2X communication and ITS. Further, Section III presents potentials of Smart Green IoV systems. Section IV and Section V showcase the key parameter interdependencies and EV standardization framework respectively. We delve into the significant environmental and economic impacts of using EVs for smart green IoV in Section VI. Finally, the paper is concluded in Section VII, where we discuss the scope for future works.

II. EVS IN THE ERA OF IOV

A. GREEN IOV ARCHITECTURE AND APPLICATION

Towards the realization of the IoV that offers communication, storage, intelligence, learning, and decision-making capabilities, it is necessary to perform the computation of massive data exchange and communication infrastructures efficiently [15]. The 3 rd Generation Partnership Project (3GPP) worked toward the development of New Radio (NR) V2X to provide connectivity in the IoV framework. The design requirements of 5G NR do not impose backward compatibility with the previous cellular technology. In the future road-map of 3GPP standardization, the enhanced features include in 5G/6G systems, machine-type communications and Internet of Things (IoT), and V2X communication capabilities on vehicle platooning, advanced driving, extended sensors, remote driving, etc. With this primary focus, there is a huge interest in developing a green IoV towards emerging 6G for sustainable vehicular communication [16]. IoV includes not only communication between vehicles (V2X) and their immediate environment but also the integration of vehicles into the larger internet, enabling various services and applications.

The concept of the IoV in ITS and its applications in autonomous driving offer solutions to alleviate traffic congestion, reduce accident rates, enhance safety, optimize routing, minimize energy consumption, and mitigate negative environmental impacts. It also gains an advantage in traffic monitoring to improve traffic guidance systems, safe navigation, and vehicle control, and enhances versatility and security towards promising smart city vision. Fig. 2 shows the proposed Smart Green IoV architecture for the 6G era and provides a new role for sustainable resource utilization and energy efficiency to support its end users such as EV fleets, power grids, utilities, infrastructure computations, EV charging stations, connect people, etc. The system overview and example use cases primarily focus on four key domains as listed below towards the vision of Smart Green technologies for the emerging 6G network deployment.

1) EV BATTERY CHARGING TECHNOLOGY

The EV battery charging technologies are broadly classified into various methods as summarized in Fig. 3 with the scope of opportunities. These are described as,

1) *Plug-in Charging Technology:* EV users prefer various charging plan options either at home, work, home and work, or at public stations. In general, when having the option to charge the vehicle battery, an EV user prefers to charge at a home parking space, particularly at night. Workplace charging option is also widespread among EV users by sharing charging time with other EV owners, as it cuts costs and helps the grid. More frequently, it is observed that EV drivers have access to both at-home and workplace charging. The interest in public EV charging ecosystem is increasing to take shape around the world because of government-initiated subsidies and incentives.

   Charging levels and times are critical factors when it comes to EVs. These levels define the charging power and speed at which an EV can be charged. The term "charging level" encompasses both the voltage and power of the charging system. In general, a higher charging level equates to a faster charging process, as it delivers more power to the vehicle. Charging stations are categorized into four levels of EV charging based on the type of current they deliver and their maximum power output [5]. We delve into each level:

   Level 1: charging uses single-phase Alternating Current (AC) for slow charging and provides a voltage of 120 V and up to 2.4 kW. This charger level is commonly used in countries like the United States and Canada, where residential electrical systems typically provide a standard household voltage of 120 V. Here, the electric power is converted from AC to Direct Current (DC) using the on-board converter. These charging options are very economical but on a large scale may negatively impact the grid because there is no communication control to the power grid. Currently, the integration of an on-board converter (charger) for communication with the power grid is technically feasible, even though such a product is not yet available in the market. However, what is presently accessible is a smart charging station equipped with two-way communication. Nevertheless, ongoing research is actively directed toward

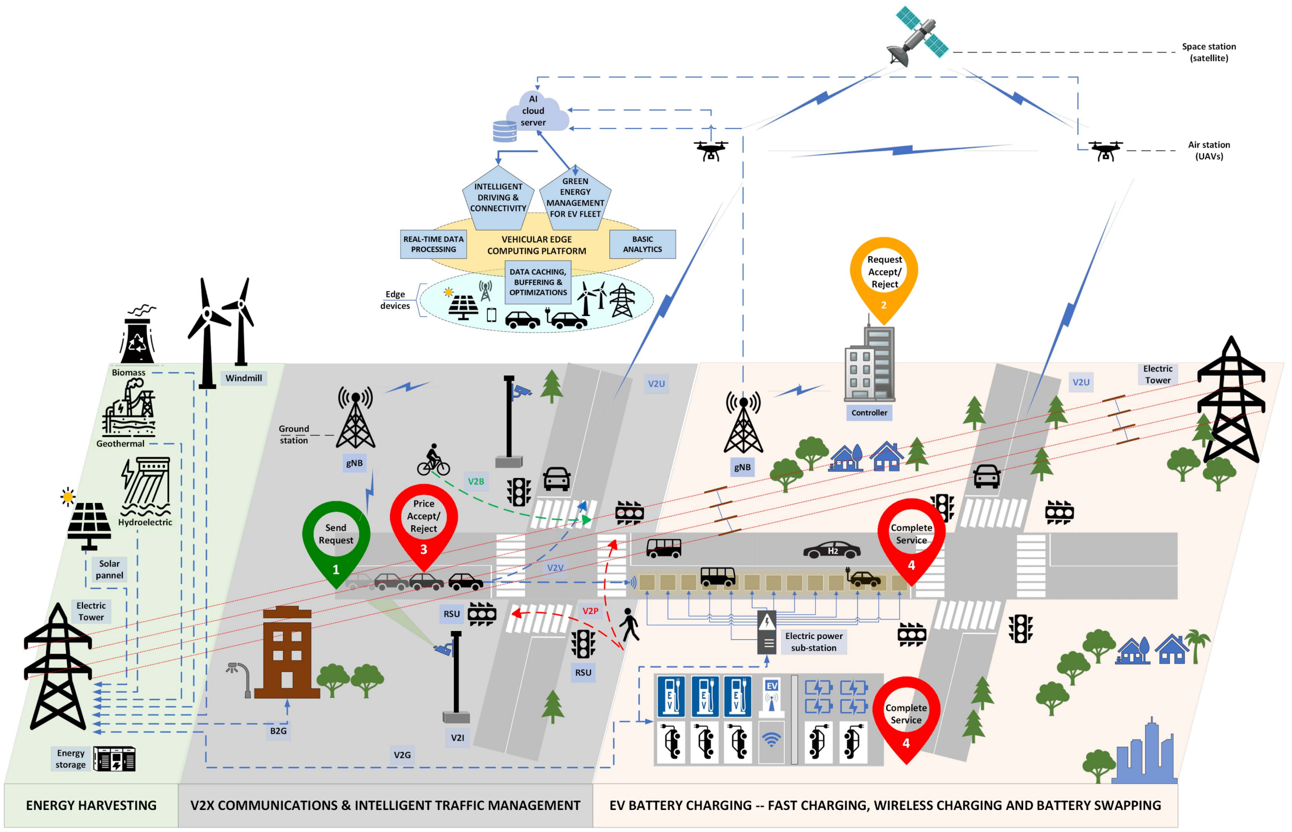

FIGURE 2. Green IoV architecture for 6G era.

the integration of on-board converters that can directly communicate with the power grid to address this issue.

Level 2: provides single- or three-phase charging up to 22 kW. EV fleet users prefer vehicle-to-charger connectors provided by the supplier to charge EV batteries outside their homes to avoid over temperature and current.

Level 3: charging uses DC and provides a DC voltage of typically 500 V. This charger bypass the on-board converter and directly charge the battery. It has FCSs that are available at petrol pumps, shopping malls, airports, parks, and other public facility spaces for the EV fleet. FCSs use special electrical connectors and support high power output, but they have some disadvantage such as being bulky, heavier, higher installation costs, expensive maintenance to sudden overloads, and requiring additional cooling setup for high power electronics.

