Renewable and Sustainable Energy Reviews 208 (2025) 115050

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

State-of-the-art review of smart energy management systems for supporting zero-emission electric vehicles with X2V and V2X interactions

Gokula Manikandan Senthil Kumar [a], Xinman Guo [a], Shijie Zhou [a], Haojie Luo [a], Qi Wu [a], Yulin Liu [a], Zhenyu Dou [a], Kai Pan [c], Yang Xu [d], Hongxing Yang [a,e], Sunliang Cao [a,b,e,*]

[a] Renewable Energy Research Group (RERG), Building Environment and Energy Engineering, Faculty of Construction and Environment, The Hong Kong Polytechnic University, Kowloon, Hong Kong Special Administrative Region
[b] Research Institute for Smart Energy (RISE), The Hong Kong Polytechnic University, Kowloon, Hong Kong Special Administrative Region
[c] Department of Logistics and Maritime Studies, Faculty of Business, The Hong Kong Polytechnic University, Kowloon, Hong Kong Special Administrative Region
[d] Department of Land Surveying and Geo-Informatics, The Hong Kong Polytechnic University, Kowloon, Hong Kong Special Administrative Region
[e] Research Institute for Sustainable Urban Development (RISUD), The Hong Kong Polytechnic University, Kowloon, Hong Kong Special Administrative Region

ARTICLE INFO

Keywords:
Energy management system
Smart charging
Zero-emission vehicles
Electric vehicles
Autonomous electric vehicles

ABSTRACT

The accelerated penetration of electric vehicles (EVs) into the transportation market has resulted in increased stresses on the existing electric infrastructure and required charging facilities, boosting intensive research efforts in recent years for addressing energy management challenges. However, a systematic review is missing for summarising the following three academic progresses: (1) The sorting of energy management systems for supporting the zero-emission charging of EVs; (2) The classification of solutions to address the challenges of EV charging with increased automation levels, which are increasingly interacted with diversified information, typically represented by the "X2V" and "V2X" technologies; (3) The summary of diversified methodologies for seeking the multi-objective optimal decisions of charging processes and patterns, while coordinating the energy resources and impact between the generation, demand, and grid sides. Accordingly, this paper has conducted a state-of-the-art review of energy management systems for low-emission and zero-emission EVs to cover the above three unsorted review areas. Both the non-autonomous and autonomous EVs are covered in this review, with an aim to identify and classify the different features of energy supporting solutions, the role of X2V and V2X functions, and the required business models. Via this review, recent research trends have been noticed for the smart inclusion of EVs as part of future energy infrastructures, typically in the form of controllable demand and power reserves, mobile energy storage, and backup energy flexibility resources. Nevertheless, practical business models for better incentivising the smart charging of autonomous zero-emission EVs are still largely missing and limited.

Abbreviations

AEV	autonomous electric vehicle	V	vehicle
AV	autonomous vehicle	V2B	vehicle-to-building
B2V	building-to-vehicle	V2C	vehicle-to-charging station
BIPV	building integrated photovoltaic	V2Cl	vehicle-to-cloud
CAV	connected autonomous vehicle	V2D	vehicle-to-device
CAEV	connected and autonomous electric vehicle	V2G	vehicle-to-grid

(*continued on next column*)

(*continued*)

DR	demand response	V2H	vehicle-to-home
EMS	energy management system	V2I	vehicle-to-infrastructure
EV	electric vehicle	V2In	vehicle-to-information
EVA	electric vehicle aggregator	V2N	vehicle-to-network
FPV	floating photovoltaic	V2P	vehicle-to-pedestrian
G2V	grid-to-vehicle	V2S	vehicle-to-sensor
GHG	greenhouse gas	V2V	vehicle-to-vehicle
H2V	Home-to-vehicle	V2X	vehicle-to-everything
I2V	infrastructure-to-vehicle	WEC	wave energy converter
PV	photovoltaic	X	everything

(*continued on next page*)

* Corresponding author. Renewable Energy Research Group (RERG), Building Environment and Energy Engineering, Faculty of Construction and Environment, The Hong Kong Polytechnic University, Kowloon, Hong Kong Special Administrative Region.
E-mail addresses: sunliang.cao@polyu.edu.hk, caosunliang@msn.com (S. Cao).

https://doi.org/10.1016/j.rser.2024.115050
Received 16 October 2023; Received in revised form 9 September 2024; Accepted 23 October 2024
1364-0321/© 2024 Elsevier Ltd. All rights are reserved, including those for text and data mining, AI training, and similar technologies.

(*continued*)

R2V	renewable-to-vehicle	X2V	everything-to-vehicle
SAEV	shared autonomous electric vehicle	ZA/EV	zero-emission and autonomous electric vehicle

1. Introduction

Fossil energy usage accounts for most industry and city electricity supply today and huge greenhouse gas (GHG) emissions, resulting in serious environmental issues [1]. Climate change, especially global warming, may lead to severe storms, drought, and a warming and rising ocean, increasingly attracting the public's concern. Threatens from extreme weather and environmental change exacerbate the negative impacts of fossil energy usage. The Paris Agreement is a milestone for such actions and shows the world's ambition to achieve carbon neutrality in 2050 [2]. Traditional vehicles burn gasoline or diesel, emitting significant GHG emissions and accelerating global warming progress [3]. The combination of renewable generation and new energy vehicles has a promising potential to reduce GHG emissions for the transportation sector. Wind, solar, wave, tidal, and geothermal energy are commonly used renewable sources. New energy vehicles, such as EVs and electric and hydrogen vehicles, outperform combustion engine-based vehicles in energy efficiency because of lower heat dissipation and mechanical losses, and with streamlined drivetrains, new energy vehicles boast fewer components, leading to reduced maintenance needs [4]. Emitting no tailpipe pollutants, new energy vehicles play a pivotal role in curbing air pollution and GHG emissions, and in essence, new energy vehicles emerge as sustainable and eco-conscious substitutes for conventional vehicles [5]. The application of zero-emission vehicles has been increasingly investigated these years. All the publications related to the keywords "zero-emission vehicle" and "smart charging systems& electric vehicle" were searched on the Web of Science from 2013 to August 2024, and their number is summarised in Fig. 1 [6]. These works mainly focus on the investigation of everything-to-vehicle (X2V) and vehicle-to-everything (V2X) technologies, such as building-to-vehicle (B2V), grid-to-vehicle (G2V), vehicle-to-building (V2B), and vehicle-to-grid (V2G).

The increasing penetrations of new energy vehicles greatly burden charging stations and grids [7]. Moreover, optimising the charging of new energy vehicles with renewable energy, subject to the variability of weather conditions, necessitates the development of advanced energy management methods [8]. In these control strategies, the new energy vehicles can directly absorb renewable energy and release the energy to the grids or buildings in need [9]. It reduces GHG emissions, increases energy flexibility and renewable energy utilisation, and benefits vehicle users, grids, building owners, and renewable energy systems. Non-autonomous vehicles have shown their capability to improve energy flexibility and renewable energy usage. In addition, autonomous zero-emission vehicles have a promising potential to enhance deeper cooperation of zero-emission vehicles, grids, buildings, and renewables [10,11]. Autonomous vehicles (AVs) can add more X2V and V2X interactions without additional requirements of human resources and account for a more complex energy management system (EMS) to reach zero-emission and benefit vehicles, houses, buildings, grids, and renewable energy systems.

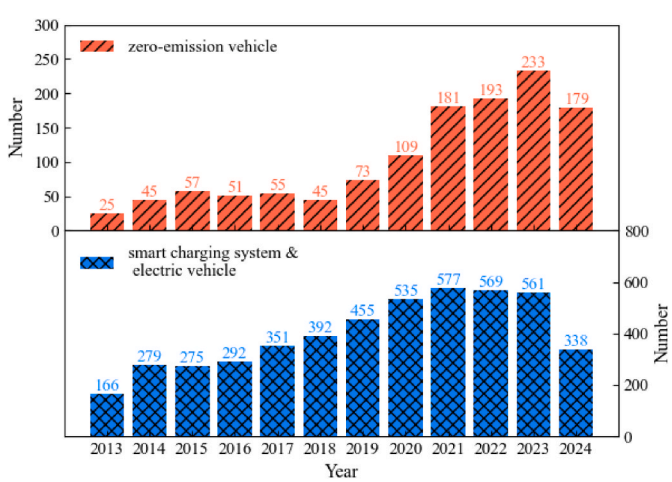

Fig. 1. The number of publications related to (a) "zero-emission vehicle" and (b) "smart charging system & electric vehicle" from 2013 to August 2024 on the Web of Science.

The incorporation of EVs into existing energy frameworks represents a rapidly expanding area of research that encompasses technological, environmental, economic and traffic dimensions [12]. Numerous studies have explored the intricate relationships between EVs and diverse energy infrastructures, spanning from buildings to public charging stations and utility grids [13,14]. These inquiries consistently underscore the dual role of EVs as both energy consumers and the potential enablers of renewable energy integration [15]. Research consistently underscores the significant capacity of EVs to promote the adoption of renewables and reinforce initiatives aimed at enhancing energy flexibility [16]. Through active participation in demand response mechanisms and the fortification of energy resilience, EVs stand poised to shape the trajectory of sustainable energy systems [17,18]. The energy flexibility of the heating and cooling system and EV battery can be released for the energy demand of the associated energy system for reducing the utility bill, and it shows that utilising the energy flexibility resources until their design limit adds economic benefit [19,20]. Studies emphasise the critical role of harnessing EVs as adaptable assets capable of responding to grid requirements, fortifying grid stability, and efficiently utilising renewable energy reservoirs [21]. Furthermore, academia increasingly acknowledges the necessity of evaluating both non-autonomous and autonomous EVs in the pursuit of achieving emissions reduction targets, whether aiming for low or zero emissions.

To optimise energy interactions and enhance overall performance, interaction decisions must be made regarding energy exchanges among interconnected systems by sharing relevant information [22]. The nature of X and V data varies based on the technological advancement of each specific project, particularly influenced by the type of EVs involved, whether autonomous or non-autonomous [23,24]. Autonomous electric vehicles (AEVs), for instance, demand advanced communication protocols and sophisticated sensing technologies to facilitate smooth charging and discharging processes [25]. The current landscape of research in smart charging and discharging is characterised by a wealth of information and discrepancies across various projects investigating X2V and V2X interactions. This diversity has created a complex and fragmented terrain, posing challenges in deciphering the impacts of smart charging and discharging strategies. It is imperative to categorise X2V and V2X interactions based on EV type, as both AEVs and non-AEVs exhibit unique requirements and traits, necessitating tailored approaches for each category.

Enhancing the intelligence of AVs, an energy management system can optimise the charging process and serve as a central hub by dynamically considering the status of charging facilities at locations like homes, offices, and available charging stations [26]. A sophisticated energy management system will improve the convenience of EV users by guiding when, where, and how to charge and discharge vehicles based on a wealth of information [27]. Ray et al. [28] utilised an algorithm to improve the performance of the design issue, such as the capacity of renewable energy and energy storage systems, the number of EV chargers and their rating, and dynamic power from charging stations. Additionally, the smart charging business model, encompassing various interconnected systems like charging stations, the utility grid, and home charging, significantly influences economic decision-making processes

[29,30]. Currently, conventional methods predominantly rely on utilising grid electricity for charging vehicles via home and public charging stations, while the discharge of vehicles to support associated energy systems remains ambiguous. Given the novelty of smart charging energy management systems, the business dynamics surrounding smart charging and discharging, involving interconnected systems like vehicles, buildings, renewables, charging stations, the utility grid, and road traffic, are scattered [31]. Moreover, the smart charging and discharging business models of AEVs and non-AEVs differ based on constraints related to information accessibility and decision-making capabilities.

There are three cut-in points in this work, which highlight the special features and significance in academia and industry as below:

Firstly, EVs currently interact with various energy systems, such as buildings, public charging stations, and utility grids for charging and discharging, to attain various technological, environmental, and economic perspectives. Moreover, EVs have a large potential to penetrate renewable energy and contribute to energy flexibility measures, demand response (DR), and energy resilience. In those cases, it is important to review both non-autonomous and autonomous vehicles towards low or zero-emission targets for academia.

Secondly, the research on the management of EV smart charging and discharging is in an early stage and with fast acceleration for various objectives; thus, the vast and diverse information regarding the X2V and V2X is unorganised and confusing. This paper aims to systematically conclude the various X and V information encountered for EV smart charging and discharging. In addition, this work sorts the various X and V information regarding the vehicle type, like non-AEVs or AEVs.

Thirdly, the comparison of energy management systems and business models between non-autonomous and autonomous zero-emission vehicles is not fully understood. AEVs may further enhance energy flexibility and renewable energy usage and bring more complex control strategies and business models than non-AEVs. Therefore, this review also aims to summarise the status of the control strategies and business models for non-autonomous and autonomous vehicles.

This review paper is unique and comprehensively discusses the topic of "smart energy management systems for supporting the zero-emission electric vehicles with X2V and V2X interactions". It detailly covers subject matters such as EVs, autonomous and non-autonomous vehicles, smart energy management systems, charging and discharging business models, renewable generation up to zero-emission level, and bidirectional energy interaction with associated energy systems. All the previous reviews on the related topics do not provide enough details about these abovementioned subjects as a compiled one, and the comparison of all the previous reviews is mentioned in Table 1. It shows that Olayode et al. [25] and Barman et al. [32] reviewed the smart EMS for AEVs, and the remaining review works only covered the non-AEVs. In addition, Li et al. [33] and Barman et al. [32] reviewed the renewable penetration in the smart charging of EVs, but they also did not consider up to zero emission levels. The bidirectional energy interaction between EVs and the associated energy systems is reviewed by Teimoori et al. [34], Li et al. [33], and Barman et al. [32]. This comparison with the previous review on related topics illustrates the importance of this review paper for academia and industry. This review topic bears substantial implications for a diverse array of stakeholders, encompassing industry players, nations, researchers, professionals in various fields, and policymakers [35]. Within industries, it catalyses innovation and progress, opening doors to new market prospects, fostering competitive edges, and enhancing collaborative efforts. Particularly, organisations with a focus on sustainability and environmental, social, and governance considerations may perceive this study as pivotal in aligning their operations with overarching goals and strategies aimed at sustainable practices.

Section 2 provides the methodology and, and Section 3 focuses on the smart EMS design to support non-AEV charging. Several studies that have provided information on novel technologies for smart charging have been highlighted as well. Additionally, it lists recent progress in how to meet low-emission and zero-emission requirements. Moreover, the section details the role of non-AEVs in various X2V and V2X scenarios, where EVs can first store energy and then supply energy to the grid or other devices. The section also compares different business models that support smart charging for EVs worldwide. Section 4 shifts the focus to the smart EMS for AEVs. The section explores the development of the smart charging EMS from several angles, including emissions, control strategies, and business aspects. The section also collects employed business models from different references. Section 5 compares the key differences between the two types of EVs. Section 5 provides a summary of the key differences of smart charging energy management systems between non-AEVs and AEVs with X2V and V2X functions. Section 6 discussed the perspectives of different stakeholders. Section 7 is the conclusion that the key findings and insights are summarised. To provide a clear overview of the content, Fig. 2 concisely illustrates the logical structure and information flow of this work.

2. Methodology

This is a state-of-the-art review of the recent development and progress of smart charging energy management systems for supporting zero-emission and autonomous electric vehicles (ZA/EVs). The methodology section serves a crucial purpose in outlining the systematic approach employed to identify, select, and synthesise relevant research studies. This section begins by defining the scope and objectives of the review, delineating databases, and identifying key research questions. The scope and objectives of this review include energy management, X2V and V2X technologies, business models, and policy frameworks for both non-AEVs and AEVs, as well as the literature selection and search criteria and keywords. Comprehensive database searches using the abovementioned keywords are involved, and the current development status and literature are collected from authoritative databases and online sources, such as Google Scholar, Web of Science and Science Direct. Screening and selection processes follow to ensure the relevance and quality of the studies included. Concentrate on recent literature released after 2016. The latest primary and secondary statistics are used to summarise the essential X2V and V2X information on smart charging and supporting energy tariffs. The entire review and literature searching process is shown in Fig. 3.

An EV runs on electricity from external sources or has its power through a battery or by converting fuel to electricity using a generator or fuel cells. AEVs are self-driving EVs equipped with sensors and computer vision to navigate independently, mimicking traditional cars and human drivers without requiring a human operator. AEVs have the potential to eliminate human error during driving, enhancing safety for motorists and passengers. Non-AEVs often spend numerous hours commuting on

Table 1
Comparison among all the previous review articles related to this title.