Level 4: charging has direct access to the power grid and is a super-fast charger, employing DC, and carrying voltage above thousand volts, and can be connected for long-distance driving, Large Goods Vehicles (LGVs). Currently, only the Tesla manufacturer provides level 4 EV DC chargers and runs at high power requirements. The EV owners pay more for Level 3 and Level 4 charging options. The choice of which charging level to use depends on your needs, your vehicle's compatibility, and the charging infrastructure available in your area.

Moreover, elevating the charge level of a battery can accelerate its aging and degradation, resulting in the formation of undesirable chemical compounds, elevated temperatures, and an increased risk of detrimental side reactions. Cumulatively, these factors contribute to a gradual deterioration in the battery's overall health and performance over time. While the internal control management of the battery is designed to effectively handle and mitigate issues related to degradation as long as the charging level adheres to the battery warranty, this paper does not delve into the steps required to address and mitigate these issues.

In the realm of plug-in charging, a wide range of innovative strategies and findings are presented in the literature. Each study contributes uniquely to the evolving landscape of EV plug-in charging, addressing a spectrum of challenges from dynamic pricing and customer satisfaction to grid stability and renewable energy integration. The key areas in the literature on plug-in EV charging are highlighted below:

- Dynamic Pricing and User Satisfaction: The studies in [17] and [18] focus on optimizing charging station economics and user satisfaction, employing techniques like deep reinforcement learning and fuzzy-based response indicators.
- Efficient Scheduling and System Security: The authors in [19] and [20] propose systems for efficient

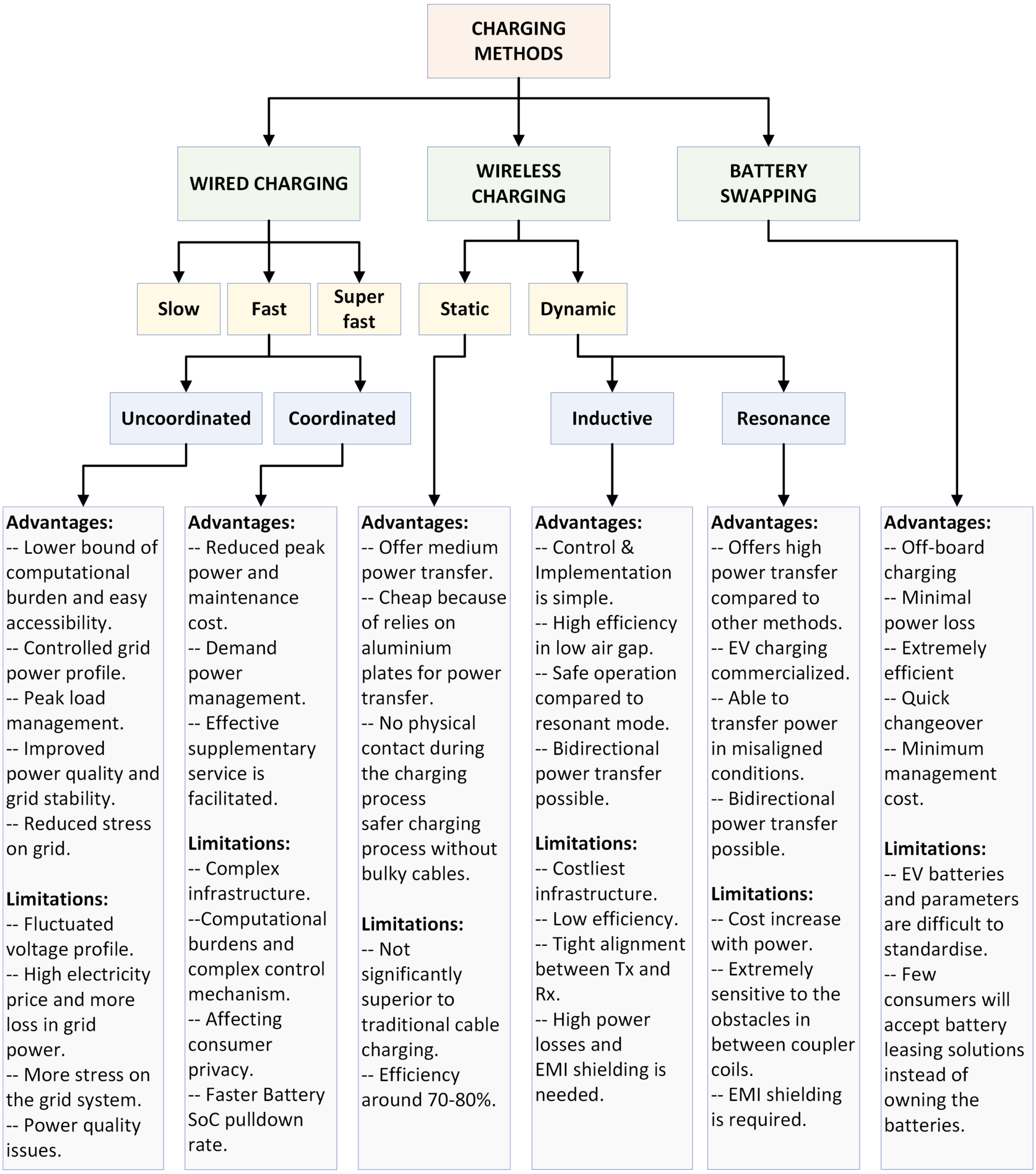

FIGURE 3. Overview of charging techniques.

EV charging scheduling, emphasizing on minimizing energy charges and operating costs while ensuring system security.

- Renewable Energy Integration and Grid Stability: The works in [21], [22], and [23] delve into optimizing the planning of EV charging stations with a focus on renewable energy sources and enhancing grid stability.
- Behavioral and Incentive-Based Strategies: New behavioral and price incentive-based strategies to enhance charging station utilization and route EVs according to driver priorities are introduced in [24] and [25].
- Technological and Operational Innovations: The works in [26], [27], and [28] explore novel technological and operational methods, including game-theory-based schemes and agent-based simulations, to manage power allocation and infrastructure needs.

2) *Wireless Charging Technology:* In the field of wireless charging for EVs, a variety of innovative approaches have been explored to enhance charging efficiency, system integration, and practicality. The literature covered the following key areas:

- Comparative Analyses and Control Systems: In [29], a review of wireless charging methods for EVs, comparing capacitive and inductive power transfer, is

TABLE 1. Field Test Sections of Electrified Roads With Inductive Coupled Power Transfer (ICPT) [41]

Organizations	Projects	Air Gap (*cm*)	Power Capacity	Efficiency (%)	Frequency (*kHz*)	Remarks
KAIST (South Korea)	OLEV 1st generation	10	3 kW/pick-up coil	80	20	Pick-up unit dimension: 55x18x4 *cm*; Length: 45 *m*; E-type ferrite core.
	OLEV 2nd generation	17	6 kW/pick-up coil	72	20	Pick-up unit dimension: 160x60x11 *cm*; 4 track of 60 *m* each; Planar U-type ferrite.
	OLEV 3rd generation	17	17 kW/pick-up coil	71	20	Pick-up unit dimension: 170x80x8 *cm*; W-type dual rail.
	OLEV 3rd+ generation	20	15 kW/pick-up coil	83	20	Pick-up unit dimension: 170x80x8 *cm*; Planar E-type rail; width of 70 *cm*.
	OLEV 4th generation	20	25 kW/pick-up coil	80	20	Pick-up unit dimension: 80x100x8 *cm*; 24 *m* track; I-type transmitting rail.
Scania Bombardier (Germany)	PRIMOVE	6-10	200 kW	90	20	Pick-up unit dimension: 2x1 *m*; four wireless charging segments of 20 *m* in 800-*m* track.
FABRIC (Spain)	Victoria	15	50 kW	83	26	8 coils split by 12.5 *m*; track of 100 *m*. Receiver coil 0.6x2.5 *m*; Emitter coil 0.6x0.8 *m*.
Utah State University (United States)	WPT	25-38	30 kW	90	20-140	75 *m* of wireless charging track in 400-*m* road section; circular coils.

provided, emphasizing control systems for dynamic charging efficiency.

- System Integration of DWC: The work in [30] and [31] focus on DWC within transportation systems, examining wireless charging lane design and its impact on EV energy consumption and traffic management, as well as exploring optimal locations and pricing for dynamic wireless charging links.
- Enhancing Wireless Charging Efficiency: The studies in [32], [33], and [34] propose methods like multi-coupling and mesh-based strategies to enhance power transmission efficiency and suppress power fluctuations in dynamic wireless charging systems.
- Optimizing Power Transmission: The works in [35] and [36] address network design for in-motion wireless charging and propose solutions like magnetic couplers to achieve uniform output power and cost-effective deployment.
- Cost Optimization: The authors in [37] and [38] developed integrated systems and new designs that aim to reduce complexity, cost, and size of wireless EV charging systems while maintaining efficiency. In [39] and [40], research is presented on optimizing the cost and efficiency of wireless EV charging systems, focusing on integrated magnetic structures and cost-efficiency optimization algorithms for ground assemblies.

Table 1 presents a compilation of assessments and tests conducted on electrified roads (eRoads) utilizing Inductive Coupled Power Transfer (ICPT) technology across Asia, Europe, and the United States [41]. The table outlines key system attributes, including air gap, power capacity, efficiency, and frequencies, along with detailed structural information.

In wireless charging, electrical energy can be transmitted from the sender to the receiver using both near-field and far-field transmission methods. Far-field transmission employs microwave and laser beams, while the near-field wireless charging methods encompass the capacitive (static), inductive, and resonant inductive approaches, which will be the primary focus of this paper. Below, we describe the opportunities and limitations associated with both static and dynamic aspects of wireless charging.

Dynamic Wireless Charging: DWC is a promising technology that allows EVs to charge while they are in motion, rather than requiring them to be stationary at a designated charging station. It's a concept that has gained attention as a potential solution to address some of the limitations of traditional plug-in electric vehicle charging infrastructure, but it is still in the experimental and developmental stage.

The key benefits of DWC include: convenience, extended range, and reduced battery size. DWC offers numerous advantages to EV users, but its implementation necessitates substantial infrastructure investment and a high degree of alignment between the transmitter and receiver to achieve optimal efficiency, albeit with some power losses.

Static Wireless Charging: Static wireless chargers present a safer charging process without the need for bulky cables and eliminate physical contact during the charging process, unlike traditional wired charging. This technology shares similarities in its impact on the network with conventional conductive chargers, which require management. The research and development of Wireless Power Transfer (WPT) for EVs is gaining popularity, fostering a rapidly growing community of both academic and industrial stakeholders. However, achieving market readiness for this technology entails overcoming several challenges while simultaneously exploring potential opportunities. Currently, wireless charging technology is found in only a limited number of passenger cars, like the BMW 530e, and in a few electric buses, such as the K9S BYD electric bus [42]. The opportunities of WPT charging for EV are summarized in Fig. 3.

3) *Battery Swapping Stations:* Battery Swapping Stations (BSS) is an innovative solution aimed at reducing the time required for EV drivers to charge their batteries. This approach involves exchanging the depleted EV battery with a fully charged one at specialized battery swapping stations. Such a method offers several notable advantages, primarily in terms of reducing wait times at charging stations and alleviating the strain on the power grid by slowing down the charging process, thereby minimizing battery degradation and grid power losses. Furthermore, adopting battery swapping aligns with the V2G initiative, facilitating the integration of additional renewable energy resources for charging purposes. However, it is important to acknowledge that there are still certain limitations to this technology. These limitations include the necessity for standardization of EV batteries to ensure compatibility with the swapping stations. Additionally, EV owners must be willing to embrace a battery leasing model rather than traditional battery ownership.

The research in the BSS focused on making BSS a viable, efficient, and integral part of the EV ecosystem, addressing technical, economic, operational, and user-centric challenges. Key areas in this research:

- *Operation Optimization:* New approaches and decision-making scenarios for efficient operation of BSS are introduced in [43] and [44]. This includes reviewing different operation modes, identifying potential challenges, and suggesting future research directions.
- *Economic and Reliability Impact:* The authors in [45] and [46] delve into the contribution of BSS to the economic viability and reliability of the power distribution systems. These studies emphasize the importance of V2G interactions and the role of BSS in enhancing network performance.
- *Resilience and Energy Management:* The authors in [47] investigate the integration of BSS in home energy systems, focusing on energy resilience and cost reduction. This involves coordinating the use of EVs, reserve batteries, and renewable energy sources to ensure continuous operation under various grid conditions.
- *User Choice and Behavior:* The works in [48] and [49] consider the user aspect, examining how EV owners' preferences impact the location, sizing, and operation of BSS. This includes developing models to predict user behavior and incorporating these into the planning and operation of BSS.
- *Technological Innovations and Models:* New studies in [50] and [51] introduce advanced models and strategies like deep reinforcement learning and integration with power generation scheduling.

2) V2X COMMUNICATION & INTELLIGENT TRANSPORTATION SYSTEMS FOR EV ROUTING

V2X encompasses a broad range of wireless technologies including Vehicle-to-Infrastructure (V2I) e.g., traffic signal timing/priority, V2V e.g., collision avoidance safety systems, Vehicle-to-Network (V2N) e.g., real-time traffic/routing, cloud services, Vehicle-to-Pedestrian (V2P) e.g., safety alerts to pedestrians, V2G, Vehicle-to-Devices (V2D), Vehicle-to-Bicycle (V2B) e.g., safety alerts to bicyclists, Vehicle-to-Home (V2H), Building-to-Grid (B2G), and more. In recent years, there have been two main technologies for V2X communications: a) Dedicated Short-Range Communication (DSRC)-based vehicular network and b) the cellular-based vehicular network or cellular V2X (C-V2X), a 3GPP standard for V2X applications. C-V2X offers automotive manufacturers and road operators a technology that enhances urban mobility, efficiency, and environmental sustainability, considering safety, fuel savings and emission reductions.

To comprehend the role and positive impact of V2X in the realm of EVs, it is crucial to underscore the primary factors that influence energy consumption in EVs, including driving behavior, aerodynamic drag, and environmental conditions, among others. V2X communication significantly boosts energy efficiency for EVs, leveraging real-time data exchange between vehicles, infrastructure, and the grid. This technology offers tangible benefits. While this list is comprehensive, these specific elements are where V2X can make a substantial impact. For instance, a noteworthy application of V2X, known as eco-routing, and platooning can reduce fuel consumption by up to 16.8%, EV energy consumption by up to 36.9%, travel time by up to 21.7%, total delay by up to 43.1%, stopped delay by up to 68.7%, and CO_2 emissions by up to 16.8% [52] and energy savings in EV integration up to 30% [53].

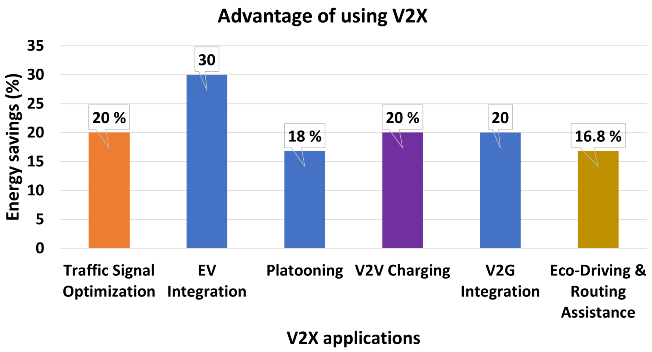

FIGURE 4. Energy saving through V2X application.