Electric vehicle	Autonomous vehicle	Energy management system	Business model	Renewable energy	Zero emission system	Bidirectional interaction	Reference
✓		✓				✓	[34]
✓		✓					[36]
✓	✓						[25]
✓		✓		✓		✓	[33]
✓	✓	✓		✓		✓	[32]

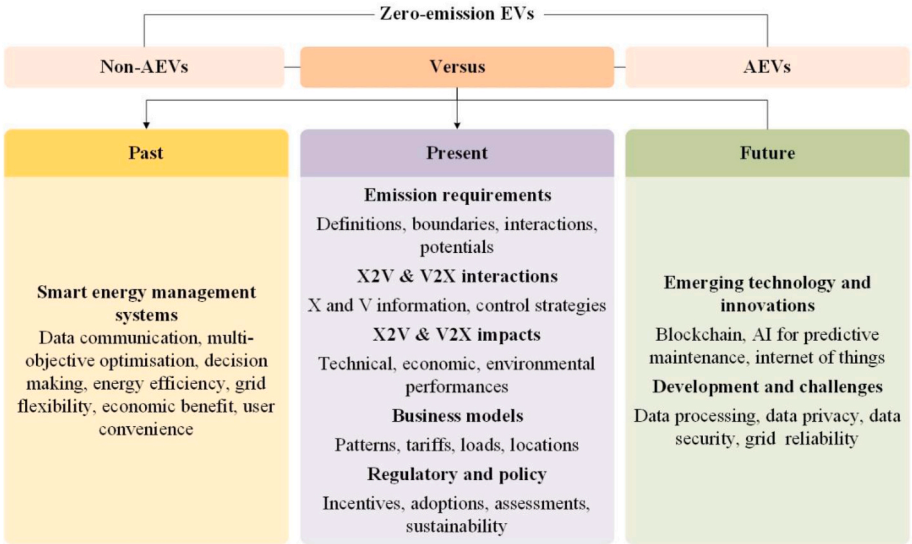

Fig. 2. Outline of the smart energy management systems for supporting zero-emission electric vehicles.

congested roads. AEVs offer the promise of reducing vehicle emissions and fuel expenses typically associated with commuting [37]. V2X and X2V signify the connections between EVs and various infrastructure elements like roads, charging stations, grids, and buildings. These connections involve not just energy exchange but also the sharing of valuable information. These interactions play a crucial role in assisting EVs in selecting the best options based on multiple goals and efficiently managing energy to enhance overall performance.

This article will present both ZA/EVs with X2V and V2X functions. The content for these two types of EVs is roughly divided into three sections. The first subsection briefly introduces the smart charging energy management system for both non-AEVs and AEVs. Then, the second subsection summarises the recent progress in developing the smart charging energy management system, including the progress related to low or zero-emission requirements, the role of X2V and V2X, and the supporting business model. The third subsection describes the future development and the current challenges in the smart charging of both types of EVs. After comparison, the critical difference of smart charging energy management systems between the non-AEVs and AEVs is highlighted.

As a literature review, certain limitations are inherent. One significant issue is the potential for bias in selecting and interpreting specific studies, influencing the overall conclusions. This review specifically concentrates on energy management and charging of electric vehicles, excluding topics like EV manufacturing and design. The evolving landscape of EV research means that discoveries may swiftly arise, potentially rendering parts of the review outdated. Moreover, the quality and coherence of the incorporated studies warrant careful consideration.

3. The smart energy management system for supporting the non-autonomous electric vehicle charging

3.1. A brief introduction to the smart charging energy management system for non-autonomous electric vehicles

The grid and drivers need a complete and efficient charging system due to the rapid increase of EVs. The integration of the internet of things and data sharing enhances the intelligence of EV charging and EMSs. This smart approach offers advantages to both the power grid and EV drivers, ensuring efficient and effective operation.

A smart EV charging EMS is composed of EVs, charging stations, and the data-share function from charging operators. This smart charging system can allow the charging station operator to monitor, manage or restrict the charging behaviour and charging device usage to optimise energy demand with real-time data sharing. Smart charging also allows the charging stations to include new functions and update the existing features [38]. Compared to uncontrolled charging, smart charging energy management can effectively utilise renewable energy to enhance grid flexibility, adjust the peak demand caused by EV charging away from the peak and fill the valleys while ensuring the requirements of EV drivers [39].

The benefits of a smart charging system include cost savings for EV drivers, safety, convenience, environmental benefits, and balancing grid demand. Smart charging can optimise the charging pattern automatically to delay the charging session at peak until the off-peak period when the charging prices are low to save charging costs. This kind of charging pattern can also avoid increasing the energy demand during the peak period, which can relieve the grid burden, enhance grid stability, and balance the grid demand [38,40]. The basic components of a smart charging system include smart changepoint units, internet connection to share data, smart devices for drivers, smart meters, and EV charging tariff, as shown in Fig. 4.

The role of the cloud in the smart charging system of EVs is crucial. Charging stations, EVs, and driver-carried smart devices can interconnect via wireless network, ethernet, or third/fourth/fifth generation of wireless mobile telecommunications technology to a centralised cloud-based management platform. This platform shares real-time data to supervise and control the charging process efficiently, aiming to optimise energy use and satisfy the preferences of EV drivers. For a smart charge point to function effectively, a mobile phone app is typically required on driver-carried smart devices. This app facilitates access to details on available charging locations, station usage, pricing, and other pertinent information. Additionally, it empowers customers to set and modify their charging preferences as needed [40].

Smart charging systems for electric vehicles aim to tackle various challenges, including reducing traffic congestion, minimising charging wait times, enhancing charging efficiency, and optimising resource utilisation. Smart charging offers a secure and convenient method to charge EVs when electricity demand is low. By leveraging cloud-based platforms and network connectivity, real-time data sharing enables drivers or in-vehicle systems to make informed choices, selecting less crowded charging points with lower loads. This approach alleviates traffic congestion, improves convenience, reduces waiting times, and maximises the efficient use of charging resources.

In academia, there is substantial research dedicated to smart charging for electric vehicles, mainly focused on studying smart

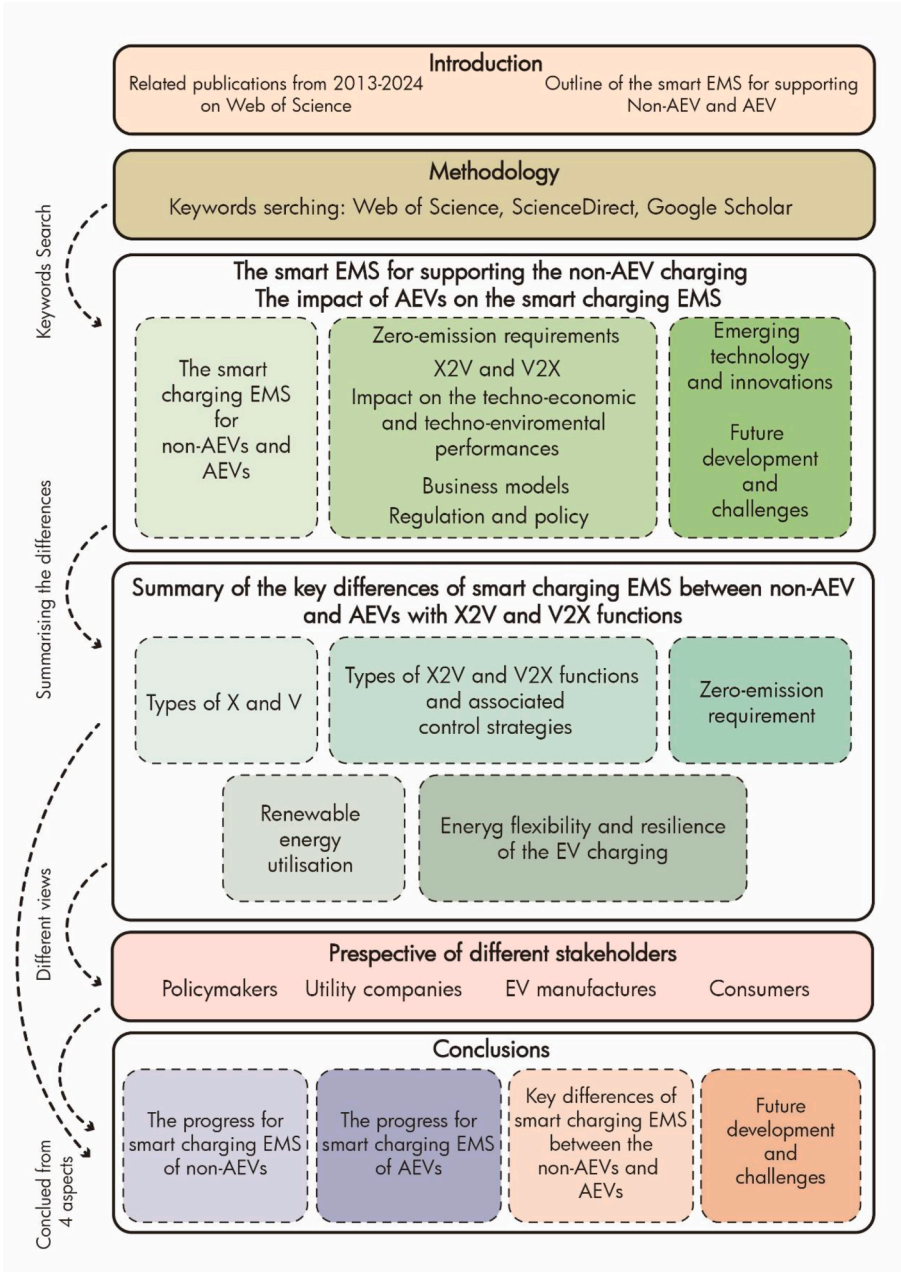

Fig. 3. The flow chart of the review process.

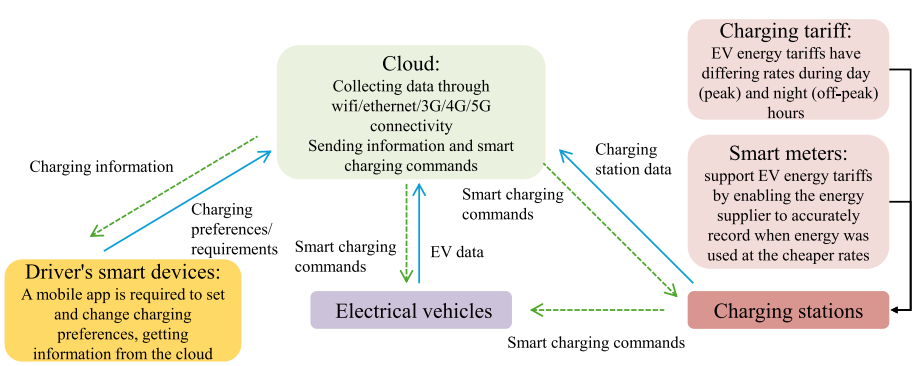

Fig. 4. Basic components and structure of the smart charging energy management system.

charging strategies. Sachan et al. [41] investigated a comprehensive study of the three basic infrastructures of EV charging. They evaluated the performance of three specific smart charging strategies, confirming the advantages of distributed infrastructure and smart charging strategy. Crozier et al. [42] analysed the potential impact on the grid when a large fleet of EVs was charged by smart charging, considering variations in vehicle usage, electricity demand, and network infrastructure across different locations using modelling-based analysis. To manage the EV charging process with maximum benefit, Nour et al. [43] provided a fuzzy logic controller-based method for smart EV charging. Through simulation studies, they demonstrated the capability of this approach to alleviate the adverse effects of EV charging on the power grid. Fachrizal and Munkhammar [44] suggested a centralised smart charging framework for EVs in residential buildings equipped with photovoltaic (PV) systems. Their approach involved establishing optimal EV charging schedules to minimise the total load on the electrical system. Okwuibe et al. [45] introduced a smart EV charging infrastructure to determine and utilise the EV load flexibility, including power and time, and this flexibility can be traded within the blockchain platform.

3.2. Recent progress in the development of the smart charging energy management system

3.2.1. State-of-the-art low-emission and zero-emission system requirements

Incorporating EVs into the transportation system helps decrease operational emissions [46,47]. However, the total amount of emissions generated during operation depends on the emissions from the source of electricity and the overall life cycle emissions from production to disposal. It is advisable to promote the adoption of EVs for emission reduction [48]. Depending upon the source and quantity of the electricity charged into an EV, it is defined as a low-emission EV or a zero-emission EV [49]. An EV that charges only renewable energy and some amount of grid or non-renewable electricity is called a zero-emission EV and a low-emission EV, respectively. It raises an interesting question of whether to check the net-zero energy balance of the EVs individually or to define them with the other associated systems like a renewable energy-supported home. Most research considers EVs as part of the zero-energy system or home rather than a separate zero-emission system [20,50]. It is difficult to determine whether EVs are low or zero-emission without checking the abovementioned emission factors. For instance, a real-time EMShelps a renewable energy-supported off-grid smart house with an EV to perform as a zero-emissive using fuel cell as supplementary energy [51].

EV-sourced in-home loads obtain grid energy to support the EV via G2V, and they can also be utilised as backup energy storage units associated with the power network. During DR periods, these EVs can return energy to the grid via V2G [52,53]. Other than the electricity from the utility grid, the possibility of charging the vehicle by renewable generation from the building should be incorporated to improve the self-consumption of renewables via B2V when the building faces a shortage to improve resilience or decrease grid interaction via V2B in reverse [54,55]. When smartly charging the EV, the various demands, generations, and supporting sources integrated with the system should be considered [56,57]. To reduce yearly electricity costs, a study aims to explore various renewable energy sources, including fuel cells, PV, wind turbines, an EV as an energy storage system, and an external grid [58]. In addition, the study investigates the impact of different EV smart charging methods and EV utilisation patterns on battery life and DR performance in a constructed environment. Specifically, the study considers 65 scenarios that combine various forms of EV charging, charging limits, and travel distances in a pilot community located in Sweden [59].

Besides the renewable energy support from the building integrated technologies, EVs are also supported by the distributed renewable energy system and renewable energy from the EV charging station [60,61]. The uncoordinated charging process of EVs complicates the energy management system. A coordinated scheduling algorithm works for the charging/discharging management of aggregated EVs to maximise wind energy integration and minimise charging expenses of EV owners in a V2G framework [62]. Moreover, multi-objective optimisation of various objective variables to reduce voltage fluctuations, energy losses, charging costs, demand supplying costs, and EV battery expenses helps to improve the system performance [15,63]. The optimisation problem involves identifying various variables, including the sizing and location of renewable sources and charging stations, as noted in Ref. [15]. When designing a fast-charging station, it is vital to consider the crucial factors related to PV, energy storage, wind turbines, DR programs, and stochastic models involved in renewable energy resources. The results showed that load management in the charging station can considerably enhance profitability and decrease initial capital investment [64].

Past studies show that most vehicles spend about 95 % of the day in parking mode [15], which enables EVs to serve for load shifting, load reduction, load following, and peak shaving by V2B or V2G [65]. The potential of V2B or V2G is related to the battery capacity and charging capability. Fully electric vehicles are the most effective storage and can contribute more to DR, and their participation in V2G will generate income for EV owners from its energy flexibility [53,66]. Most hybrid electric vehicles are unsuitable for interacting with grids or buildings because they cannot be plugged into external power resources for charging [67]. Although the battery of plug-in vehicles is smaller, they can be connected to external power, which makes it possible to conduct V2B or V2G.

V2B and V2G can provide great flexibility in balancing intermittent renewable energy generation by saving excessive generation in the battery and delivering it back to the utility when required [62]. Load shifting and tuning are analysed using EVs in an autonomous zero-emission system to increase the renewables used for the demand, where 10.8 % and 13.65 % are from wind turbines and PV. It annually reduces hydrogen consumption by 7.03 % and increases the mean efficiency of the fuel cell by 4.6 % [51]. The integration of renewable energy and local dispatchable generators, such as wind turbines, PV, fuel cells, and microturbines, has been applied to the optimal operation of a smart parking lot [68]. Implementing a time-of-use tariff-based DR program enables cost savings by shifting a part of the demand, smoothing out the demand curve [68]. To maximise the flexibility potential of smart charging, the electric vehicle aggregator (EVA) performs as an EMS, effectively handling the intricate smart charging process across dispersed nodes of connected charging stations. It is essential for EVAs to clearly establish a business model tailored to particular business demands [29].

Although the discharging behaviour of EVs may make efforts to improve grid stability and load balancing, the degradation of the EV battery should also be considered in case of economic loss for EV customers. Thus, the V2B and V2G are more suitable for the following conditions. The first condition is that when buildings are faced with some emergency conditions, like the power off or unstable power supply, where energy safety will be the first choice instead of economic benefits [69]. The second condition is that the stakeholders are in the DR program, where the EV discharging can help shave the peak demand and reduce electricity bills or get more incentives; thus, an overall economic benefit can be achieved with well-planned discharging [70]. The third condition is that the system is equipped with renewables, and the surplus energy can be stored for free and then given back to grids or buildings during the on-peak periods to earn benefits instead of some unnecessary discharging [71]. The fourth condition is when the utilisation of the EVs is low, and a large number of charging cycles remain at the end of the battery's life term, those EVs are encouraged to participate in the discharge possibilities [72]. When engaged in the V2G or V2B schemes, EV customers are also encouraged to conduct battery health checks regularly, focus on the depth of discharge, and conduct the frequency regulation of V2G to reduce battery wear [73].