Moreover, V2X facilitates smart charging, allowing EVs to identify optimal charging times. This strategy not only promotes the use of cleaner energy but also helps balance the grid. The Electric Power Research Institute (EPRI) suggestes that by 2050, leveraging V2G capabilities could potentially decrease dependency on global central-station generation capacity by up to 20% [54]. V2G has the potential to alleviate stress on overloaded distribution systems, reduce power flow in the transmission and distribution system and minimize power losses and contribute to peak demand management, voltage, and frequency regulation. Additionally V2G holds promise in integrating renewable energy into the grid by addressing fluctuation between energy generation from renewable resources and power demand. A study has shown that Aggregated EV batteries can provide support to 82% of wind turbines' installed capacity in an isolated grid through V2G services [55].

Another promising application of V2X is traffic light management systems. Research indicates that such systems could result in up to 20% reduction in energy consumption through dynamic energy management by preventing wasteful braking and accelerations at signalized intersections. By receiving live updates through V2X sensors on traffic conditions, energy prices, weather conditions, and grid demand, EVs can optimize their operations, adjusting speed, route, and charging times to achieve substantial energy savings. In summary, the application of V2X demonstrates remarkable statistics, as shown in Fig. 4. These showcase the transformative impact of V2X in fostering a sustainable and energy-efficient future for intelligent transportation systems in terms of energy savings.

The high driving automation of vehicle autonomy (i.e., Level 4) holds significant potential for contributing to energy savings. These advanced vehicles are equipped with comprehensive planning capabilities from the outset. This inherent capability enables predictive energy management, optimal driving behavior, and the implementation of efficient charging strategies.

In addition, the emergence of pivotal technological trends, coupled with the integration of ML technology, has paved the way for energy-efficient V2X communications and mobility management within intelligent transportation systems. These developments offer innovative solutions for Smart Green IoV with full-duplex operation and network power-saving in the context of the 6G era. V2X technology plays a pivotal role in enhancing connectivity for vehicles, endowing them with the capability to communicate not only with one another but also with broader networks (i.e., road and telecom infrastructures, pedestrian, cyclists, etc.). This interconnection transforms vehicles into intelligent nodes within a comprehensive vehicular network.

To enable a safe, efficient, and enhanced driving experience, it's imperative to establish new levels of connectivity and intelligence within V2X communications. This entails, but is not limited to, an array of technologies and features, including wireless EV charging, real-time Global Positioning System (GPS) navigation, Bluetooth, Wi-Fi hotspots, cellular networks, always-on telematics, Control Area Network (CAN) bus or Ethernet/Powerline, and more. Concurrently, distributed intelligence plays a crucial role in the context of V2X communications. It empowers intuitive instrumentation, immersive multimedia, augmented reality, computer vision, enhanced security, ML, and always-on sensing, among other functionalities, where the energy saving can reach up to 30% [53].

3) ENERGY HARVESTING

Wireless energy harvesting is one of the main focuses to achieve energy neutrality in the next-generation communication networks. The emerging research interest in energy-harvesting wireless devices has gained more attention to achieve the truly green communication goal [7]. The best-known energy harvesting methods from ambient environments are photovoltaic (solar panels), hydro-power, windmills, biomass, thermal, Radio Frequency (RF), vibrations, etc (see Fig. 2). Among these, solar-powered EV charging stations with harvesting forms a popular application that will reduce the stress on the grid, especially during peak hours.

The main aim of energy harvesting methods is to provide connectivity to an enormous number of low-power sensors deployed to collect data for monitoring and surveillance. Generally, being a time-varying process the design methods to store and manage the harvested energy are critical, and challenging due to difficulties involved in measuring the state-of-charge, energy cost to receive and decode the data, battery size, battery capacity, etc. The vision to support future zero-energy devices (no battery, no manual charging) and 6G networks with the capabilities of low-cost, low latency, and low-compute sensors that can power themselves and share data in real-time, will enhance secure connectivity and edge computing functionalities.

4) VEHICULAR EDGE COMPUTING AND CACHING

Vehicular edge computing is a way to deal with the massive amounts of data around us and runs nearby of the edge devices or the end users. It has huge potential to drive future AI applications toward future 6G network deployment. The benefit of running closer to the endpoint devices will reduce power consumption and low processing latency and increase system efficiency [7]. In addition, edge computing provides advantages over cloud computing in terms of network bandwidth, data security, system reliability, etc. and improves overall network performance. Adding edge computing resources enables applications to be segregated to run at the optimal network level to enhance high Quality of Service (QoS), task offloading and security/privacy.

The processed results are sent directly to edge devices such as in EV, grid transmission, solar devices, windmills, thermal stations, cellular stations, mobile devices, etc. to enable efficient and intelligent usage of distributed power grids. Some of the critical problems on edge device platforms lead to low computational capabilities and low memory capabilities and high software costs.

Similarly, the edge caching mechanism is a promising solution that reduces network latency of the edge computing tasks and enhances the caching decisions by ensuring a secure video/audio streaming. An optimal and efficient cache computing at edge devices is possible using a decision-based learning approach which involves learning, prediction, and decision-making algorithms (e.g., Reinforcement Learning (RL)).

Fig. 2 also demonstrates real-time response of the charging service on road. The charging service protocol is as follows:

i) Firstly, the electricity consumer will send a request to the central controller.
ii) The controller can either accept or decline the request based on the demand-supply capabilities and then acknowledges various charging and pricing options.
iii) The controller then forecasts and decides which EV user can finish its assigned tasks in the allotted time.
iv) Finally, upon agreeing on the pricing, the EV user will go to the agreed location (static or dynamic) to complete the charging process.

III. POTENTIAL OF SMART GREEN IOV

By 2030, the global EV industry is projected to represent approximately 42%, 27%, and 48% of light-duty vehicles in Europe, the United States, and China, respectively [56]. With the growing interest in EVs, the development of diverse charging mechanisms is of paramount importance to accommodate the increasing number of EVs. These mechanisms are vital for ensuring a smoother and less stressful driving experience for all EV owners. Innovative strategies, such as re-routing algorithms and recharge scheduling of EVs to dedicated DWC lanes, are becoming the norm. Additionally, optimizing the total journey time, energy consumption, and expected waiting time at charging stations through the selection of the preferred charging or battery swapping station is crucial, given the remarkable growth of EVs in the market.

Several studies in the literature explore various aspects of EV routing and charging strategies, employing innovative models and algorithms. Key themes include:

- Modeling of EV Routing: The work in [57] proposes a novel, comprehensive model for the EV Routing Problem (EVRP) that includes realistic features such as nonlinear charging and energy consumption, demonstrating efficiency in EV logistics planning. Mao et al. [58] and the study in [59] introduce variations of EVRP that incorporate time windows and multiple recharging options, including the impact of queueing at charging stations on overall costs.
- Optimization Algorithms for EV Routing: Different algorithms are introduced in [60] and [61] that focus on developing new optimization algorithms for EV routing, including a Two-Layer Genetic Algorithm and a bi-level ant colony optimization algorithm, both enhancing the balance of driving times, charging stops, and recharging durations.
- Advanced Scheduling and Routing Methods: The works in [62], [63], and [64] present advanced scheduling and routing methods, including the use of deep reinforcement learning and joint routing and wireless charging scheduling, to enhance the efficiency and scalability of EV routing solutions.
- Innovative Solutions for Specific EV Routing Challenges: The works in [65], [66], and [67] propose innovative solutions to specific challenges in EV routing, such as minimizing trip delays in on-demand EV systems, decentralized energy management for urban EV charging hubs, and distributed frameworks for EV assignment and charging navigation.
- Strategies for Cost Reduction and Network Stability: The strategies introduced in [68] and [69] explore optimal pricing and routing mechanisms in public charging stations, focusing on efficient demand management and minimizing construction and travel costs. While, other studies like [70], [71], and [72] develop strategies for reducing operational and customer costs, enhancing renewable energy integration, and improving charging utility and network stability, employing methods like bi-level graph reinforcement learning and pricing-based navigation schemes.