3.2.2. The role of X2V and V2X technologies in the smart charging energy management system

(1) Different types of X and V in the X2V and V2X interactions

The X2V and V2X performance of EVs mainly depends on the X and V information involved in the smart charging energy management system. Researchers have analysed various V information from non-autonomous vehicles such as EVs, electric taxis, electric minibuses, and electric buses [51,58]. Even though most smart charging research is on roadways, some researchers have extended the scope by covering railways and waterways [46,50]. The X information varies according to the interaction of EVs with various systems such as utility grids, homes, offices, hotels, distributed renewable energy, parking lots, public charging stations, on-road charging, metro stations, residential communities and other EVs [26,74,75]. The common way of the X2V currently is G2V by charging in a grid-supported charging station, as some buildings cannot support EV charging due to renovation or power limitations [76]. EV stakeholders are encouraged to engage in some DR programs to save money by optimising EV charging scheduling in charging stations during off-peak periods. The utility company may also benefit from more stable grid conditions and avoid urgent upgrades to infrastructure. In the future, the more low- or zero-emission buildings may facilitate the development of B2V by higher renewable integration (solar, wind, and ocean energy) and advanced energy storage. For the V2X function, the V2G may have a broader influence on the utility grid, and the V2B may contribute to localised demand management and energy resilience. Both V2G and V2B will be more important with the development of smarter grids and higher renewable penetration in the future, some reasonable incentives may need to be provided to promote V2G and V2B by considering the battery degradation. The various kinds of V and X information have been summarised in Table 2, where the classification method of the emission levels depends on the amount of carbon emissions. The net-zero emission means that the amount of emitted and removed emissions will be balanced annually. As some of the publications may not mention their emission levels, the quantitative scale of energy support from the utility grid and their renewable energy installation from on-site and off-site should be referred.

The EVA, whether a third party or a utility company, obtains various types of information, including details about the existing renewable energy, market energy prices, and information related to EV status, charging requirements, and the preferences of EV owners [62]. Other than the typically available information about the abovementioned EV charging sources, depending upon the system design and expected performances, the smart charging energy management system may require real and predicted data about weather, renewable energy generation, road trips, road congestion, and parking lot availability [81,82]. For instance, electric vehicle charging stations can intelligently schedule charging for the following day based on renewable energy generation forecasts. This approach optimises charging using the predicted green energy availability throughout the day. The charging power can be dynamically adjusted to match the dispatch rate of vehicle discharging and charging at the charging facility. Additionally, vehicle users can utilise V2G interaction to modify their discharging and charging status by getting information about charging services from different charging facilities [77]. Weather data can be trained to predict the weather-based power outage. In addition to the EV information, such as state-of-charging and movement, the resilience-oriented operation can help improve the economic benefit and resilience of the distributed charging networks [80]. The EMSof vehicle-to-vehicle (V2V) can collect the charging level of the different vehicles assigned to each other in charging stations for sharing the energy when the utility grid is unavailable to support [78]. Some charging stations follow V2V with their customers to level the charging station load to improve the stability of the utility grid [79].

(2) Different types of X2V and V2X interactions, as well as the associated control strategies

Past research has shown that the control strategies of EVs are mainly based on when, where, and how to handle smart charging and discharging, X2V and V2X, to attain major technical, environmental, and

Table 2
"X" and "V" information, and X2V and V2X types of non-autonomous electric vehicle projects.

V	X	X2V or V2X interaction types	Renewable (whether renewable is equipped or not, types of renewables)	Emission levels	Individual or aggregated levels	Application country or region	Reference
Non-autonomous electric train	Metro station, utility grid	B2V, G2V and V2B	Yes, 660 kW PV, 515 kW wind	Net positive emission	1 train	HKSAR, China	[46]
Non-autonomous minibuses and private cars	Office, Hotel, utility grid	B2V, G2V and V2B	Yes, 1.44 MW wind, BIPV, and PV	Net positive emission	24 minibuses and 30 private cars	HKSAR, China	[47]
Non-autonomous electric boat	Hotel, utility grid	B2V, G2V and V2B	Yes, 5528 m^2 FPV, 800 kW WEC	Net zero emission	16 boats	HKSAR, China	[50]
Non-autonomous electric car	Smart home	B2V and V2B	Yes, 3.4 kW PV, 2.4 kW wind	Renewable energy supported	1 private car	Turkey	[51]
Non-autonomous electric buses and electric taxi	Charging station	Charging and V2G	Yes, PV and wind	Renewable energy supported	400 EVs	China	[77]
Non-autonomous electric car	Smart home, utility grid	B2V and G2V	Yes, PV, Wind, fuel cell	Renewable energy supported	1 private car	Iran	[58]
Non-autonomous electric car	Office building, utility grid	B2V, G2V and V2B	Yes, 74 kW PV	Renewable energy supported	10 EVs	Portugal	[63]
Non-autonomous electric cars	A community of three buildings	B2V, G2V and V2B	Yes, PV	Net zero emission	65 scenarios of EVs	Sweden	[59]
Non-autonomous electric cars	Charging station	G2V and V2V	No	Grid-supported	150 EVs	Finland	[78]
Non-autonomous electric cars	Charging station	G2V and V2V	No	Grid-supported	10 EVs	China	[79]
Non-autonomous electric cars	Charging station, utility grid, weather	G2V and V2G	Yes, 1 MW wind	Renewable energy supported	100 EVs	Iran	[80]

economic objectives. Firstly, the key term 'where' represents the location of EV interaction, whether homes, offices, grids, distributed renewable energy, public charging stations, and on-road charging. Kumar and Cao [46] studied the techno-economic feasibility of a battery-powered railway network, and they detailly studied where to do the B2V, V2B, and G2V in a specific railway station to enhance the overall multi-objectives. Secondly, the word 'when' represents at what time, and it especially refers to peak or off-peak grid period, renewable energy surplus or shortage period, and traffic congestion or non-congestion period. The objective of reference [77] is to optimise the usage of renewable energy sources while minimising EV owners' waiting time and expenses. Once an EV is plugged into the charging station's port, an organised charging and discharging plan is estimated according to the initial battery state of charge. This approach enables the determination of real-time schedulable levels for entire charging stations [77]. Guo and Cao [50] studied the interaction of an electric boat with a renewable energy-supported hotel building. They recommended that it is more beneficial to use the early morning surplus generation and the off-peak electricity for charging the electric boat. The keyword 'how' represents the tariff rate, charging speed such as super-fast, fast, medium, and slow, charging mode like wired or wireless charging and type of energy source, whether renewable or non-renewable energy. Implementing variable tariff techniques to regulate the EVs' charging and discharging helps prevent overloading that may occur during peak times, as well as voltage drops in sensitive buses [15]. It indicates that selecting appropriate multi-objective optimisation coefficients and applying the real-time energy pricing approach can enhance the load factor and effectively alter the load curve. The findings suggest that this approach can improve the overall performance [15].

Several studies have proposed using advanced computing algorithms and techniques to manage complex interactions involving EVs and achieve specific goals. This review discusses a few of these interesting techniques. One is an EMSdepending upon a linear programming paradigm with non-linear constraints, proposed for a future home with controllable demands and an EV supported by a hybrid renewable generation interacting with a utility network [54]. This EMS enables switch controls of the connected architectures and manages scenarios involving vehicle-to-home (V2H), home-to-vehicle (H2V), and G2V when the grid is involved during H2V mode [54]. Secondly, another technique involves aggregating a large number of EV fleets at smart chargers and scheduling their charging process using a coordinated algorithm [62]. The scheduling algorithm leverages superior communication techniques in advanced grids, and the EV flexibility and V2G improve the intermittent condition of wind power [62]. When wind generation is low, the EV chargingwill be postponed and timed to take advantage of higher amounts of wind energy, and EVs can discharge to support the system [62]. The fuzzy logical controller is another technique commonly used for smartly charging and discharging EVs, focusing on load prioritisation. Shemami et al. [52] used a fuzzy logical controller in an efficient EMS to connect home and vehicle bidirectionally. The fuzzy logic control of the system determines the discharging and charging of the vehicle battery depending on power management priorities. Beheshtikhoo et al. [58] designed two type of fuzzy logic controllers in a load-side EMS for a smart home integrated with an EV, which resulted in a 71.5 % and 64.6 % reduction in electricity costs and the peak-to-average ratio, respectively, after applying the proposed strategy. Boynuegri et al. [51] aimed to decrease hydrogen consumption and efficiently use excess renewable generation by handling controllable demands, including EVs, using a fuzzy logic control while managing comfort. Lastly, a particle swarm optimisation related to vehicle charging is designed to minimise the building's grid interactions and examine the battery degradation under various charging cases using the rainflow-counting algorithm [59].

(3) The role and impact of X2V and V2X on the smart charging energy management system: from the perspectives of technical, economic, and environmental performances.

Increasing EV penetration causes a rise in electricity demand and a considerable shift in the demand curve if the discharging and charging process is unplanned. Firstly, using G2V charging can increase load variability and affect the power framework, making it challenging to estimate the demand accurately. The capacity needs of the power generation and transmission system are determined by peak demand, and an increase in peak demand can impact the electricity infrastructure. Secondly, charging EVs using renewable energy via B2V helps convert EVs that currently emit no pollutants to zero-emission in their operation. Thirdly, using EVs as portable storage units to stabilise intermittent renewable generation and reduce the grid interaction during DR periods via V2B can help the interacting building in multiple ways and avoid congestion in the utility grid. Fourthly, an approach that has been proposed is to integrate EVs as a dispersed generation/storage and dynamic and flexible load to balance the grid supply and demand through the V2G concept, similar to V2B [62]. In V2B, most of the time, the EV user is the owner of the building, whereas the scenario is different in V2G. Allowing a third party to access the EV battery can negatively affect the EV users' willingness to commit to V2G since they may not be confident about the desired charge level at departure [62]. Additionally, unclear information from the aggregators about the charging/discharging rate and the frequency of charging/discharging, which can accelerate battery degradation, is another reason for the low acceptance of V2X among EV users. To address this problem, aggregators or public charging stations should strictly consider the owners' preferences and requirements, guarantee the EV's health, and share vehicle status information with EV users [62].

3.2.3. Impact of smart charging of non-autonomous electric vehicles on the techno-economic and techno-environmental performances

A growing number of EVs may increase electricity demands due to unplanned charging behaviours; thus, the EV smart charging system is worthwhile to investigate, especially for their potential impact on the techno-economic and techno-environmental aspects. These impacts of the EV smart charging system are listed in Table 3. The techno-economic performance of EV smart charging systems is mainly influenced by electricity sources, infrastructure development, tariffs, and consumer engagement [83]. EV stakeholders may change their charging schedules according to time-of-use pricing to save charging costs, which also helps to shift energy consumption to off-peak periods [84]. The well-planned EV charging system may also facilitate the development of EV discharging (V2B or V2G) to further reduce the power interaction with the utility grid and obtain more incentives for EV stakeholders. Zheng et al. [85] coordinated EV charging and renewables, which reduced around 21 % electricity bills and 25 % battery degradation costs. Some developed smart charging systems for low- or zero-emission EVs can further promote the self-consumption of renewable generation, as their mobility promotes energy sharing among various buildings, and then the operational costs and grid interaction may be further reduced. Li et al. [24] conducted the energy sharing between two coastal buildings, and the case with V2B function achieved the relative net present value of 4.92×10^7 HKD and the renewable matching capability of 0.63. Besides, EV smart charging can also optimise or fully utilise the charging cycles within the battery lifetime and then reduce the replacement, operational, and maintenance costs. Das et al. [70] developed a decision-making system for the optimisation of techno-economic-environmental performance, and it can reduce 67 % battery degradation and potential wear costs. For the stakeholders of charging stations and grid operators, the EV smart charging system may help to balance the grid load at an aggregated level in case extensive and unpredictable charging demand worsens the grid stability and results in associated costs; otherwise, the charging infrastructure for the power

Table 3
The impact of smart charging of non-AEVs on the techno-economic and techno-environmental performances.

Control methods	Technical impact	Economic impact	Environmental impact	Pros	Cons	Reference
Optimisation of PV size and EV charging control	Around 12 % peak demand reduction	Up to 9.2 % net annual energy cost reduction	N.A.	No need for further renovation	N.A	[87]
Multi-objective optimisation	Enhance the grid stability and intermittent renewables	Benefit EV owners and grids	N.A.	Mitigate the barriers to participation in V2G	Lack of actual EV data	[71]
Multi-objective optimisation	67 % reduction in battery degradation	88.2 % reduction in energy costs	34 % reduction in carbon emissions	Social benefits of smart grids	N.A	[70]
Synergistic operation	1.25 % increment in equivalent battery relative capacity	0.18 US$ reduction in system cost for Li-ion battery	Around 47 kg/m^2·a carbon emission reduction	Various battery degradation models and control strategies are compared	Lack of schedule of stochastic EVs	[88]
Loss and cost optimisation	Increase the self-consumption of solar PV	61 % reduction in charging cost	Maximum of 7 % energy losses	Alleviate the burden on the transformer for the management of load demand	Further incentives can be provided	[89]
Daily electricity cost optimisation	Boost V2B and limit the number of EVs for charging	Even 10 % savings on daily utility bills for the worst-case scenario	N.A.	Day-ahead planning promotes V2B	Lack of flexible control of building load	[90]
Two-stage optimisation	19%–100 % reduction in load variance	40%–110 % reduction in charging cost	N.A.	Benefits for both EV stakeholders and utility grid	Lack of application	[91]

generation and transmission system will be urgently upgraded [86].

The techno-environmental impact of EV smart charging systems is related to electricity sources, battery technology, and consumer engagement. The smart charging of low- or zero-emission EVs makes extensive efforts to reduce carbon emissions and air pollution compared to fuel-powered vehicles or grid-supported EVs. Song et al. [88] conducted a synergistic operation and set some regulations on charging/-discharging, and the carbon emissions were reduced by about 47 kg/m^2·a by adopting a positive energy system. Meanwhile, the renewable charging of EVs also helps enhance grid stability and flexibility and increases the proportion of renewables in the electricity mix [86]. As EVs are considered distributed energy storage, some incentives have been proposed to encourage EVs to be charged by the renewable surplus and then prepare for other environmentally beneficial behaviours. For example, EVs can discharge to the building/utility grid when peak demand happens, which can alleviate the burden of fuel-fired power plants during energy shortage periods. Although renewable generation can reduce operational emissions of EV smart charging systems, the manufacturing and disposal emissions of the battery should also be considered when assessing the overall environmental impact [92]. Thus, some policymakers also pay attention to the recycling of EV batteries due to some contaminated materials used for production.

The EV smart charging system aims to improve operational efficiency at an aggregated level considering several stakeholders, and the system performances are subject to their control objectives (techno-economic and/or techno-environmental). In general, the charging management systems try to optimise charging decisions to alleviate or defer the burden on the infrastructure renovation, where higher renewable penetration is essential to support the increased EV adoption. Besides, EV smart charging systems can promote EV discharging behaviours in certain conditions for more energy flexibility, economic benefits, and carbon reduction.

3.2.4. The business models to support the smart charging energy management system

As one of the fundamental components of the EV smart charging system, the charging tariff is an important reason for guiding the EV to modify the charging mode manually or automatically, achieving the benefits of the smart charging system such as cost saving and balancing the grid demand. Therefore, the smart charging system focuses on establishing a sensible, detailed, and effective EV charging tariff.

Different EV charging service providers have developed current EV charging tariffs. As a result, there are various EV charging tariffs, and the most common four EV charging tariffs are energy-based, time-based, subscriptions, and free charging. The main EV charging service providers in the world, the regions where they provide services, and the types of tariffs included in charging stations are summarised in Table 4. This table provides an overview of the various charging tariffs available to electric vehicle charging providers in different areas. However, each charging station typically offers only one type of charging tariff. The energy-based model is one of the most popular and straightforward models for EV charging stations. The drivers pay for every unit of electricity delivered to the EV. The instant charging tariff differs based on current times concerning on- and off-peak. The charging service platform monitors real-time information and displays the related information. EV should evaluate the cost and necessity to decide whether to charge. The exact price of this EV charging tariff model will vary from location to time [93]. Some charging networks may offer time-based pricing for automated EV charging, and it depends on the charging time. Independent of the unit of electricity consumed, the rates are set on a minute/hour scale. It will benefit users whose EV has a fast-charging rate; however, it is not fair for the slow-charging. The time-based tariff model usually sets a period after charging starts, during which charging is cheaper. If the charge duration exceeds this time, the charge price will increase. Meanwhile, some companies may offer subscription-based charging services for automated EV charging. The subscription model provides users with a monthly/annual EV charging service for those who frequently use it. Within the subscription period, the drivers can charge for free at the charging facilities unlimitedly or with discounts. The service provider should ensure that the charging stations are adequately covered to attract users to join the membership. Some shopping malls and enterprises provide free charging services to attract customers, which is similar to the free parking that encourages visitors to come. At some charging stations integrated with car parks, EVs can be charged for free after a parking fee has been charged. Besides, some charging service operators utilising the advertising model provide EV charging for free or at a low price. This type of charging station is funded by advertisement fees [94–96]. Time-based charging tariffs have limitations as they might be inequitable due to differences among EV models, not just in battery capacity but also in battery design and driving range. Consequently, certain EVs may require more time to charge for an equivalent amount of power. Subscription-based charging tariffs offer advantages to the charging provider by ensuring a steady income stream. For the driver, the benefits are tied to the charged energy within a set period. Charging frequently can result in a more cost-effective scenario, whereas infrequent charging may appear more expensive per unit of electricity charged.

Research on the charging tariff in smart charging systems in academia was also one of the main focuses of the EV study. Afentoulis et al. [126] introduced a business model framework to create workable

Table 4
Summary of the major global EV charging service providers, their service locations and charging tariff types.

Providers	Locations	Energy-based	Time-based	Subscribe-based	Charging-station based	Utility-based	Reference
National Grid	Mainland China	✓			✓	✓	[97]
Tesla	North America, Europe, Middle East, Asia/Pacific	✓			✓		[98–100]
Smart Charge	HKSAR, China			✓	✓	✓	[101]
Shell Recharge	Africa, Americas, Asia-Pacific, Europe, Middle East	✓			✓		[102]
HKE	HKSAR, China	✓			✓	✓	[103]
CEM	Macau, China	✓			✓	✓	[104]
Recharge	Sweden, Norway, Finland	✓			✓		[105]
E. ON	Europe	✓			✓	✓	[106,107]
EnBW	Germany	✓			✓		[108]
Fortum	Sweden, Norway, Denmark, India, Germany, Poland, Finland	✓			✓	✓	[109,110]
Elli	Europe	✓		✓	✓		[111]
British Gas/Octopus	UK	✓			✓	✓	[112,113]
EDF	UK	✓			✓	✓	[114]
Clever	Demark	✓		✓	✓	✓	[115]
Helen Ltd	Finland	✓	✓		✓		[116]
Virta	Europe	✓			✓	✓	[117]
Allego	Germany, France, the Netherlands, Belgium, UK	✓			✓	✓	[118]
CHAdeMO	Europe, Japan, North America	✓	✓	✓	✓		[119]
Audi	Europe, Japan	✓	✓	✓	✓		[120,121]
EVgo	US	✓		✓	✓		[122]
ChargePoint	North America, Europe	✓			✓	✓	[93]
KEPCO/SK Energy/ Hyundai	South Korea	✓	✓	✓	✓	✓	[123–125]

business models for EVAs. The framework was designed to help EVAs leverage flexible charging opportunities in electricity markets and was based on three key factors. The researchers validated the feasibility of the framework with a business model balancing the market by real settlement rules and signals. Knirsch et al. [127] suggested a blockchain-based solution to improve EV charging selection's dependability, transparency, and privacy. Their proposed approach utilises pricing and the proximity of the EV to identify a reliable, automated, and privacy-preserving charging option. This implementation aims to ensure EV owners' privacy is safeguarded while enhancing the transparency and reliability of the charging process. Bonin et al. [128] investigated the effects of home PV system incentives and variable electricity prices on EV charging patterns, household finances, and grid load. They conducted simulations to compare different optimised charging configurations with an unregulated charging approach and found that the optimised charging strategies had the potential to decrease peak grid load significantly. Their analysis also evaluated the impact of these charging strategies on the household economy. Pasetti et al. [129] introduced a comprehensive model to assess the uncoordinated charging expenses of EVs in situations involving distributed, irregular power generation, and fluctuating electricity tariffs. Their study demonstrated that this model could identify opportunities for energy conservation and create specific price signals for EVs, thereby promoting the optimal utilisation of distributed energy resources. Baumgartner et al. [130] investigated user preferences and requirements on the V2G charging tariff and evaluated multiple charging strategies; their results can be essential to designing profitable business models. Rancilio et al. [131] presented a range of regulatory measures that can be used to facilitate smart charging, with an emphasis on specific charging modes. The proposed measures were geared towards achieving specific targets, such as reducing carbon emissions from EV charging, mitigating the impact of peak demand on the public grid, and managing EV charging prices. The authors suggested that these toolboxes of measures could inform the development and implementation of effective regulatory frameworks for smart charging.

3.2.5. Regulatory and policy frameworks for non-autonomous electric vehicles

Given the benefits of electric vehicles compared to traditional cars, specific regulations and policies may be establised in place to support their adoption and advancement. These official guidelines and measures aim to facilitate the integration and growth of electric vehicles within different geographical areas, promoting sustainable transport solutions and reducing environmental impact. Therefore, the formulation and adjustment of these rules and policies have become crucial research topics in the EV field. The primary focus lies in designing and improving regulations and policies to incentivise increased EV adoption and usage while addressing the associated challenges. This section examines studies on EV-related policies from various regions. Belgiawan et al. [132] explored the impact of fiscal policies and range extenders on EV adoption in Indonesia, highlighting the significant influence of purchase price subsidies on choosing battery electric or plug-in hybrid vehicles. Meanwhile, Peng and Bai analysed urban incentives in Shanghai through an online survey of EV drivers to facilitate policy implementation and effectiveness, emphasising how incentives such as highway access during peak hours and free license plates encourage EV purchases. Challenges in policy implementation mainly revolve around the lack of supportive private charger installation environments and insufficient services [133]. Mekky and Collins investigated state-level policies in the U.S., including financial incentives policies for EV purchase, public EV charging infrastructure-based policies and environmental policies from renewable energy generation, noting that increasing renewable energy sources has a more substantial impact on EV adoption compared to incentives and public charging infrastructure [134]. Vidyattama et al. [135] evaluated the Australian government's EV incentives on adoption in the capital territory, underscoring the pivotal role of reducing EV prices and how incentives benefit lower to middle-income households. Mouhy-Ud-Din et al. [136] evaluated the comparative techno-economic performance of EV charging preferences in-home charging or fast public charging, and the aim is to help develop EV adoption policies in Pakistan. They quantitatively assess the techno-economic aspects of fast and home charging. Their results highlighted the importance of Solar PV for fast and home charging. Ledna et al. [137] utilised a consumer choice tool to simulate the adoption of electric vehicles and associated emissions. Their objective was to increase the adoption by implementing a strategy that combines the development of public charging infrastructure with subsidies for purchases. In conclusion, the drive for EV adoption hinges on

well-crafted policies related to economics and charging infrastructure, although challenges like EV pricing and insufficient public charging infrastructure remain key obstacles to future EV development.

3.3. Future development and challenges relating to the smart charging energy management system of non-autonomous electric vehicles

3.3.1. Emerging technology and innovations

There are kinds of technologies in the early stage of development that may bring significant changes in the smart charging energy management system of non-AEVs. The first is blockchain technology, which links blocks of data and forms a chain. The blocks store the data and confirm the sequence, avoiding the false insertion of blocks. The subsequent block validates the previous blocks and hence contributes to the security of the blockchain [138]. Blockchain technology can contribute to the secure and transparent energy sharing between participants. Research has been conducted on smart grid development, presenting an integrated approach to improving the security and integrity of smart grid systems through innovative data analytics and blockchain technology [139]. Moreover, the decision-making system is distributed, leading to no necessity for central authentication like traditional smart grids. For non-AEVs, blockchain technology provides secure data sharing to support the individual decision-making process of V2X and X2V behaviours. The second is artificial intelligence for predictive maintenance. Predictive maintenance plans the maintenance using the forecasting methods before the failure [140]. Artificial intelligence is powerful since it can be trained on past failures with a large scale of data. In the designing of smart charging energy management of non-AEVs, the predictive maintenance provides information on the associated infrastructures or equipment, such as the charging ports and battery residual capacity and operational life. This information is collected and presented to non-AEV drivers for decision-making. The third is the internet of things, referring to the connected devices and software and their capability of exchanging data with others, which significantly enhances connectivity and data sharing. Facing the challenges of transportation electrification, the internet of things provides real-time information sharing regarding charging stations, traffic conditions, and renewable generation to support smart charging energy management systems. For non-AEVs, suggestions can be provided based on the real-time conditions of associated devices, such as the charging port occupancy.

3.3.2. Future development and challenges

The wide application of electric vehicles is promising to speed up the transmission towards carbon neutrality, while some challenges still need to be addressed [8]. Firstly, investigations of methods that encourage electric vehicles to use renewable energy are desired, as the generation capability for renewable systems is challenged by the huge energy demand from electric vehicles [141]. The scales of renewable energy systems and electric vehicles do not match because electric vehicles are mainly supported by non-renewable energy. The study [142] encouraged using renewable energy to generate electricity and trade energy with nearby consumers, thus facilitating localised energy exchange. Facilities and spaces limit local renewable energy generation, but it is promising to support the vehicle energy demand and reduce grid burdens. Methods can encourage the local renewable energy system establishment to relieve the grid burdens from the burst increase of electric vehicle charging demand. Secondly, current research mainly focuses on energy management systems regarding traditional alternating or directing current charging technology. Battery swapping technology may have superiority over traditional charging to realise future carbon neutrality since the stationary battery modules will prolong the battery interaction time with grids or buildings [143]. The difficulty in battery maintenance and long-term profit earning challenge the wide application of battery swapping mode. For non-AEVs, battery swapping mode requires suitable business model development to achieve long-term earning, and the V2G, V2V and V2B functions are to be considered. Scheduling the battery swapping behaviours add the complexity of the management system design, as such behaviours may have impacts on the traffic and charging service [144]. Thirdly, non-AEVs may account for low charging facilities using efficiency and redundant establishment of extra charging resources. Hence, individual vehicle users decide to charge rather than manage the charging based on urban vehicle groups. The latter benefits local energy resilience, flexibility, renewable energy usage, and efficient use of charging facilities. Fourthly, a control strategy towards mitigating energy shortage impacts is desired. Energy shortages may happen in systems with low resilience, especially in remote islands and high-altitude villages for their independence or limited interactions with other systems. In this condition, it is important to find approaches to improve resilience. Fifthly, disturbance can be considered for energy management systems. Most research has ideal assumptions, such as fixed schedule and energy consumption rate of electric vehicles. However, electric vehicles can deviate from the schedule due to different traffic and weather conditions. The energy consumption rate can also be affected by different travelling speeds. Sources, impacts, and countermeasures towards disturbances are essential to develop an efficient control strategy. Sixthly, current charging business models focus on mitigating the impacts of the interactions between electric vehicles and grids, lacking the encouragement to charge electric vehicles with local renewable energy generation [29]. Future business models should guide more charging with local renewable energy rather than directly importing energy from the grids, which will surely decrease the grid burdens. There are challenges for the combination of emerging technologies and energy management system design for non-AEVs. For blockchain technology, even though it enables the transparency and security of shared data, pricing strategies are to be carefully designed to incentivise the sharing of data in the internet of things. The challenges of using artificial intelligence for predictive maintenance can be the accuracy of prediction and the processing of data for the training of artificial intelligence models. The challenges of internet of things in the field of supporting the decision-making of non-AEVs can be processing the big data from connected devices, the high computational load in a short time scale to support real-time decision-making, interference of wireless communication, and the security and privacy. Kumari et al. [145] discussed security and privacy challenges in smart grid systems that provide load management, load forecasting, and energy trading services. By addressing these challenges, the increasing penetration of electric vehicles can benefit both electric vehicle owners and electric suppliers, speeding up our pace to meet carbon neutrality.

4. The impact of autonomous electric vehicles on the smart charging energy management system

4.1. A brief introduction to the smart charging energy management system for autonomous electric vehicles

Autonomous vehicles can operate without a human driver, also called driverless or self-governing vehicles, relying on various sensors and detectors such as optical and thermographic cameras, radar, lidar, GPS, ultrasound, sonar, and odometry to carry out intelligent control [146]. By combining sensory information with traffic and navigation, the vehicle's autonomous driving system can decrease the risk of accidents caused by improper driving behaviour or blind spots [147,148]. In contrast to non-AEVs, AEVs are characterised by their driver-free and automatic vehicle relocation features [149].

Unmanaged charging processes for EV clusters can adversely affect the electric grid. Therefore, a smart energy management system is necessary to support AEV charging [150]. Smart charging evaluates electricity demand, renewable energy generation, and time to provide an efficient decision-making process for EV charging [151]. Many EV tariffs offer off-peak periods with lower prices that typically run from

midnight to early morning. AEVs can take advantage of these off-peak periods by plugging in and informing the charging system to wait before starting the charge. Off-peak charging not only saves costs but also avoids grid overload. Afentoulis et al. [126] investigated EVA for optimising smart charging management. To conduct smart charging, a smart charging unit is required to schedule charging by identifying periods of lower electricity demand and price. Connecting with wireless signals such as 4G/5G and Wi-Fi, real-time information on charging status, charging point availability, and grid pressure can be transmitted to an AEV system to facilitate self-managed charging [40].

The charging stations must be designed to communicate with AEVs, enabling them to park and charge automatically [152–154]. To achieve smart charging, higher automation at level 4 and level 5 for AEVs is important to communicate and share the surroundings, such as infrastructure, route network, and vehicles [112]. After that, AEVs can intelligently process the shared information (hidden obstacles and dangerous crossing) to conduct V2C, V2V, and V2I functions [113]. Making the payment process as easy and convenient as possible is important to encourage EV owners to use charging stations [103,104]. The business model for AEV charging involves deploying a network of charging stations equipped with autonomous technology [155]. The key elements of a business model for AEV charging are as follows: First, a charging station network should be deployed in strategic locations, such as urban areas, highways, and parking lots. The charging stations must be designed to communicate with AEVs, enabling them to park and charge automatically [152–154]. It requires a robust and reliable communication system to exchange information between the charging station and EVs. AEV charging stations must be maintained and supported to ensure they are always available for use, including regular inspections, repairs, and software updates. A schematic diagram concerning smart energy management for AEVs is listed in Fig. 5. Starting from the introduction of AEV, the management, basic components, and benefits were listed. After that, the section focuses on smart charging for AEV and the relevant business models.

4.2. Recent progress in the development of the smart charging energy management system for autonomous electric vehicles

4.2.1. The progress relating to the low-emission and zero-emission requirement

The impact of AEVs on CO_2 emissions is significant, and companies have expressed varying degrees of confidence in the future of this technology. PricewaterhouseCoopers [156] analysed various projections to evaluate the effects of electric vehicles and provide answers to pertinent questions. Their focus was on a set of scenarios that have been recently introduced. One of these scenarios, called "Rethink X", suggests that AEVs powered by renewable energy sources could account for approximately one-third of the difference between the decarbonisation rates observed between 2011 and 2016 is around 2.7 % and the annual reduction of 6.3 % required to achieve a 2-degree Celsius temperature increase by 2030 [157,158]. Based on the findings, implementing self-driving EVs will reduce GHG emissions by 2050. By 2050, self-driving electric vehicles could cut 34 % of total transport emissions. In the research of Vaidya and Mouftah [159], they noted that the connected autonomous vehicle (CAV) is an innovative technology that has the potential to revolutionise the current transportation system by offering sophisticated communication and sensing features, enhancing the travel experience and creating sustainable business models for low-carbon mobility. CAVs are typically EVs with high energy efficiency, thus helping to lower carbon footprint. Research studies [159,160] have demonstrated that autonomous vehicles with electric motors produce 40 % less GHG emissions over their life cycle than vehicles powered by engines. This significant reduction highlights the environmental benefits of the transition to AEVs, which help improve air quality and support global efforts to combat climate change. These vehicles integrate advanced technologies that further improve efficiency and sustainability. In a related study, Yao et al. [161] designed a numerical simulation to examine how deploying CAVs would affect fuel consumption and transportation emissions in mixed-traffic scenarios. The simulation outcomes indicated that CAVs can substantially mitigate fuel consumption and transport emissions. By optimising traffic flow and reducing congestion, CAVs improve overall transportation efficiency and significantly reduce the carbon footprint of daily commutes. These findings underscore the critical role of self-driving and connected vehicle technologies in achieving a sustainable transportation future. When all vehicles were equipped with connected autonomous technology, the maximum percentage reductions in hydrocarbon, oxides of nitrogen, carbon monoxide, and fuel consumption were between 24 % and 40 %. Wadud et al. [162] investigated the carbon footprint of highly automated vehicles and evaluated the overall impact of automation on emissions using multiple scenarios. Their findings suggest that automation can lead to a reduction of up to half in GHG emissions and energy consumption in road transportation or a potential increase by almost twice, depending on which factors predominate. In addition to fully autonomous vehicles, Vasebi and Hayeri [163] assessed the impact of emissions of low-level autonomous vehicles in 86 metropolitan areas. The results indicate that low-level autonomous vehicle technologies could reduce the emission cost for society by $9 billion to $20 billion per year. This significant potential for cost savings highlights the importance of integrating low-level autonomous vehicle into urban planning

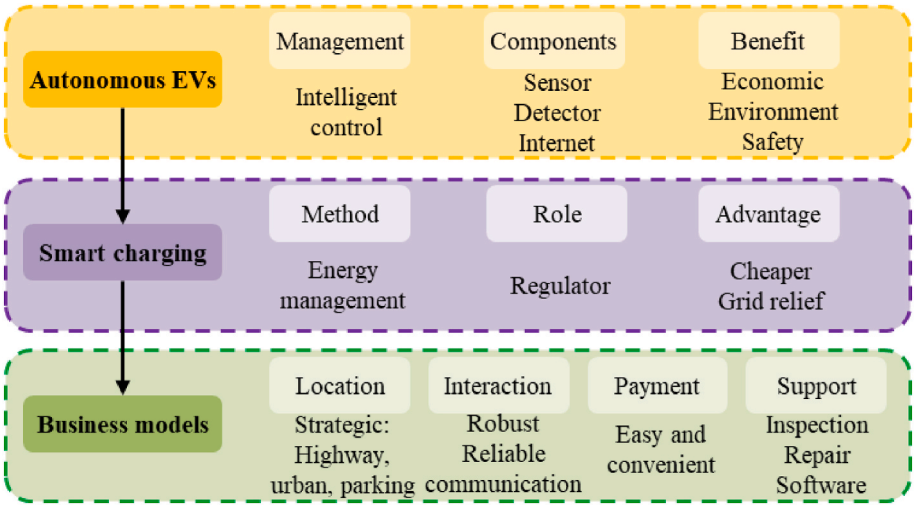

Fig. 5. Schematic diagram of smart energy management for AEVs.

and transportation strategies to improve environmental sustainability.