In this context, AI and ML techniques are employed to predict the stochastic nature of EVs, thereby enhancing routing and charging decisions. Furthermore, energy demand predictions under dynamic conditions and ensuring the privacy of EV owners are addressed by incorporating Federated Learning (FL) into the design approach. FL offers the advantage of maintaining privacy by avoiding the need to share raw data. Further, to enhance passenger comfort in transportation, the Autonomous EV (A-EV) market is expanding. A-EVs harness the power of AI, next-generation charging options, and other advanced technologies. The integration of autonomous, connected, and EVs within the IoV framework offers the potential for safer, smarter, and more eco-friendly mobility in the realm of sustainable transport.

Therefore, A-EVs can serve as catalysts for achieving significant reductions in greenhouse gas emissions in the transport sector. Additionally, the utilization of renewable energy resources, such as Photovoltaic (PV) systems, can play a pivotal role in providing sustainable energy for EVs and reducing stress on the power grid. The advent of hydrogen-powered vehicles also introduces new routing and re-routing strategies into the equation. The development of smart IoV systems further enhances routing by providing real-time data on traffic volume, flow, and charging. This not only ensures that EVs are routed to the nearest charging station but also plays an essential role in managing charging and discharging at these stations. The goal is to maximize customer satisfaction and reduce charging costs. Satisfying both EV owners and aggregators, who seek to increase profits, while maintaining the stability of the electric power system, is essential. Further, utilizing V2G, V2V and V2H communications can assist in reshaping the load profile and providing frequency regulation. This multifaceted approach contributes to the development of an EV ecosystem aligned with a decarbonized future, aiming to achieve net-zero emissions and minimize the impact on the climate.

In the following, we introduce consideration to '*Green IoV*' from several scenarios including DWC, it's impact on smart mobility & sustainability, advanced EV driving & safety aspects, intelligence in fast changing environments, privacy & security, energy harvesting & sharing, futuristic non-terrestrial UAV wireless charging stations, and potentials of metaverse & digital twin platforms.

A. DYNAMIC WIRELESS CHARGING FOR ON-THE-MOVE SMART CHARGING

In the modern era, the world is embracing electric mobility to combat pollutant emissions from conventional fossil fuel vehicles and to offer an economical alternative to traditional fuel-based transportation. This transition, from conventional wireless charging to the dynamic concept of EV charging, promises substantial benefits. It provides EV owners with the convenience of charging while driving, eliminating the need to wait at charging stations. DWC offers a straightforward and efficient approach to charging EVs, contributing to cleaner and more intelligent urban mobility. Unlike conventional methods that rely on large and heavy batteries, DWC directly and efficiently supplies power to EVs as they move along the road, reducing the reliance on battery size and dedicated charging time and infrastructure. Dubai, for example, conducted tests on wireless charging while driving for EVs and city buses in 2020 [73], drawing inspiration from similar trials carried out in South Korea in 2013 [74] and by Qualcomm in 2018 with their Halo wireless EV charging technology. This innovative approach to DWC enables the exchange of power between the grid and the EV (V2G) using Shaped Magnetic Field In Resonance (SMFIR) technology [74]. This charging mechanism generates an electromagnetic field powered by the electricity grid, activated when an EV drives over it through sensors placed along the roadside [75]. However, the adoption of DWC technologies in the EV market is contingent upon ensuring the safety of human contact and interaction with these systems. Standards for evaluating safety levels concerning human exposure to radio-frequency electromagnetic fields (3 KHz to 300 GHz) are determined by the Institute of Electrical and Electronics Engineers (IEEE) in the USA. These standards are designed to safeguard humans from the potential health risks associated with electromagnetic radiation from man-made devices.

Despite the significant advantages that EV wireless chargers, both static and dynamic, offer over traditional plug-in chargers, there are still challenges related to health and safety, financial considerations, and power range limitations. With cutting-edge technology available today, the placement of coils beneath the asphalt can securely transfer energy directly to EVs. This allows on-demand charging while driving on the road and incorporates integrated smart payment services. This breakthrough paves the way for revolutionary wireless electric charging field tests.

B. TOWARDS SMART MOBILITY AND SUSTAINABILITY

DWC holds immense potential for revolutionizing smart mobility and promoting sustainability in several key ways. It addresses one of the primary concerns associated with EVs – range anxiety. By embedding DWC infrastructure into roadways, EVs can charge while in motion, significantly increasing their appeal to consumers [76]. To maximize the sustainability benefits of DWC, it is essential to power these systems with renewable energy sources [77]. Therefore, smart EV wireless charging is a crucial enabler of both smart mobility and sustainability, as it combines the advantages of EVs with the convenience and efficiency of wireless charging systems. This technology advances key aspects such as: (a) Efficient and Convenient Charging, (b) Smart Grid Integration, (c) Energy Management and Traffic Optimization, (d) V2G Integration, (e) Urban Planning and Mobility Solutions, (f) Enhancing the EV User Experience, (g) Expanding Charging Infrastructure, (h) Reducing Carbon Emissions, (i) Minimizing Noise Pollution, (j) Extending Battery Life, and more. Furthermore, it enhances the overall convenience of EV ownership, optimizes energy utilization, and contributes to a cleaner and more efficient transportation ecosystem. As technology continues to evolve, the integration of wireless charging into urban planning and infrastructure development will play a pivotal role in achieving sustainable and smart transportation solutions.

C. ADVANCED EV DRIVING & SAFETY ASPECTS

The pillar of advanced EV technology is the V2X system, which plays a pivotal role in enhancing Advanced Driver Assistance System (ADAS). Beyond the electrification of vehicles, both EVs and ADAS offer significant efficiency and sustainability advantages [78]. ADAS, equipped with increasingly sophisticated systems, not only assists drivers and saves lives but also contributes to improved vehicle-based intelligent safety systems, enhanced traffic efficiency, and heightened situational awareness. This combination of sensors including Light Detection And Ranging (LiDAR), Radio Detection And Ranging (RaDAR), cameras, and software results in a more predictable EV driving experience.

ADAS features like intelligent cruise control, lane departure warning [79], blind-spot detection, parking assistance, and collision avoidance greatly enhance the user-friendliness and safety of EVs [80]. These technologies ensure a more secure and efficient driving experience, making ADAS a crucial component of advanced EVs.

D. INTELLIGENCE IN FAST-CHANGING ENVIRONMENT

One of the ongoing challenges related to Smart Green IoV for Intelligent and Connected Vehicles (ICV) systems is the inherent instability resulting from their dynamic nature and the rapidly changing environment. For instance, the location of the node transmitting data changes with the vehicle's movement. Intelligent drone-assisted vehicular edge computing offers a more flexible, intelligent, and adaptive solution for dynamic environments [81]. Swift adaptation to changes is a crucial aspect of ICV systems. This can be addressed by limiting the number of nodes and reducing computational latency, ensuring fast and accurate processing and transmission of data to vehicular applications. Deep Reinforcement Learning (DRL) can be applied in such environments to enhance the process.