However, there is limited research and reporting on AEVs and building-integrated technologies. More research was interested in the AEV barriers and their influence on the city. Nissan recently partnered with Studio Pixellence to create the PixCity Virtual City as a key component of the project, "Calling on 100 Architects to Co-build a Future City With Autonomous Moving Vehicles" [164]. Through the PixCity Virtual City, participants can simulate different urban scenarios such as rush hour, special events, and emergencies to test the performance and responsiveness of autonomous vehicles and other modes of transport. In the [165], the researchers reviewed 185 papers on the future social context in the usage of autonomous vehicles and found that the impact of autonomous vehicles on the natural environment is minimal. Bezai et al. [166] proposed a more in-depth analysis of the upcoming autonomous vehicle technology and how it affects cities and lives. Dlugosch et al. [167] conducted a study to exemplify the potential of shared autonomous electric vehicles (SAEVs) in reducing resource investments. Meanwhile, the quality of service was sustained, thus providing valuable insights for decision-makers on the interplay between economic and sustainability-related factors in the shift towards sustainable urban mobility.

As the transportation industry seeks to reduce its carbon footprint, integrating AEVs with renewable sources is becoming increasingly relevant to achieving sustainable and environmentally friendly mobility. Iacobucci et al. [168] analysed the scenarios of grid-connected virtual power plants that integrate rooftop solar panels and isolated microgrids that incorporate solar, wind, and dispatchable power generation. The study found that the cost of SAEVs is considerably lower than individual cars. Furthermore, SAEVs can significantly boost the utilisation of renewable energy sources in microgrids. In the quest to decarbonise the transportation sector, the potential of solar PV technology in autonomous vehicles and robots was explored in Ref. [169]. The study involved a simulation of an EMS for a fast-charging station with multi-generation power production instead of the power grid. Another study evaluated the optimal scale of renewable energy systems and storage capacities required to uninterruptedly meet the daily demand for EV charging [170]. This integrated approach emphasised the importance of integrating various renewable technologies to support the growing charging infrastructure. Further discussion on SAEVs, Dean et al. [171] investigated the application of SAEVs and the integration of charging and repositioning events to enhance service quality, reduce idling time, and improve fleet utilisation by the average number of daily journeys and charging queues per vehicle. The study found that integrating charging and repositioning events led to a 39 % reduction in passenger waiting times and a 28 % increase in the average daily number of services per SAEV compared to a heuristic charging and repositioning approach. This demonstrated that SAEV improves operational efficiency and delivers a better overall experience for the user, thus enhancing SAEV's potential to transform urban mobility and support a sustainable mobility future. Building on these insights, Yi and Smart [172] investigated the difficulties associated with AEV-hailing fleets and their interactions with charging infrastructure. They proposed an integrated decision-making framework based on a system optimisation perspective for scheduling and AEV charging. The study also demonstrated the advantages of the optimisation approach in minimising fleet size and reducing charging downtime. Vosooghi et al. [173] evaluated the effects of AEV charging infrastructure on service performance. The simulation process involved an analysis of the impact of the infrastructure on the dynamic demands of the response network and traffic flow. The study found that incorporating a battery-switching infrastructure can markedly enhance the performance metrics of the SAEV service. This innovative approach not only increases vehicle availability and reduces downtime, but also promotes efficiency in the transportation network.

Generally, the main difference between AEVs and non-AEVs is that AEVs have self-driving features that enable them to operate without human intervention. Previous research works underscored the potential advantages of connected and autonomous electric vehicles (CAEVs) in various domains, including safety, mobility, parking management, car-sharing, road capacity, reduction of CO_2 emissions, air pollution, fuel consumption, and optimisation of traffic flow [105,112,119]. According to the research studies, CAEVs significantly enhance road safety by decreasing or eliminating human error, which is a leading cause of accidents. CAEVs can also increase mobility by providing transportation options to individuals who cannot drive, like the elderly or disabled. Additionally, CAEVs can potentially reduce parking needs by allowing for more efficient use of space. They can potentially reduce the number of vehicles on the road through car-sharing programs, and the traffic flow, congestion, and fuel consumption can also be optimised. Furthermore, the paper notes that CAEVs are expected to have significant environmental benefits, including reducing CO_2 emissions and pollution in urban environments. The transition to CAEVs is consistent with global sustainable development goals and improves public health and urban livability by reducing harmful emissions contributing to deteriorating air quality. Supporting this perspective, the report of [160] investigated the fuel efficiency of CAV technologies and highlighted their potential energy impacts. The CAVs could have better energy impacts on the smoothness of drive profiles and traffic flow by reducing abrupt accelerations and decelerations. V2I and infrastructure-to-vehicle (I2V) communication can improve traffic flow and reduce congestion at intersections. CAVs equipped with collision avoidance technology can potentially reduce accidents and collisions. CAVs can also reduce queuing and waiting times by optimising route planning and reducing congestion. Additionally, CAVs with optimised vehicle and powertrain sizing can improve fuel efficiency and reduce energy consumption, reducing environmental impact. However, it is important to consider that faster travel speeds can potentially worsen the energy impact of CAVs due to increased wind resistance and higher power demands at higher speeds. Previous research emphasises the distinctive characteristics of the internet of autonomous vehicles, which include facilitating safe and efficient self-driving, mitigating traffic congestion and emissions, and improving the overall mobility experience [174]. Moreover, based on the studies by Zhuge and Wang [175] and Lam et al. [176], it is understandable that AVs will enter the market when EVs have a high marketing share. Therefore, the future AVs are likely to be electric. AVs will be part of the transition to AEVs. The shift from conventional cars to AVs or AEVs is driven by a combination of connectivity, electrification and changing consumer demands. Todorovic et al. [177] underscored the need for more research to explore the different aspects of this paradigm shift to address the challenges posed by the transformation of the global automotive industry.

There is growing recognition that innovative strategies are needed to manage traffic and improve the energy efficiency and energy saving of connected electric vehicles and CAVs in an increasingly complex driving environment. Liang et al. [178] investigated how the driving behaviours of vehicles in front could significantly impact the energy consumption and safety of connected electric vehicles. They introduced a control strategy to enhance energy efficiency and safety in response to dynamic changes in the preceding vehicle's behaviour. Dong et al. [179] investigated how the CAVs in front significantly affect the ecological driving control of the vehicle behind, especially at signalised intersections. The problem of long vehicle queuing times at signalised intersections, which leads to increased energy consumption for connected electric vehicles, is addressed by introducing the enhanced eco-approach control strategy [180]. All three studies aim to improve energy efficiency, but in different backgrounds, and solve different issues for transportation systems [178] involving traffic communications [179] overtaking scenarios at intersections, and [180] predicting queuing behaviour to optimise approach strategies. The implementation of these control strategies not only contributes to improving vehicle performance but also to broader societal goals related to safety, sustainability and efficient urban mobility.

4.2.2. The role of X2V and V2X in the smart charging energy management system

(1) Different and special types of X, V, and X2V types of AEVs

X2V and V2X technologies play important roles in the smart charging EMS of AEVs, as reported in Table 5. X2V technology enables bidirectional communication between the EV and the power grid or other external devices, allowing for more efficient and dynamic EMS. V2X technology is a two-way communication system that enables vehicles to exchange information with other devices or infrastructure in their surrounding environment. V2X communication covers many different types, such as V2V, vehicle-to-infrastructure (V2I), vehicle-to-pedestrian (V2P), and vehicle-to-network (V2N) communication. V2X allows vehicles to exchange information with other vehicles, traffic signals, road signs, and other devices, leading to more efficient and coordinated driving behaviour. This technology improved road safety and driving experience and reduced traffic congestion. Some studies [181] show how AEV integrates with renewable energy systems. Iacobucci et al. [168] developed an optimisation method for the charging and discharging of SAEVs to minimise costs in virtual power plants or microgrids. Their research was concerned with the V2G function. In isolated microgrids, SAEVs with V2G reduce costs by 16 % and carbon emissions by 50 %. V2X mainly focus on renewable-to-vehicle (R2V) and G2V. The study mentioned the unique features of the internet of autonomous vehicles [174], V2V, and V2I functions were concerned.

The internet of things is increasingly central in intelligent transport systems, where AVs serve as a key component [184]. The paper notes that networks are pivotal in realising the future of AVs. These networks facilitate V2X communication between vehicles and various nodes, including V2V, V2I, and V2P communication. The study discussed the emergence of fifth-generation cellular network technologies that offer real-time data communication, which can enhance the experience of fully autonomous driving [185]. The cellular solution is called cellular vehicle-to-everything, where everything can refer to both vehicles and infrastructure. Non-AEVs may still rely on traditional advanced driver assistance systems sensing technologies or short-range communication systems such as dedicated short-range communications [185].

Although various modes of information interaction for AVs are mentioned in some articles, the section dealing with smart charging energy management systems is generally less mentioned. Most studies on AV/CAV have focused on congestion mitigation and traffic capacity enhancement. For example, the findings of Zhang et al. [188] and Yoo et al. [189] may improve vehicle queue management. Moreover, Mersky and Samaras [190] mentioned a significant improvement in fuel economy when efficiency-focused control strategies were applied in AVs. However, these studies do not discuss in depth what kind of information interaction is involved, and more research could be done in this area in the future.

(2) The role and impact of X2V and V2X on the smart charging energy management system (and associated control strategies) of AEVs: from the perspectives of technical, economic, and environmental performances

Based on previous studies, limited papers focus on the smart charging EMS. However, with the implementation of X2V and V2X technologies along with suitable control strategies, the performance of the smart charging EMS of AEVs can be enhanced. These technologies facilitate bidirectional communication between EVs and the power grid, which helps to address challenges related to the efficient utilisation of energy resources, the optimisation of charging schedules, and the reduction of the impact on the power grid and carbon emissions. For example, Iacobucci et al. [186] proposed a new control strategy for SAEV systems with V2G capabilities based on cascaded model predictive control, which is an advanced control method for optimising the performance of complex systems with multiple inputs and outputs. This study showed a potential decrease in charging costs while also reducing passenger waiting times, highlighting the capacity of SAEV systems to support load shifting and storage services without detracting from transportation quality. Another study by Iacobucci [187] has demonstrated the potential of SAEVs to provide effective energy storage solutions to the grid and alleviate grid congestion through dynamic pricing.

The optimal control strategies for smart charging energy management systems of AEVs that are enabled with V2G and V2H communication depend on several factors, including the size of the AEV fleet, the charging infrastructure, and the energy demand of the AEVs. Different approaches, such as optimisation models, machine learning algorithms, and control theory, can be used to develop efficient and effective control strategies. X2V and V2X technologies have significant potential to improve the performance of smart charging energy management systems of AEVs from technical, economic, and environmental perspectives. Further research is needed to explore the optimal control strategies for these systems and fully leverage these technologies' advantages. Kumari et al. [181] explored the challenges posed by the exponential growth in energy demand, which has led to increased

Table 5
Type and information of "V" and "X" in X2V and V2X of autonomous electric vehicles.

V	X	X2V or V2X interaction types	Renewable	Zero emission levels	Individual or aggregated levels	Location	Reference
SAEVs	Virtual power plant, microgrid	R2V[1], G2V[2], V2G[3]	Wind, Solar (PV)	95.86 ton	33,600 SAEV trips per day	Japan	[168]
Electric, hybrid, and autonomous vehicles	Renewable	R2V	Solar (PV)	/	/	India	[169]
AEVs	Renewable	R2V	Solar (PV), Wind	3.66 tons	50 EVs	Qatar	[170]
Internet of autonomous vehicles	Vehicle, infrastructure	V2V[4], V2I[5]	/	/	/	/	[174]
CAEVs	Vehicle, infrastructure, internet, smart device	V2V, V2I	/	/	/	/	[182]
CAEVs	Infrastructure, device, pedestrian, cloud, network, grid	V2I, V2D[6], V2P[7], V2Cl[8], V2N[9], V2G, G2V	/	/	/	/	[183]
AVs	Vehicle, Infrastructure, personal device, human device, sensor, roadside	V2V, V2I, V2D, V2S[10]	/	/	/	/	[184]
CAEVs	Infrastructure, vehicle	V2I, V2V	/	/	/	/	[185]
SAEVs	Grid	V2G, G2V	/	/	20-40 EVs	Japan	[186, 187]

Note: 1. R2V- renewable-to-vehicle; 2. G2V- grid-to-vehicle; 3. V2G-vehicle-to-grid; 4.V2V- vehicle-to-vehicle; 5.V2I- vehicle-to-infrastructure; 6.V2D-vehicle-to-device; 7. V2P- vehicle-to-pedestrian; 8. V2Cl-vehicle-to-cloud; 9. V2N- vehicle to network; 10.V2S- vehicle-to-sensor.

demand response gaps and reduced quality of service in smart grids. Increasing demand not only puts pressure on existing infrastructure but also requires innovative solutions to improve the efficiency and reliability of energy distribution. Building on this [191] discussed the application of smart grid technologies for efficient power management. They proposed a scheme to improve demand-side load forecasting. In the future, by linking technology and data analytics to the development and operation of self-driving EVs, stakeholders can enhance security, improve efficiency, and create a more integrated and sustainable transport ecosystem. Moreover, integrating AEVs with smart grid systems can significantly improve energy efficiency, reduce costs and support sustainable energy practices. This synergy can create a more resilient and responsive energy ecosystem by utilising advanced technologies such as V2G and V2X, dynamic charging, and blockchain.

(3) Other unique and special features for the smart charging of AEVs compared to the non-autonomous ones

There are several unique and special features for the smart charging of AEVs compared to non-autonomous ones. AEVs can communicate in real-time with the grid and other EVs through X2V and V2X technologies. It allows for efficient energy management, including optimising charging schedules based on grid availability and EV driving patterns. Additionally, AEVs can be deployed as part of shared mobility services, such as ride-sharing or car-sharing, which require sophisticated charging strategies to ensure efficient utilisation of energy resources while maintaining a high level of service. Moreover, AEVs can also offer grid services, such as V2G, which allows them to feed energy back into the grid during periods of high demand.

The charging station is the general infrastructure of the electric vehicle supply equipment. With the rapid growth and development of electric vehicles, unmanned charging technology is expected to become an important means of energy supply for self-driving intelligent networked vehicles. The smart charging system can reduce manpower intensity, fully realise automatic operation, reduce labour costs, and improve the operating efficiency of the charging station. Various unmanned charging technologies have been developed to align with the growing penetration of AEVs as reported in Table 6.

Table 6
The available unmanned charging technologies for EV and AEV.