E. PRIVACY AND SECURITY FOR SMART IOV SYSTEM

The ICV ecosystem involves the exchange of sensitive information, including vehicle data, location details, and personal information, across interconnected entities. This exchange creates potential vulnerabilities and privacy risks, including unauthorized access, data breaches, identity theft, and malicious attacks. Traditional security measures and privacy protection techniques may not suffice to address the unique complexities of the ICV environment [82]. However, preliminary studies suggest that utilization of Large Language Models (LLMs) such as GPT-3 or similar models can enhance security and data privacy [83] in the ICV ecosystem (for example, ensuring privacy in autonomous driving [84] by chopping data model into manageable pieces of network computations). Further investigation and contribution are required to realize such models for EV deployment to improve data privacy and software vulnerabilities. The key strategies in data privacy and security include:

- Strong Authentication and Access Control: Implement robust authentication and access control mechanisms to ensure that only authorized entities can access sensitive data.
- Secure V2X Communication: Establish secure communication channels to protect data in transit.
- Intrusion Detection and Prevention Systems: Implement systems that can detect and prevent potential intrusions or security breaches. For example, FL based intrusion detection approach is considered to identify the cyber attacks and protect private data for IoV system [85], [86].
- Secure Software and Firmware Updates: Ensure that software and firmware updates are delivered securely to prevent malicious tampering.

Furthermore, addressing security and trust management requires consideration of users' privacy data, information credibility, channel security, and protection against malicious attacks during data transmission. Common security methods include data encryption and the creation of communication network adjacency lists through reputation evaluation. Blockchain technology presents another promising solution to address security concerns, mitigating the risks associated with centralized application platforms and trust issues within distributed edge networks [87], [88]. The adaptive selection of optimization learning methods to predict and prevent real-time threats is a critical direction for DRL in the development of green ICV systems. This approach can effectively tackle common optimization challenges, such as gradient vanishing, associated with ensuring the security and privacy of ICV systems.

F. SMART ENERGY HARVESTING AND SHARING

Another significant challenge lies in energy harvesting based on renewable resources. To ensure the sustainable development of Green IoV systems, it is vital to maintain a continuous energy supply to IoV devices, enabling them to make optimal charging and discharging decisions. This is crucial for a seamless transition between different charging devices without requiring manual intervention. To achieve this, new protocols need to be developed, allowing for the seamless handover between various communication interfaces. These protocols should be designed to ensure high reliability, low-latency communication in dynamic traffic environments, and enhanced energy efficiency. Furthermore, the upcoming 6G networks are expected to feature a high density of BS. Consequently, frequent transitions between IoV users and Base Stations (BSs) will become inevitable. This increase in IoV users will lead to heightened energy consumption during communication and computation switching processes. Therefore, there is a pressing need to develop integrated network interfaces and innovative communication protocols tailored to minimizing handover costs and enhancing energy efficiency in the context of 6G-enabled green IoV systems.

In summary, the "Smart energy harvesting and Sharing" needs a seamless connectivity, which can be achieved by using hybrid communication. 6G is likely to focus on energy-efficient communication, considering the limited energy resources of EVs and aiming to minimize the impact on their battery life.

G. NON-TERRESTRIAL UAV WIRELESS CHARGING STATIONS (NT-WCS)

The concept of non-terrestrial UAV wireless charging stations for Green IoV is an exciting and forward-looking idea that could revolutionize UAV operations. These are UAVs that include electric drones, high-altitude platforms (HAPs), or even satellites equipped with wireless charging capabilities i.e., wireless recharge in flight. It is an innovative and relatively futuristic concept that combines emerging technologies to support sustainable and efficient aerial operations.

The NT-WCS could be equipped with advanced solar panels to capture solar energy, which would then be converted into electrical energy for wireless charging in a Smart Green IoV system. An NT-WCS could utilize advanced wireless power transmission technologies such as microwave or laser-based power transfer. These technologies would enable UAVs to receive power even at high altitudes. IoT sensors can monitor the SOC, vehicle location, and other relevant data, ensuring efficient charging and communication. Advanced navigation and control systems for non-terrestrial UAV services are essential to ensure precise positioning over the Green IoV vehicles during the charging process. AI and ML can be employed to optimize the charging process.

The main benefits include extended operational range, reduced environmental impact and electric UAVs could give silent operation, and continuously, making them suitable for applications such as surveillance, monitoring, and communication relays. However, it involves numerous technical, regulatory, data security, and cost-related challenges that would need to be addressed for its successful implementation. If successfully executed, such a system could contribute significantly to reducing carbon emissions, promoting sustainable transportation, and advancing the Smart Green IoV ecosystem.

H. POTENTIAL OF DIGITAL TWINS PLATFORM & METAVERSE TO EVS

The integration of real-world data into virtual environments through the Digital Twin (DT) concept stands at the forefront of addressing challenges in EV networks. This transformative technology not only enhances model accuracy by reducing the gap between the real and virtual worlds but also presents innovative solutions for the pressing issues in the EV industry. DTs will play a crucial role in the EV sector, offering a variety of applications and benefits, as evidenced by using Virtual Sensors (VSs) within a DT framework. VSs act as logical entities, extracting new insights from physical sensors to optimize EV charging experiences and enhance user interactions. The DT role extends further into accurate simulations of EVs, enabling the study of charging efficiency and mobility behaviors. Its integration into the IoV empowers real-time monitoring and decision-making, illustrated by simulation platforms for large-scale EV fleets contributing to smart grid management [89].

Furthermore, the cooperative integration of 5G with DT technology propels advancements in capacity, mobility, and security, particularly in real-time traffic prediction models. Researchers advocate for innovative approaches, such as combining DT with reinforcement learning and expert knowledge, showcasing the pivotal role of this synergy in optimizing 5G network performance for the IoV. Moreover, the strategic implementation of DT before deploying EV networks proves instrumental in achieving cost-effective and reliable infrastructure, reducing maintenance costs, and enhancing overall efficiency. Additionally, the integration of 3D graphics and AI in the DT overcomes limitations in visualization within the EV industry, promising an improvement in user experiences and optimizing charging infrastructures. DT technology acts as a robust safeguard against data attacks, ensuring privacy and facilitating the development of high-accuracy intrusion detection systems. Drawing parallels with successful applications in various industries further solidifies the potential for DT to play a pivotal role in enhancing the reliability, efficiency, and security of EVs and Autonomous Vehicles (AVs). This presents a comprehensive and promising perspective on the transformative impact of DT in the EV network landscape [89].

Envisioned as the future of the internet, the Metaverse is set to revolutionize not only collaborative platforms with immersive experiences but also play a pivotal role in the advancement of EVs. The Metaverse platform will empower the ADAS in EVs, providing tactile high-definition live 3D maps and extended reality features that bridge the gap between real and virtual environments [90]. Furthermore, various charging opportunities for EVs can be showcased on the virtual screen, offering drivers optimal routes to access charging points. This includes information on cost, waiting times, and energy consumption, providing comprehensive guidance to drivers.

IV. KEY PARAMETERS FOR SMART GREEN IOV

This section provides an overview of the significant parameter inter-dependencies among the infrastructure systems, EV parameter optimization and routing, as well as predictive parameters and the utilization of ML in the context of the Smart Green IoV system. The diagram in Fig. 5 illustrates the inter-dependencies among parameters in energy resources, transport, infrastructure, and communication (packet data transmission). The central controller oversees the coordination of EV chargers, accounting for dynamic pricing and diverse charging options based on demand. It also supports V2G and Grid-to-Vehicle (G2V) services but necessitates regulatory and network integration standards to enhance efficiency [91]. Below, we explain these key parameters in detail.

A. OPTIMIZATION OF EV PARAMETER AND ROUTING

Efficiently managing signal control, adjusting transmission power, scheduling routing, and optimizing various parameters in a smart Green IoV system is essential to ensure effective and sustainable communication and connectivity. Below, we outline key optimization strategies for each of these aspects:

1) SIGNAL CONTROLLING

a) Signal Strength Optimization: Ensure that signal strength is optimized to minimize interference and energy consumption. Utilize power control algorithms to dynamically adjust signal strength based on the distance between vehicles and channel quality.
b) Spectrum Management: Implement dynamic spectrum allocation to efficiently allocate frequency bands, thereby reducing interference and congestion.