Company	Technology	Application/test	Reference
Electreon	Wireless charging (dynamic electric vehicle charging)	Israeli	[192]
Qualcomm	Wireless charging (dynamic electric vehicle charging)	N.A.	[193]
WiTricity	Wireless charging (charging pad)	N.A.	[194]
InductEV	Wireless charging (charging pad)	US	[195]
Volkswagen	Robotic charging (mobile charging robot)	Germany	[152,153]
Hyundai	Robotic charging (Robotic arm)	Korea	[154]
Ford	Robotic charging (Robotic arm)	Germany	[155]
ChargeBots	Robotic charging	N.A.	[196]
Volterio	Automatic conductive charging	Austria	[197]
Gaussin	Electric container carrier	France	[198]
ABB Group (Swiss-Swedish)	Pantograph charging	N.A.	[199]
Siemens	Pantograph charging	Denmark	[200,201]
Siemens	Pantograph charging (dynamic electric vehicle charging)	Hesse, Germany. Scania trucks, Sweden.	[202]
Heliox	Pantograph charging	Bettembourg, South of Luxembourg. Amsterdam, the Netherlands.	[203–205]

4.2.3. Impact of smart charging of autonomous electric vehicles on the techno-economic and techno-environmental performances

This subsection will present the impact of smart charging of AEVs on techno-economic and techno-environmental performance. Table 7 compares the techno-economic performance of several commonly studied autonomous vehicles in different studies. What they all have in common is optimising the charging process through a control or energy management system, which leads to improved technical performance. The technical indicators are usually the charging or transmission efficiency and energy loss. Most studies focus on charging costs when considering economic performance and may focus more on electricity costs if renewable energy is used. Few studies focus more on battery life, but some studies compensate for this limitation by considering the cost of battery cycling. In addition to charging costs, some studies focus on socio-economic aspects, such as a focus on AEVs to mitigate pandemics and reduce charging wait times. Concerning limitations, the most frequently mentioned aspects are the capacity of the battery and the number of EVs. Especially considering the cost of charging and interaction, more modes of energy interaction and dynamically changing battery prices need to be considered for future studies. The performance of AEV smart charging systems can be improved by adopting X2V and V2X technologies and effective control strategies based on the previous research. These technologies enable more energy interaction among AEVs, renewables and the grid, addressing challenges related to efficient energy resource use, optimising the charging process, and reducing grid impact and carbon emissions.

In addition to studies focusing on techno-economic aspects, there are also studies focusing on techno-environmental aspects. Huang et al. [212] found that CAVs can reduce emissions by about 35–50 % compared to human-driven vehicles. Li et al. [213] showed that the emission reduction effect of SAEVs is obvious, and the CO_2 emissions of SAEVs are more than five times less than those of conventional internal combustion vehicles. They also found that smart charging can produce up to 95 % fewer emissions with higher levels of renewable energy integration. Synergising SAEV charging with grid operation can have significant emission benefits, as well as the result of smart charging control and activation of the V2G interactive function. Hong and Zimmerman [214] investigated the reduction of GHGs and particulate matter. They found that CAVs could help reduce GHGs by 6%–20 % compared to no-CAV scenario. Particulate matter could be reduced by 20 %.

4.2.4. The business models to support the smart charging energy management system

The rise of EVs has spurred the development of new business models for EV charging stations. Pricing schemes for these stations are based on the electricity used [97–100], the charging time spent, or a combination of these factors [119–121]. Some popular smart charging business models for EVs have been explored. Generally, pricing schemes for AEV charging are likely to resemble those for non-AEVs, as both vehicles require access to charging infrastructure [147,187,215–218]. Some charging networks may also offer subscription-based pricing, where customers pay a monthly or yearly fee for access to charging stations at a discounted rate [101,115].

As AEV technology advances, new pricing schemes may emerge specifically tailored to the unique needs of AEVs. For instance, charging networks might offer higher prices for faster charging speeds, which are essential for AEVs to optimise to recharge quickly and minimise downtime for the vehicle. Automated EV charging encompasses types, including wireless and robotic charging. Moreover, pricing schemes that consider the autonomous capabilities of the vehicle, such as charging rates optimised to minimise downtime, may be developed. The pricing

Table 7
Techno-economic implications of smart charging for AEVs.

Types of Vehicles	Smart charging strategies	Impact on grid stability	Impact on economic	Impact on EV battery life	Other Pros and cons	Reference
SAEV	Shifting electricity demand from high-priced peak hours to renewable generation hours	Higher self-consumption	Reduced electricity costs by 34–43 %	N.A.	Dynamic congestion is not included; single renewable energy source.	[206]
CAEV	Static wired and wireless charging systems and dynamic charging systems	N.A.	decreased the charging costs via larger batteries and more vehicles	N.A.	There is an upper limit on the number of batteries and EVs that can be charged.	[207]
AV	Cloud-based solutions	N.A.	N.A.	N.A.	Ethical safety and agency problems; Tackling pandemics with self-driving cars	[208]
AEV	Wireless power transmission	N.A.	N.A.	N.A.	Higher transfer efficiency; minimised energy losses	[209]
AV	Wireless charging	N.A.	N.A.	N.A.	Higher charging efficiency; V2G and G2V technologies could be considered and investigated.	[210]
SAEV	Cascaded model predictive control	V2G services help balance the energy between vehicles and grids.	Decreased charging costs	Battery cycling cost is considered	Limited impact on passengers' waiting times.	[186]
SAEV	Dynamic depth of discharge management	N.A.	The total cost was decreased by 51.3 %	The battery replacement cost is considered	The battery degradation model still needs to be improved; the uncertainties are less considered.	[211]

of automated EV charging may vary depending on the charging stations and the companies that provide the charging service. Regarding different charging locations, suppliers, and modes concerning various types of AEV, there are some examples [147,187,215–218] of pricing for automated EV charging, as listed in Table 8.

In addition to X2V functions equipped with AEV, researchers have investigated various V2X services. Iacobucci et al. [217] suggested that AEVs can absorb surplus renewables to regulate DR, which increases the proportion of renewable energy integrated into the power grid. With the increasing penetration of EVs, the cluster of charging behaviour may rapidly raise grid peak demand. However, autonomous demand-side flexibility control from EVs has shown the potential to release additional grid peak demand, as demonstrated by Ireshika et al. [219]. Yumiki et al. [220] proposed flexibility control for autonomous V2G to provide ancillary services, while Monios and Bergqvist [221] investigated the smart network business model using AEVs for freight transport and suggested that AEVs can sell stored electricity to support the grid. Kester et al. [222] identified the fleet of AEVs as a suitable adopter for V2X service, and Lam et al. [176] found that a suitable quantity of AEVs can facilitate parking to support V2G. Despite the significant investment in infrastructure, technology, and maintenance, the business model for AEV charging is promising due to the increasing demand for EV charging and convenient charging solutions [223]. As the technology becomes more widely available and more companies enter the market, pricing schemes for automated EV charging are likely to evolve. Local regulations, energy prices, and competition among charging providers may also influence the pricing for automated EV charging.

Table 8
The referred business models for the studies concerning AEV charging.

Business model	Charging mode	Vehicle type	Charging method	Reference
California pacific gas and electric company tariffs	Time-of-day rate	Ride-hailing AEVs	Charging station	[215]
Consolidated Edison company of New York	Time-of-day rate	Electric taxi fleets	Charging station	[216]
Tokyo electric power company	Time-of-day rate	Shared AEV	Charging station	[217]
National average retail price data	Time-of-day rate	Shared AEV	Home charging Charging station	[218]
Japan electric power exchange	Time-varying electricity price	Shared AEV	Charging station	[187]
US national residential electricity average	Energy-based	Shared AEV fleet	Charging station	[147]

4.2.5. *Regulatory and policy frameworks for autonomous electric vehicles*

Regulatory and policy frameworks play a critical role in shaping the acceptance of innovative technologies. To address environmental issues, regulations focused on decreasing carbon emissions and advancing sustainability are key to adopting zero-emission vehicles and intelligent energy management systems. As one of the dominant sources of greenhouse gas emission (37.5 % CO_2 emissions of total in the US), the transportation sector sought the potential of emission reduction by SAEVs. Li et al. found that the alignment between the charging schedule and renewable energy generation was determined towards economic and emission impact. Under a high renewable energy penetration, 95 % of emission reduction was obtained by synergising charging with grid operation from an SAEV fleet [171]. When coupled with the renewable power grid, the SAEV fleet will provide the potential to reach zero-carbon transportation. Loeb and Kockelman learnt that 6–10 privately held vehicles per SAEV [183]. Except for the environmental benefit, the SAEV fleet gained a 19.6 % operational cost reduction over a 30-year simulation conducted by Liao et al. This benefit was provided by the integration of V2G services [184]. Varone et al. tested a software platform designed to optimise the management of energy flows in a solar-powered parking internet of things that serves a fleet of EVs. An economic evaluation is conducted to assess the viability of the smart charging algorithm and internet of things platform. They aimed to maximise the self-consumption of renewable energy generated on-site, thereby reducing reliance on the external grid and contributing to the goal of achieving net-zero emissions. It showed the potential of the software platform to optimise energy usage, reduce greenhouse gas emissions, and enhance the sustainability of energy systems in the transportation sector [185]. Smart charging strategies provide several benefits under the regulatory and policy framework. To avoid the intense peak load caused by unpredictable charging behaviour, control strategies like energy shift, valley filling, and peak shaving can reduce operational costs. The AEV aggregator showed more potential and ability to maximise the profit and minimise the cost [164].

Current regulatory and policy frameworks have not been globally standardised. Different works showed the respective characteristics of the studied area. Therefore, the employed control strategies may not be

applied to others. Besides, the stochastic events were not considered strictly. Dynamic congestion, infrastructure availability, and unpredictable issues will impact the decision-making process of smart charging.

4.3. Future development and challenges relating to the smart charging energy management system of autonomous electric vehicles

4.3.1. Emerging technology and innovations

The emerging technologies and innovations impact the development of smart energy management systems of AEVs, especially for the blockchain, artificial intelligence, and the internet of things. The technology of blockchain contributes to the development of a transparent, decentralised and trusted energy trading market, incentivising the adoption of V2X and X2V functions. The behaviours of AEVs can be motivated to optimise the objectives. There is still a lack of specific investigation of AEVs and blockchain technology [224]. The second technology is artificial intelligence for predictive maintenance. For AEVs, it is expected that artificial intelligence for predictive maintenance is more useful compared to non-AEVs. The third technology is the internet of things. For AEVs, the internet of things is essential to the realisation of autonomous behaviours, especially for those with external equipment like autonomous charging and discharging. The collaboration of blockchain and internet of things is promising to transform transportation and grid systems to be more efficient, secure, and resilient [225].

4.3.2. Future development and challenges

Compared to non-AEVs, AEVs enhance mobility and have an impact on emissions, building and vehicle performance, energy management systems, and charging facilities. Firstly, the comparison of emission reduction between individual AEVs and non-AEVs is desired. Current research mainly focuses on the emission of entire city transportation systems by adopting autonomous vehicles rather than the benefits for residential or business building stakeholders to improve their local renewable energy utilisation ratio [11]. Before full self-driving automation, electric vehicles in partial autonomous levels should also positively impact local renewable energy utilisation regarding their enhanced information-sharing technology and flexibility. Secondly, investigations for technical performance enhancement for residential and business buildings by adopting AEVs and renewable energy systems with customised control strategies are rare. It is challenging to fulfil the potential of AEVs to mitigate battery degradation, enhance renewable energy utilisation, and relieve grid burdens [226]. When the goal of full self-driving automation is achieved, the swap strategy considering different local renewable generation sites, buildings, and vehicles with complex real-time information sharing should be developed. Investigating the possibility of enhancing energy utilisation before fully self-driving automation is also important. Thirdly, energy management of urban AEV groups is complex, especially regarding the multiple kinds of real-time shared information, such as the state of charge of the battery, vehicle location, and vehicle potential journey arrangement [227]. Control decisions should be made to get optimal impacts on traffic, passengers, buildings, grids, and vehicles, considering a certain degree of trade-offs. Fourthly, Fourthly, supporting facilities should be integrated into the frame of energy sharing via AEVs. To realise full automation, automated parking, charging, repairing, etc., are desired, and they will impact the control strategies of AEVs. For instance, if wireless charging is adopted for AEVs, energy loss and cost should be considered for the system evaluation. Developing cheap and reliable unmanned charging facilities is also future AEVs and smart traffic systems. Swapping battery packs can be considered for time-saving feature instead of alternating or directing current charging [143]. Fifthly, coupling control strategy with the various kinds of real-time information is challenging. Grid, renewable, building, traffic, vehicle, and pedestrian information can be acquired by smart sensors integrated into the roads, buildings, and AEVs. Efficient approaches are to be developed to enhance the use of such information. Sixthly, the business model suitable for AEVs is rare. Even though the current business model can be directly adopted for AEVs, improvement is still desired to utilise their flexibility and automation better. Contradiction may occur between EV owners and the public. For instance, energy sharing can be enhanced by more travel, but it leads to battery degradation. Hence, the desired business model should properly motivate EV owners to share their vehicles. There are still challenges regarding the emerging technology and innovations. The increasing number of electric vehicles and limited charging stations challenge the design of combining blockchain technology and the energy management system. The deployment of blockchain technology in motivating energy sharing between vehicles and other storage systems is to be investigated. This combination is promising to handle the future increasing energy demand and enhance the reliability and resilience of the smart grid. As for artificial intelligence for predictive maintenance, the increased number of supporting equipment for AEVs, such as robot arms for automatic charging, contributes to the difficulty in predictive maintenance and increased calculation load for artificial intelligence. In addition, smart sensors are to be developed to provide sufficient and accurate information on equipment for both model training and maintenance predictions. In the combination of internet of things and the smart energy management system of AEVs, the processing of data from connected devices in a limited time is challenging. Sensors in AEVs need to be reliable, and the interference of wireless communications is to be carefully considered. Data security and privacy are to be considered. Kumari et al. [228] outlined the importance of data analytics for organisations seeking to leverage data for improved decision-making and operational efficiency. This approach can also be effectively applied to AEVs. In conjunction with these insights, Golyan et al. [229] highlighted the need to prioritise ethical considerations and privacy in data analytics practices to promote trust and accountability in data-driven environments.

5. A summary of the key differences of smart charging energy management systems between non-autonomous and for autonomous electric vehicles with X2V and V2X functions

The conceptual diagram of smart charging energy management systems between non-AEVs and AEVs with X2V and V2X functions is shown in Fig. 6. The key distinction between vehicle types lies in their decision-making processes. Non-autonomous vehicles typically rely on human input for decision-making. Although the decision-making of some vehicles can be aided by acquiring more information resources by equipping them with devices that can help humans optimise their decision-making, the decision-making of some cars can be assisted with more information resources. It is worth noting that the automated vehicle can exchange information by itself to get a final optimised decision. To some extent, the potential loss of a wrong decision is circumvented. The forthcoming subsections will explore the differences between non-autonomous and autonomous vehicles in more detail.

(1) Types of X and V

The key differences between non-AEVs and AEVs with X2V and V2X functions in smart charging energy management systems can be understood by looking at the types of X and V, and those details are summarised in Table 6 and **Fig. 6**. V2X refers to the communication between vehicles and other entities in the transportation system, such as infrastructure, traffic signals, and other vehicles. This communication can help vehicles decide on an optimal route and speed to reduce energy consumption and improve traffic conditions. X2V refers to communication from external sources to the vehicle, such as grid operators or charging infrastructure. In the case of AEVs, X2V communication can be used to optimise charging schedules, manage energy storage and discharging, and coordinate with the power grid.

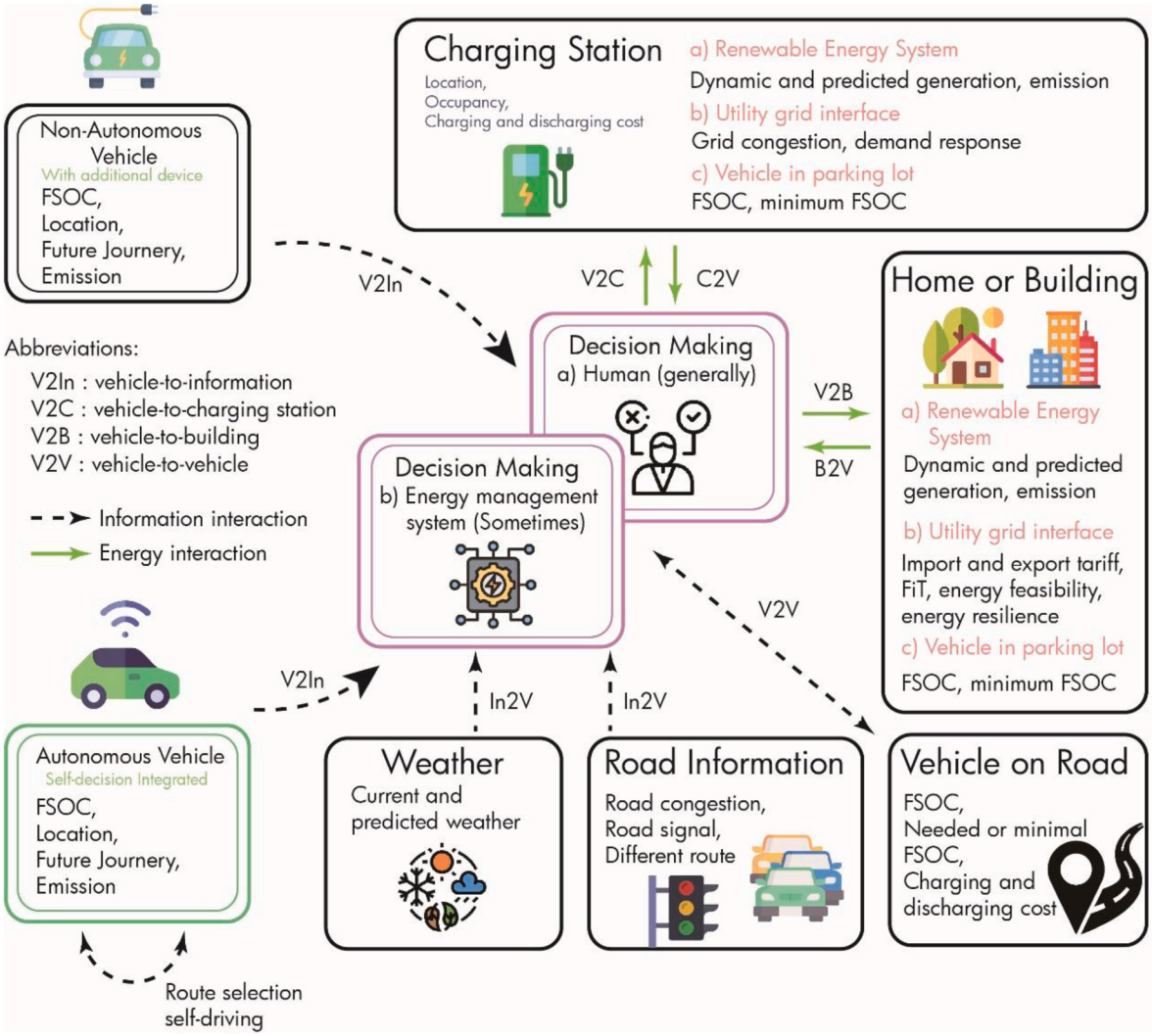

Fig. 6. The conceptual diagram of smart charging energy management systems between non-autonomous and AEVs with X2V and V2X functions.