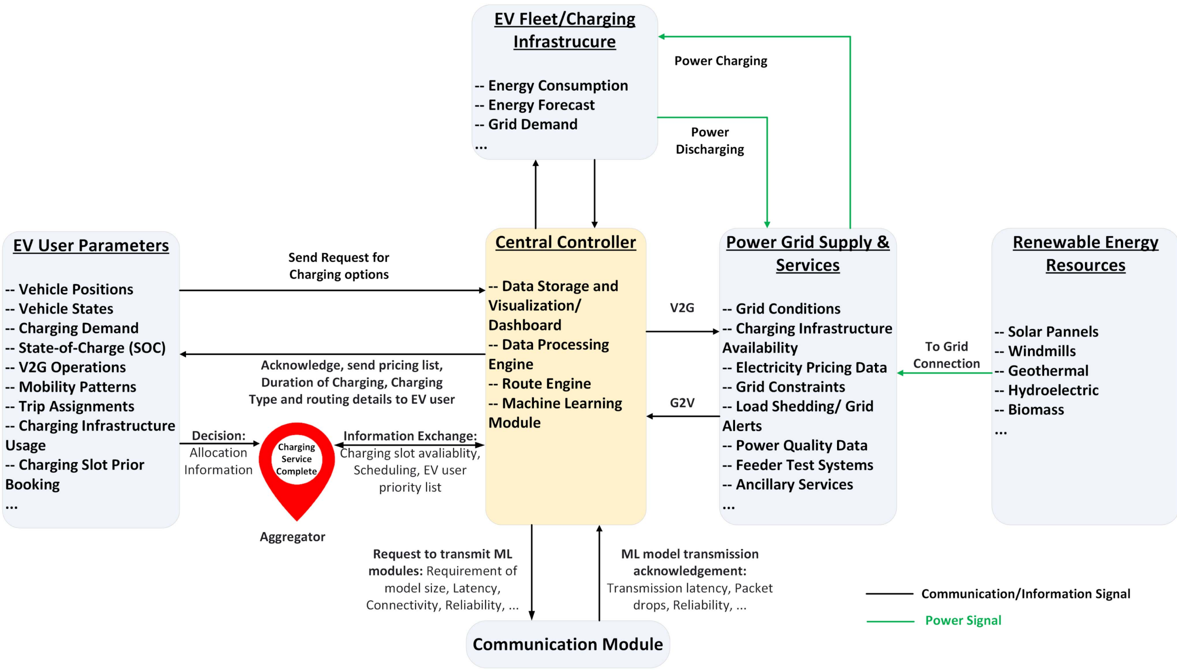

FIGURE 5. Parameter inter-dependencies between the infrastructure systems.

c) Beamforming: Employ beamforming techniques to direct the signal towards the intended receiver, enhancing communication efficiency and decreasing power consumption.

d) Multi-User MIMO: Utilize Multiple-Input Multiple-Output (MIMO) technology to improve signal quality, increase capacity, and reduce interference. This technology enhances the overall performance of the communication system.

2) TRANSMISSION POWER ADJUSTMENT

a) Dynamic Power Control: Develop algorithms that adaptively adjust transmission power based on variables such as the distance between vehicles, signal quality, and traffic conditions. These adaptive adjustments help conserve energy and reduce interference.

b) QoS-aware Power Allocation: Optimize power allocation to prioritize high-priority traffic, ensuring reliable communication for critical data while minimizing power consumption for less essential data.

c) Energy-Efficient Modes: Implement energy-efficient transmission modes, such as sleep mode or power scaling, during periods of low communication activity. These modes help reduce power consumption when full power is unnecessary.

d) Collaborative Communication: Enable vehicles to collaborate in adjusting their transmission power levels, minimizing interference and maximizing network efficiency by sharing information and making coordinated power adjustments. This collaborative approach enhances overall system performance.

3) ROUTING SCHEDULING

a) Intelligent Routing: Utilize intelligent routing algorithms that take into account various factors, including traffic conditions, vehicle locations, network congestion, and link quality when selecting routes and prioritizing data. Dynamic route planning can alleviate congestion and enhance overall network performance.

b) Load Balancing: Implement load balancing techniques to evenly distribute traffic across available routes, preventing bottlenecks and ensuring efficient resource utilization.

c) Traffic Prediction: Employ machine learning algorithms for traffic prediction to proactively adjust routing paths based on anticipated traffic patterns, leading to more efficient route selection.

d) Quality of Service (QoS): Prioritize critical services and applications by assigning appropriate QoS parameters, such as latency, throughput, and packet loss, to different traffic classes. This ensures that essential services receive the necessary network resources for optimal performance.

Other essential parameters encompass data compression, energy-efficient protocols (e.g., IEEE 802.11p and 5G NR-V2X), robust security measures (encryption, authentication, access control), and environmental considerations. ML and AI can dynamically optimize these parameters by learning from real-time data.

B. PREDICTIVE ALGORITHMS AND USAGE OF ML

We envision predictive parameters and ML playing a pivotal role in advanced vehicular communication and fault diagnosis systems to enable smart, green ICV systems. Predicting EV charging demand, renewable energy availability, and charging station locations through ML techniques offers numerous use cases, primarily focused on minimizing energy costs and maximizing charging efficiency [92]. This results in reduced charging wait times, minimized travel to charging stations, and optimized EV battery life (remaining useful life or SOC). Predictive analytics also extend to forecasting traffic patterns, signal strength, and other parameters, facilitating proactive optimization and resource allocation. These predictions take into account historical traffic data, weather conditions, time of day, special events, road infrastructure, and vehicle data (e.g., GPS, speed, and acceleration). ML techniques such as time series forecasting (e.g., ARIMA or LSTM), regression analysis, and deep learning models help predict traffic patterns and congestion, which aids in optimizing routes to reduce emissions and energy consumption.

Furthermore, ML has become indispensable for highly autonomous and intelligent vehicular networks. Accurate modeling (e.g., interference models and precise channel estimation) and traffic prediction using ML algorithms are critical in most wireless communication scenarios. While a plethora of ML-based applications is expected in smart EVs, autonomous vehicles, or hybrid driving, leverages AI-enabled technologies to enhance intelligent mobility, connectivity, smart power distribution management, and edge computing mechanisms in advanced vehicular communications. Incorporating predictive parameters and ML techniques into smart environments fine-tunes the mentioned key metrics, leading to more efficient and sustainable transportation systems. These technologies contribute to reduced energy consumption, lower emissions, and a cleaner, eco-friendly future for ICV systems.

V. REGULATORY AND STANDARDS DEVELOPMENT FOR IOV

Governments and industry stakeholders play a crucial role in shaping the future of V2X and IoV systems. Regulatory frameworks and standardization efforts are essential to ensure interoperability, environmental sustainability, data privacy, and security in IoV. These regulations and standards are typically established by government agencies, industry organizations, and international bodies [93], [94], [95]. The new shift towards EV standardization are illustrated in Fig. 6. Below, are some key classifications of regulatory and standards development for EVs in terms of safety, security, charging topology & connectors and communication aspects.

A. SAFETY STANDARDS

1) VEHICLE SAFETY

Regulations like the Federal Motor Vehicle Safety Standards (FMVSS) in the United States and similar standards in other countries set safety requirements for EVs, including crashworthiness, occupant protection, and vehicle systems.

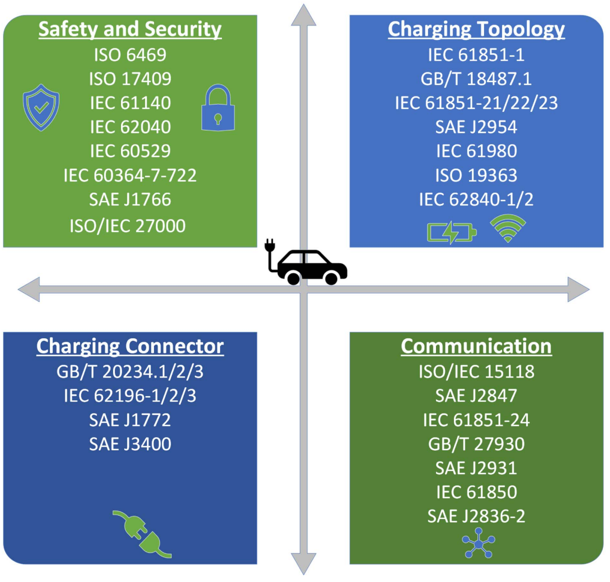

FIGURE 6. New shift towards EV Standardization.

2) BATTERY SAFETY

Standards like United Nations Economic Commission for Europe (UNECE) Regulation 100 and IEC 62660 address the safety of EV batteries, including crash safety, thermal management, and protection against thermal runaway.

B. CHARGING INFRASTRUCTURE STANDARDS

1) CONNECTOR AND COMMUNICATION STANDARDS

Organizations like the Society of Automotive Engineers (SAE) and the International Electrotechnical Commission (IEC) have developed standards for EV connectors (e.g., SAE J1772, Combined Charging System (CCS) in Europe, CHArge de MOve (CHAdeMO) in Japan), Tesla's North American Charging Standard (NACS) connector (e.g., SAE J3400), GuoBiao/TuiJian (GB/T) standards in China and communication protocols (e.g., ISO 15118) to ensure compatibility between EVs and charging stations. Additionally, Wireless Access in Vehicular Environments (WAVE) IEEE 802.11p DSRC and Long-Term Evolution (LTE)/NR C-V2X operate in the 5.9 GHz band and uses message communication standards, mainly SAE J2735 and J2945 for the V2X services.

2) CHARGING POWER LEVELS

Standards define various levels of EV charging power (e.g., Level 1, Level 2, Level 3 & Level 4) to ensure consistent charging experiences for users. Also, Industry standards for charging protocol such as the Open Charge Point Protocol (OCPP), ISO/IEC 15118 and IEC 61850 help ensure interoperability between charging stations and software systems for smart charging of EV.

C. ENERGY EFFICIENCY AND EMISSION STANDARDS

1) FUEL ECONOMY STANDARDS

Many countries have established fuel economy standards and emissions regulations to encourage the adoption of electric and fuel-efficient vehicles, which indirectly promote EVs.

2) ZERO-EMISSION VEHICLE (ZEV) MANDATES

Many countries have set emissions standards for EVs (e.g., ISO 14064-3), primarily related to reducing greenhouse gas emissions from power generation and manufacturing processes. Some regions, like California, have ZEV mandates [96] that require automakers to produce a certain percentage of electric or hydrogen fuel cell vehicles.

D. ENVIRONMENTAL STANDARDS

1) RECYCLING AND DISPOSAL STANDARDS

Regulations exist to ensure the responsible recycling and disposal of EV batteries and other components to minimize environmental impact.

2) MATERIALS AND MANUFACTURING STANDARDS

Standards address the use of sustainable materials and manufacturing processes in EV production to reduce the carbon footprint.

3) GRID COMPATIBILITY STANDARDS

To avoid overloading the electrical grid, ISO 15118 standards are developed for smart charging and grid integration technologies that allow EVs to communicate with the grid and optimize charging. V2G communication and control standards enable bidirectional energy flow between EVs and the grid, allowing EVs to provide power to the grid during peak demand or emergencies.

E. CYBERSECURITY

As EVs become more connected and reliant on software, cybersecurity standards are essential to protect against potential cyber threats to vehicle systems and charging infrastructure.

F. INTERNATIONAL HARMONIZATION

Harmonization efforts by international organizations like the UNECE aim to align regulations and standards globally to facilitate international trade and the adoption of EVs.

G. AUTONOMOUS AND CONNECTED EVS

As autonomous and connected features become more prevalent in EVs, standards for these technologies, such as ISO 21434 for cybersecurity in automotive systems, become increasingly important.

In summary, the deployment of V2X technology and the Smart Green IoV system will require collaboration between governments, automakers, and the technology providers to establish common standards and regulatory framework.

VI. ENVIRONMENTAL & ECONOMIC IMPACT OF USING EVS FOR SMART GREEN IOVS

Using EVs for a Smart Green IoV system can have several significant environmental and economic impacts. It can help mitigate the adverse effects of transportation on the environment while offering economic advantages such as cost savings, job creation, and technological innovation. However, successful implementation requires coordinated efforts from governments, businesses, and communities to invest in EV infrastructure and promote sustainable transportation practices. The future market trends of mobility transformation is focused on with an emphasis on connectivity, sustainability, autonomous driving, shared mobility, and electrification of vehicles [90]. Therefore, integrating these dual impacts leverages clean energy, advanced technology, and connectivity to create a more sustainable and efficient transportation ecosystem. Some of these include:

A. ENVIRONMENTAL IMPACTS

1) SUSTAINABILITY AND REDUCED EMISSIONS

Transitioning to EVs charged through wireless systems contributes to reduced greenhouse gas emissions and air pollution, providing improved air quality and public health. This is especially impactful when coupled with renewable energy sources, such as solar or wind power, for charging. Wireless charging can further enhance the appeal of EVs by aligning with sustainability goals.

EVs produce net-zero emissions, which means they do not release harmful pollutants like CO_2, nitrogen oxides (NO_x), and particulate matter into the atmosphere. By using EVs in the IoV system, we can significantly reduce air pollution and combat climate change. This results in an improved air quality, which can have significant health benefits, reducing respiratory and cardiovascular diseases associated with air pollution.

2) LOWER NOISE POLLUTION

EVs are quieter than traditional internal combustion engine vehicles. This can lead to a reduction in noise pollution, creating more pleasant and healthier urban environments.

B. ECONOMIC IMPACTS

1) REDUCED FUEL AND MAINTENANCE COSTS

EVs have lower operating costs compared to gasoline or diesel-powered vehicles. Charging an EV is often cheaper than buying gasoline or diesel, which can lead to substantial cost savings for consumers and businesses. In addition, maintenance cost is low for EV users, leading to potential savings over the life of the vehicle.

2) JOB CREATION AND OPPORTUNITIES

The shift towards EV production, infrastructure development, and the maintenance of EV fleets can create new job opportunities in various sectors, including manufacturing, technology, and transportation.

3) ENERGY INDEPENDENCE

A transition to EVs can reduce a country's dependence on imported fossil fuels, which can improve energy security and reduce the economic impact of fluctuating oil prices.

VII. CONCLUSION

A novel perspective on the Smart Green IoV system emerges through the integration of V2X connectivity, edge computing, sustainability, and intelligence. This integration aims to establish a transportation ecosystem that is not only more efficient, safer, and environmentally friendly but also revolutionizes our approach to transportation systems. Leveraging real-time communication between vehicles and their surroundings, we seek to reduce energy consumption, enhance safety measures, optimize traffic management, and improve EV routing, ultimately guiding us toward a greener future. Additionally, the incorporation of renewable energy resources into EVs and the adoption of a dynamic wireless charging approach can significantly enhance the user experience by providing wireless charging options while minimizing stress on the power grid. To achieve this visionary transformation, collaboration among stakeholders, the adoption of innovative technologies, and a steadfast commitment to addressing associated challenges are imperative. In essence, the Smart Green IoV has the potential to offer a sustainable and interconnected future, revolutionizing our transportation systems.

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