The key difference between non-AEVs and AEVs with X2V and V2X functions is the level of automation and the ability to communicate with other entities in the transportation system. AEVs have advanced sensors and real-time communication systems with other vehicles, infrastructure, and the power grid. It allows for more efficient use of energy resources, optimal charging schedules, and load-balancing services. On the other hand, non-AEVs cannot communicate with external entities, making it challenging to optimise charging and energy management.

(2) Types of X2V and V2X functions and associated control strategies

Smart charging refers to the intelligent management of EV charging to optimise energy use, reduce costs, and minimise the impact on the electricity grid. Here are some examples of X2V and V2X functions, along with associated control strategies, specifically related to smart discharging and charging of EVs with their associated system: real-time energy pricing information, V2G services, renewable energy integration, DR, fleet charging optimisation and charging scheduling and management [53,129,230]. X2V and V2X interactions of non-AEVs and AEVs with their associated systems, such as buildings, charging stations, road traffic, vehicles on the road, and weather information, are illustrated in Fig. 6. Firstly, the EV receives real-time pricing information from the utility or charging station and adjusts its charging behaviour accordingly to take advantage of lower electricity rates [128]. Secondly, in exchange for financial incentives, the EV can serve the utility grid in energy storage or demand balancing [130]. Thirdly, the EV can be programmed to charge when renewable generation, such as solar or wind power, is the most abundant and least expensive [170]. Fourthly, the communication between the charging station and the power grid helps to adjust the charging rate or delay charging during high demand to ease the strain on the grid [64]. Fifthly, fleet managers can use V2X communication to regulate the charging of multiple EVs to reduce costs and optimise energy use [29]. Sixthly, the EV can be programmed to charge at specific times, such as during off-peak periods, to minimise costs and avoid overloading the power grid [80,187]. Generally, the AEVs get more access to X details than the non-AEVs. AEVs can do all those functions mentioned above, especially those related to 'when' and 'how', but to do those, non-AEVs need external smart EMS or active user participation to perform those effectively. However, AEVs stand out from non-AEVs in terms of 'where' due to their autonomous movement by selecting a particular location among possible locations and moving towards it without the user's active participation. In addition, unlike AEVs, non-AEVs cannot perform V2V functions without having any other X between the EVs. Especially, V2V function on-road is not possible in non-AEVs.

(3) Zero-emission requirement

To meet a zero-emission requirement, EVs need to be powered by renewable generation, such as solar, wind, or hydroelectric power. This

means the electricity used to charge EVs must be generated without greenhouse gas emissions or other harmful pollutants [49]. In addition, the manufacturing and disposal of EVs must also be managed in an environmentally sustainable manner [231]. A zero-emission requirement for electric vehicles typically refers to a mandate that requires new passenger vehicles sold within a certain jurisdiction to emit zero tailpipe emissions [232]. The goal of such a requirement is to decrease the environmental impact of transportation and improve air quality by promoting the adoption of EVs, which produce no tailpipe emissions and are powered by electricity from renewable sources. Several countries and regions have already implemented or announced plans to implement zero-emission requirements for new passenger vehicles. For example, the EU has proposed a new law that requires all new passenger vehicles sold within the EU to emit zero emissions by 2035 [233]. The UK has planned to prohibit the sale of new fossil fuel-powered cars and vans by 2030 and require all new passenger vehicles to achieve zero emissions by 2035 [232]. Norway aims to sell only zero-emission new cars by 2025 and has implemented a series of monetary support for the adoption of EVs [234]. The zero-emission requirement for AEVs and non-AEVs is essentially the same. Both vehicles are expected to produce zero emissions. However, the difference in autonomy level between the two types of EVs could affect their zero-emission requirement. AEVs are self-driving vehicles that rely on advanced technologies to decide how to function, and non-AEVs are controlled by humans. Therefore, AEVs may be subject to more stringent emissions regulations or targeted to reach zero emission earlier because they are expected to operate more efficiently and reliably than non-AEVs.

(4) Renewable energy utilisation

As Table 9 and Fig. 6 report, one key difference between smart charging energy management systems for non-AEVs and AEVs with X2V and V2X functions is the potential use of renewable energy resources. With the ability to communicate with the local grid and other vehicles, AEVs equipped with X2V and V2X technologies can take advantage of renewable energy to charge vehicle batteries when the energy is available and cheaper. AEVs can help reduce the transportation sector's overall carbon footprint and promote the adoption of renewable energy resources. In contrast, non-AEVs may be limited to smart charging during peak or off-peak hours when energy prices are higher or cheaper, considering the limitation of the human decision process. Moreover, AEVs have advanced communication and control capabilities that allow them to receive and act on commands based on special functions, especially V2V and V2I. These functions help the AEVs have greater control over battery charging based on more valuable and real-time renewable information. In addition to the above, AEVs also use predictive analytics to optimise charging behaviour based on historical renewable energy information. In summary, both non-AEVs and AEVs can benefit from using renewable energy sources. However, the advanced communication and control systems of AEV could better utilise renewable energy.

Table 9
The key differences of smart charging energy management systems between the non-AEVs and AEVs.

Objects	Non-AEVs	AEVs
Types of V X and X V	Non-AEVs Grid, Renewable, Building	AEVs In addition to non-electric vehicle functions, X can be infrastructure, pedestrian, network, cloud, etc.
Types of X2V and V2X functions and associated control strategies	It can do all the X2V and V2X services only with the help of an external energy management system or human participants. Cannot perform V2V on-road	It stands out from EVs due to its autonomous movement. Can perform V2V on-road
Zero emission requirement	In general, the requirement is the same for both EVs and AEVs.	Due to the possession of advanced technologies, it may be expected to have a more stringent target.
Renewable energy resources	Constrained by the limitations of the human decision-making process and less real-time renewable information.	More and more efficient information on the use of real-time renewable energy.
Energy flexibility and resilience of EV charging	Need external energy management system or more active human participation.	Provided that the input information is accurate, AEVs perform better due to their higher autonomy.

(5) Energy flexibility and resilience of the EV charging

Energy flexibility and resilience are important considerations for EV charging, as they can help improve the charging system's reliability and efficiency while reducing costs and minimising the impact on the power grid. Intelligent charging management, V2G services, energy storage, microgrids, and DR can achieve energy flexibility and resilience in EV charging. Generally, non-AEVs and AEVs follow human decision and self-decision, respectively, to provide energy flexibility, DR, and energy resilience to their associated system, and their interactions are shown in Fig. 6. Firstly, an intelligent charging management system can optimise the discharging and charging process to balance the availability of renewable generation and the demand for grid capacity, help reduce costs, and ensure that charging is done efficiently and sustainably [57]. Secondly, EVs equipped with V2G can serve the utility grid as energy storage in exchange for financial incentives to help improve the power grid's resilience and reduce the need for expensive infrastructure upgrades [235]. Thirdly, EV batteries can store excess energy from renewable sources and release it to the associated system when needed [18,68]. Fourthly, microgrids can independently operate without utility support, and energy flexibility and resilience can be improved by integrating EV charging into a microgrid [68]. Fifthly, DR programs can incentivise EV owners to adjust their charging behaviour to reduce strain on the power grid during high-demand periods [53]. Overall, both AEVs and non-AEVs can provide all the abovementioned services. AEVs may have more flexibility regarding when, where, and how to charge, as they can be programmed to charge and discharge effectively to provide high energy flexibility and resilience. However, non-AEVs may need external smart EMS or active human participation, which is listed in Table 9. For instance, a non-AEV may be less likely to participate in DR programs if it means they must change their charging routine. In summary, the difference in autonomy level between AEVs and non-AEVs may affect their energy flexibility and resilience, but both can provide valuable services.

6. Perspectives of different stakeholders

There are multiple stakeholders in the development of the smart EMSthat supports zero-emission and/or autonomous electric vehicles with X2V and V2X functions, including policymakers, utility companies, EV manufacturers and consumers, playing different roles in the ecosystem. They all have different interests, some of their interests are aligned with each other, and some of them conflict with each other. It is essential to analyse and balance the challenges and opportunities for different stakeholders to facilitate the development of the smart charging system. Studies that focus on various perspectives in this area are reviewed in detail.

One of the important stakeholders in this ecosystem is the policymaker as appropriate policies could guide and incentivise the ecosystem development in its early stage. Development of the smart charging system can bring economic growth through the enhancement of EV penetration and bring economic benefits for carbon emission reduction [236]. In the implementation, policymakers need to balance the amount

and site allocation of the smart charging stations and the configuration of urban areas in urban planning [237]. Also, security management of the connection between EVs/AEVs and the utility grid is essential to prevent some threats to the system [238], so regulatory frameworks are essential to promote smart charging development [239]. Also, standardization of the smart charging system is another fundamental issue that policymakers should deal with to make sure that the system can be compatible with other energy supplies so that different types of charging facilities can be combined into the utility grid, and to facilitate the technology development by reducing the manufacturing cost through scale effect for the industry [240].

From the utility company's perspective, the development of the smart EV/AEV charging system may bring chances to optimise energy usage and enhance the grid stability by shifting the power peak and filling the power valley [241,242]. P. B. Jones also mentioned that one of the benefits for the utility company is that dynamic pricing can help incentivise consumers to charge during time that benefits the grid to utilise the distribution grid more efficiently, and V2G technology can turn EVs into mobile energy storage that contributes to grid stability [242]. However, integrating the smart charging system into the existing grid may also bring some challenges to utility companies. Significant investments are necessary to upgrade the electricity grid to handle the surging demand for charging. Dynamic pricing complexity may also bring pressure on utility company management [241,243]. Another challenge for utility companies in the development of the smart charging system is the accurate forecast for the EV charging load and the design of the charging and discharging rate according to it [243]. In addition to the challenges above, cyberattacks on the smart charging system are another serious issue when utility companies consider building this kind of system [244].

Another stakeholder in the development of smart EMS is the EV manufacturer. The motivation of EV manufacturers supporting the development of smart charging systems is to improve consumers' confidence in public charging, which is one key factor affecting EV consumption [242]. However, the effect of battery degradation from the V2X function of the smart charging system needs to be considered [245], as the system may increase the charge and discharge cycles. The increase in charge and discharge cycles may cause a 12 % reduction in the vehicle battery lifetime [246]. This further degradation may result in the increased warranty costs of EV manufacturers [247]. Besides the extra battery degradation issue, AEVs are another challenge for EV manufacturers. With the development of smart charging systems for AEVs, accidents during the period AEVs going to the charging stations are difficult to avoid completely, so the potential liability risks need to be considered by the AEV manufacturers [248].

Considering the EV consumers, the development of the smart charging system needs to take the consumers' travel assurance as a priority goal to enhance the acceptance of the consumers for this kind of supplier-provided charging [249]. Consumers are essential in the development of smart charging systems as they are the end-users, and they may be willing to accept the system because of the potential charging expenditure they can save from the lower charging price and the income for the discharged energy [250,251]. However, similar to EV manufacturers, when consumers are integrated into the smart charging system with their AEVs, there are potential liability and insurance fee increase risks caused by the accidents during the periods AEVs auto-driving to the charging stations [252]. Another potential challenge of integrating EV consumers into this kind of smart charging system with V2X functionality is that the further battery degradation mentioned above [246] may make the EV break the warranty obligation earlier [253].

7. Conclusions

The paper comprehensively reviews the smart energy management system that supports zero-emission and/or autonomous electric vehicles with X2V and V2X functionalities. Although extensive research exists on smart charging energy management for non-AEVs, recent advancements have focused on meeting low-emission and zero-emission requirements and exploring the potential of X2V and V2X technologies. The development of AEVs holds promising prospects for significantly reducing the transportation carbon footprint, especially when coupled with renewable energy sources and intelligent charging systems, which effectively curtail greenhouse gas emissions. Moreover, the emergence of shared AEVs equipped with self-driving capabilities offers numerous advantages, such as enhanced service quality, increased fleet utilisation, and reduced emissions and pollution. Integrating X2V and V2X technologies facilitates bidirectional communication between AEVs and external devices, optimising energy consumption, streamlining charging schedules, and mitigating carbon emissions. In this context, unmanned charging technology proves adaptable to the growing popularity of AEVs, leading to reduced labour costs and improved operational efficiency. This literature review focuses only on the energy management and charging of EVs and does not discuss aspects such as manufacturing and design of EVs. The paper concludes by outlining the future development and challenges of both types of electric vehicles while presenting the existing or referred business models catering to various aspects of smart charging energy management systems. Summarising some key findings, the review identifies significant differences in smart charging energy management systems between non-AEVs vehicles and AEVs with X2V and V2X functionalities, as detailed below.

(1) The progress for the smart charging energy management system of non-AEVs:

Renewable energy management and low-emission or even zero-emission technologies have become significantly matured compared to the smart charging of EVs. Smartly integrating the non-AEVs into these systems can greatly enhance overall performance by fulfilling roles as energy demand, storage, and generation components. When an EV solely charges and discharges within a single energy system, like a home charging setup, it primarily acts as an energy demand and storage unit. However, when it interacts with multiple energy systems, such as charging at home and a public station, it combines energy demand, storage, and generation roles. It is important to note that EVs can also act as energy generators within a specific energy system boundary, transferring energy between different systems. Consequently, depending on the consideration of system boundaries, non-AEVs possess the potential to impact the emission levels of all associated systems. As research on smart EV charging is rapidly evolving, the integration of smart charging facilities into renewable energy systems, whether at home, in communities, or in public charging stations, enables seamless connectivity with all components ("X") within the complex nexus of the energy infrastructure to effectively carry out X2V and V2X functions. While non-AEVs typically have access to less "X" information than AEVs, the design and advancement of supporting energy management systems can enhance information exchange. Depending on the capabilities of the smart charging energy management system and user participation, non-AEVs can optimally utilise their energy flexibility to improve overall system performance, especially during DR and energy resilience periods. As a result, including non-AEVs in smart charging strategies holds immense potential in advancing the efficiency and sustainability of associated energy systems.

(2) The progress for the smart charging energy management system of AEVs:

The emergence of AEVs is poised to reduce the carbon footprint of the transportation industry. Extensive analyses indicate that integrating renewable energy to power AEVs can potentially bridge up to one-third of the gap between the required decarbonisation rate and the annual reduction. This integration also leads to a substantial increase in

renewable energy utilisation within microgrids. SAEVs offer a multitude of benefits, including improved service quality, reduced idling, increased fleet utilisation, and minimised waiting times. Furthermore, AEVs equipped with self-driving capabilities promise to enhance road safety, mobility, and traffic flow, while simultaneously reducing parking needs, the number of vehicles on the road, CO_2 emissions, and pollution. In this way, the future of AEVs appears promising, particularly in meeting low-emission and zero-emission requirements.

In the smart charging energy management system of AEVs, X2V and V2X technologies play crucial roles. X2V enables seamless bidirectional communication between AEVs and the power grid or external devices, while V2X facilitates communication between vehicles and its surrounding environment or infrastructure. These technologies empower efficient utilisation of energy resources, enabling optimised charging schedules and reduced impacts on the grid and carbon emissions. By implementing X2V and V2X technologies alongside appropriate control strategies, the performance of the smart charging energy management system of AEVs can be significantly enhanced. A wide array of approaches, including optimisation models, machine learning algorithms, and control theory, can be employed to develop efficient and effective control strategies. AEVs can also contribute to V2G, allowing them to give feedback to the grid during high-demand periods. While no charging technology is exclusive to AEVs, the existing development of unmanned charging technology has been adapted to accommodate the growing popularity of AEVs. Intelligent charging systems have the potential to reduce manpower requirements and fully automate operations, thereby lowering labour costs and boosting the overall operational efficiency of charging stations. The successful integration of these technologies and strategies holds the key to realising the full potential of AEVs in driving a sustainable and eco-friendly transportation landscape.

(3) The summarised key differences of smart charging energy management systems between the non-AEVs and AEVs:

The primary distinction between these two kinds of EVs lies in their communication capabilities. The advanced sensors and communication systems allow AEVs to interact with other X2V and V2X technologies within the transportation system, while non-AEVs are limited. The real-time communication of AEVs with other vehicles, the cloud, infrastructure, and the grid enables more efficient energy resource utilisation, optimised charging schedules, and load-balancing services. Non-AEVs may not fully capitalise on real-time communication due to human decision-making or limited EMS, potentially leading to less efficient energy resource utilisation. The bidirectional interaction of vehicles with X2V and V2X functions, integrated with all the relevant "X" systems, mutually enhances the performance of connected systems. To achieve zero tailpipe emissions, the smart charging process caters to renewable energy targets, low-emissive, zero-emissive, or positive-emissive. While grid electricity may sometimes charge EVs, smart discharging (V2X) enables them to attain net-zero targets as individual energy systems. The limitations of non-AEVs regarding smart charging may be evident during fluctuating energy prices due to their limited communication capabilities. In contrast, AEVs equipped with X2V and V2X technologies can communicate in real-time with renewable energy generation data and other vehicles, thus providing more opportunities to reduce the overall carbon footprint of the transport sector and promote the adoption of renewable energy in urban development. Due to their ability to be designed for efficient charging and discharging, providing high energy flexibility and resilience, AEVs enjoy more freedom in choosing times, locations, and methods for charging. Non-AEVs, however, may require external smart EMS or active human involvement to achieve the same level of flexibility. Emphasising the benefits of real-time communication and integration with X2V and V2X technologies, AEVs emerge as a pivotal component in driving sustainable and eco-friendly transportation solutions while offering greater operational freedom and efficiency.

(4) Future development and challenges:

Through a comprehensive literature review and in-depth discussion, it is evident that both non-AEVs and AEVs with X2V and V2X functions present opportunities to enhance energy flexibility and offer benefits to EV owners, grids, traffic reduction, and renewable energy penetration when integrated with suitable energy management systems and control strategies. However, several crucial aspects still require careful consideration to maximise benefits and mitigate potential negative impacts.

Firstly, achieving an optimal balance between renewable energy penetrations and the scale of EV adoption is essential. As EVs become increasingly widespread and profitable, ensuring a corresponding increase in renewable energy penetrations to transform EVs into zero-emission vehicles is imperative. Nonetheless, the amount of renewable energy required to support electric vehicles may vary over time due to the technological development of automated driving, which can influence urban traffic patterns and energy efficiency. To address this dynamic landscape, a time-dependent or technology-dependent renewable energy penetration scheme should be developed to better align with these changing phenomena.

Secondly, a feasible and time-dependent energy management strategy is devised to optimise the ratio of renewable energy used to charge electric vehicles while accounting for the transition from non-AEVs to AEVs. The evolving technologies in autonomous vehicles promise higher vehicle mobility and shared information. However, efficiently utilising these advantages in diverse cities with varying self-driving automation levels poses a considerable challenge.

Thirdly, the efficient use and arrangement of charging facilities demand require careful attention. For non-AEVs, charging facilities may not be optimally utilised, as charging decisions are made individually by EV owners. This condition hampers charging arrangements in light of public charging resources and local renewable generation. In the future, for AEVs, fully automated self-driving scenarios will necessitate fully automated charging facilities, which may result in high initial investment costs for charging stations.

Fourthly, refining business models is crucial to incentivise charging with renewable energy for both non-autonomous and autonomous vehicles. Existing business models often lack mechanisms to encourage EVs to absorb surplus energy from local renewable generation. Developing innovative business models that address this issue can help accelerate the adoption of zero-emission and/or autonomous electric vehicles, further advancing our progress toward the carbon neutrality goal.

Fifthly, blockchain technology is to be developed with the smart energy management system of electric vehicles, achieving security, transparency, and privacy enhancement. Pricing strategies are to be designed to motivate data sharing. The increasing number of electric vehicles and limited resources of public charging stations add difficulties and complexity in incentivising energy sharing between vehicles and energy storage systems.

Sixthly, artificial intelligence for predictive maintenance is to be investigated for the operation of non-AEVs and AEVs. Preparing the data for model training and prediction accuracy can be the key concerns of the combination of this technology and energy management system design for electric vehicles. The diversity of the associated supporting equipment for AEVs will increase and add to the difficulty in maintaining suitable artificial intelligence models.

Seventhly, the technology of internet of things is essential to the AEVs, as it provides the real-time communication of associated devices. The challenges of the combination of internet of things and energy management of electric vehicles include data processing in a limited time to support real-time decision-making, interference of wireless communication, and the assurance of security and privacy.

By handling these challenges in the future, zero-emission and/or autonomous electric vehicles can be used correctly and accelerate the pace to achieve carbon neutrality. Non-AEVs and AEVs with X2V and

V2X functions have shown a promising potential to improve energy flexibility and benefit EV owners, grids, and traffic and renewable energy penetration under suitable energy management systems and control strategies.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgement

This research is supported by the Project PSRI/22/2111/PR from the Smart Traffic Fund, Hong Kong SAR.

Data availability

Data will be made available on request.

References

[1] Pudasainee D, Kurian V, Gupta R. Coal: past, present, and future sustainable use. In: Letcher TM, editor. Future energy. Elsevier; 2020. p. 21–48.
[2] United Nations Framework Convention on Climate Change. "The Paris Agreement." https://unfccc.int/process-and-meetings/the-paris-agreement.
[3] Kang J, Ng TS, Su B, Milovanoff A. Electrifying light-duty passenger transport for CO2 emissions reduction: a stochastic-robust input–output linear programming model. Energy Econ 2021;104:105623. https://doi.org/10.1016/j.eneco.2021.105623.
[4] Hua Y, Dong F. How can new energy vehicles become qualified relays from the perspective of carbon neutralization? Literature review and research prospect based on the CiteSpace knowledge map. Environ Sci Pollut Res Int 2022;29(37): 55473–91. https://doi.org/10.1007/s11356-022-21096-y.
[5] Roca-Puigròs M, Marmy C, Wäger P, Beat Müller D. Modeling the transition toward a zero emission car fleet: integrating electrification, shared mobility, and automation. Transport Res Transport Environ 2023;115:103576. https://doi.org/10.1016/j.trd.2022.103576.
[6] Pearre NS, Ribberink H. Review of research on V2X technologies, strategies, and operations. Renew Sustain Energy Rev 2019;105:61–70. https://doi.org/10.1016/j.rser.2019.01.047.
[7] Hussain MT, Sulaiman DNB, Hussain MS, Jabir M. Optimal Management strategies to solve issues of grid having Electric Vehicles (EV): a review. J Energy Storage 2021;33. https://doi.org/10.1016/j.est.2020.102114.
[8] Hoarau Q, Perez Y. Interactions between electric mobility and photovoltaic generation: a review. Renew Sustain Energy Rev 2018;94:510–22. https://doi.org/10.1016/j.rser.2018.06.039.
[9] Babayomi O, Zhang Z, Dragicevic T, Hu J, Rodriguez J. Smart grid evolution: predictive control of distributed energy resources—a review. Int J Electr Power Energy Syst 2023;147. https://doi.org/10.1016/j.ijepes.2022.108812.
[10] Kopelias P, Demiridi E, Vogiatzis K, Skabardonis A, Zafiropoulou V. Connected & autonomous vehicles - environmental impacts - a review. Sci Total Environ 2020; 712:135237. https://doi.org/10.1016/j.scitotenv.2019.135237.
[11] Massar M, Reza I, Rahman SM, Abdullah SMH, Jamal A, Al-Ismail FS. Impacts of autonomous vehicles on greenhouse gas emissions-positive or negative? Int J Environ Res Public Health 2021;18(11):5567. https://doi.org/10.3390/ijerph18115567.
[12] Guo Q, Nojavan S, Lei S, Liang X. Economic-environmental analysis of renewable-based microgrid under a CVaR-based two-stage stochastic model with efficient integration of plug-in electric vehicle and demand response. Sustain Cities Soc 2021;75. https://doi.org/10.1016/j.scs.2021.103276.
[13] Huang P, et al. Transforming a residential building cluster into electricity prosumers in Sweden: optimal design of a coupled PV-heat pump-thermal storage-electric vehicle system. Appl Energy 2019;255. https://doi.org/10.1016/j.apenergy.2019.113864.
[14] Kumar GMS, Cao S. Conversion of metro railway into smart charging zero-emission transportation hub for supporting electric train, shuttle bus, cars and public EV charging station. Energy Convers Manag X 2024;22. https://doi.org/10.1016/j.ecmx.2024.100552.
[15] Mozafar MR, Moradi MH, Amini MH. A simultaneous approach for optimal allocation of renewable energy sources and electric vehicle charging stations in smart grids based on improved GA-PSO algorithm. Sustain Cities Soc 2017;32: 627–37. https://doi.org/10.1016/j.scs.2017.05.007.
[16] Yu Z, Lu F, Zou Y, Yang X. Quantifying energy flexibility of commuter plug-in electric vehicles within a residence–office coupling virtual microgrid. Part I: system configuration, quantification framework, and optimization model. Energy Build 2022;254. https://doi.org/10.1016/j.enbuild.2021.111551.
[17] Sivasankari GS, Narayanan K. Demand response approach in the presence of plug-in hybrid electric vehicle for profit maximization of utility. Energy Convers Manag X 2022;15. https://doi.org/10.1016/j.ecmx.2022.100263.
[18] Mehrjerdi H, Hemmati R. Coordination of vehicle-to-home and renewable capacity resources for energy management in resilience and self-healing building. Renew Energy 2020;146:568–79. https://doi.org/10.1016/j.renene.2019.07.004.
[19] Tang H, Wang S, Li H. Flexibility categorization, sources, capabilities and technologies for energy-flexible and grid-responsive buildings: state-of-the-art and future perspective. Energy 2021;219. https://doi.org/10.1016/j.energy.2020.119598.
[20] Kumar GMS, Cao S. Leveraging energy flexibilities for enhancing the cost-effectiveness and grid-responsiveness of net-zero-energy metro railway and station systems. Appl Energy 2023;333. https://doi.org/10.1016/j.apenergy.2022.120632.
[21] Kumar GMS, Cao S. The positive and negative impact of novel utility demand response programme and stochastic utility-driven events on renewable penetration and flexibility activation of train and station systems. Sustainable Energy, Grids and Networks 2024;37. https://doi.org/10.1016/j.segan.2023.101258.
[22] Erdinç FG, Çiçek A, Erdinç O, Yumurtacı R, Oskouei MZ, Mohammadi-Ivatloo B. Decision-making framework for power system with RES including responsive demand, ESSs, EV aggregator and dynamic line rating as multiple flexibility resources. Elec Power Syst Res 2022;204. https://doi.org/10.1016/j.epsr.2021.107702.
[23] Adnan Yusuf S, Khan A, Souissi R. Vehicle-to-everything (V2X) in the autonomous vehicles domain – a technical review of communication, sensor, and AI technologies for road user safety. Transp Res Interdiscip Perspect 2024;23. https://doi.org/10.1016/j.trip.2023.100980.
[24] Li Y, Senthil Kumar GM, Cao S, Wang S. Electric vehicle-based distant energy sharing between zero-emission coastal office and hotel buildings. J Build Eng 2024;90:109496. https://doi.org/10.1016/j.jobe.2024.109496.
[25] Olayode IO, Du B, Severino A, Campisi T, Alex FJ. Systematic literature review on the applications, impacts, and public perceptions of autonomous vehicles in road transportation system. J Traffic Transport Eng 2023;10(6):1037–60. https://doi.org/10.1016/j.jtte.2023.07.006.
[26] Moeini-Aghtaie M, Dehghanian P, Davoudi M. Energy management of plug-in hybrid electric vehicles in renewable-based energy hubs. Sustainable Energy, Grids and Networks 2022;32. https://doi.org/10.1016/j.segan.2022.100932.
[27] Luh S, Kannan R, McKenna R, Schmidt TJ, Kober T. How, where, and when to charge electric vehicles – net-zero energy system implications and policy recommendations. Environmental Research Communications 2023;5(9). https://doi.org/10.1088/2515-7620/acf363.
[28] Ray P, Bhattacharjee C, Dhenuvakonda KR. Swarm intelligence-based energy management of electric vehicle charging station integrated with renewable energy sources. Int J Energy Res 2021;46(15):21598–618. https://doi.org/10.1002/er.7601.
[29] Afentoulis KD, Bampos ZN, Vagropoulos SI, Keranidis SD, Biskas PN. Smart charging business model framework for electric vehicle aggregators. Appl Energy 2022;328. https://doi.org/10.1016/j.apenergy.2022.120179.
[30] Zhou S, Cao S. Energy flexibility and viability enhancement for an ocean-energy-supported zero-emission office building with respect to both existing and advanced utility business models with dynamic responsive incentives. Energy Rep 2022;8:10244–71. https://doi.org/10.1016/j.egyr.2022.08.005.
[31] Ray P. Optimal charge scheduling of EVs using aggregator based charge controller with active power support to the grid. In: 2021 IEEE 18th India council international conference (INDICON); Dec. 19-21, 2021. p. 1–6. https://doi.org/10.1109/INDICON52576.2021.9691560.
[32] Barman P, et al. Renewable energy integration with electric vehicle technology: a review of the existing smart charging approaches. Renew Sustain Energy Rev 2023;183. https://doi.org/10.1016/j.rser.2023.113518.
[33] Li M, Wang Y, Peng P, Chen Z. Toward efficient smart management: a review of modeling and optimization approaches in electric vehicle-transportation network-grid integration. Green energy and intelligent transportation. 2024. https://doi.org/10.1016/j.geits.2024.100181.
[34] Teimoori Z, Yassine A. A review on intelligent energy management systems for future electric vehicle transportation. Sustainability 2022;14(21). https://doi.org/10.3390/su142114100.
[35] Barman P, Dutta L. Charging infrastructure planning for transportation electrification in India: a review. Renew Sustain Energy Rev 2024;192:114265. https://doi.org/10.1016/j.rser.2023.114265.
[36] Obu Showers S, Kamoru Raji A. State-of-the-art review of fuel cell hybrid electric vehicle energy management systems. AIMS Energy 2022;10(3):458–85. https://doi.org/10.3934/energy.2022023.
[37] Virtusa. "What are Autonomous Electric Vehicles?" https://www.virtusa.com/digital-themes/autonomous-electric-vehicles.
[38] Virta. "Smart Charging of Electric Vehicles." https://www.virta.global/smart-charging?_hstc=51530422.6ef88e51f5e2e9ad035168fb32baf7c0.1679280256348.1679280256348.1679292094254.2&_hssc=51530422.1.1679292094254&_hsfp=3115281473&hsutk=6ef88e51f5e2e9ad035168fb32baf7c0&contentType=standard-page#two.
[39] NREL. "Electric Vehicle Smart Charging at Scale." https://www.nrel.gov/transportation/managed-electric-vehicle-charging.html.
[40] Energy saving trust. "Smart charging for electric vehicles." https://energysavingtrust.org.uk/advice/smart-charging-electric-vehicles/.

[41] Sachan S, Deb S, Singh SN. Different charging infrastructures along with smart charging strategies for electric vehicles. Sustain Cities Soc 2020;60:102238. https://doi.org/10.1016/j.scs.2020.102238.
[42] Crozier C, Morstyn T, McCulloch M. The opportunity for smart charging to mitigate the impact of electric vehicles on transmission and distribution systems. Appl Energy 2020;268:114973. https://doi.org/10.1016/j.apenergy.2020.114973.
[43] Nour M, Said SM, Ali A, Farkas C. Smart charging of electric vehicles according to electricity price. In: 2019 international conference on innovative trends in computer engineering (ITCE); Feb. 2-4, 2019. p. 432–7. https://doi.org/10.1109/ITCE.2019.8646425.
[44] R. Fachrizal and J. Munkhammar, "Improved photovoltaic self-consumption in residential buildings with distributed and centralized smart charging of electric vehicles," Energies, vol. 13, no. 5, doi: 10.3390/en13051153.
[45] Okwuibe GC, Li Z, Brenner T, Langniss O. A blockchain based electric vehicle smart charging system with Flexibility**This project is sponsored by oli systems GmbH, stuttgart. IFAC-PapersOnLine 2020;53(2):13557–61. https://doi.org/10.1016/j.ifacol.2020.12.800.
[46] Kumar GMS, Cao S. Simulation-based techno-economic feasibility study on sector coupled net-zero/positive energy metro railway system in Hong Kong. Energy Convers Manag 2021;248:114786. https://doi.org/10.1016/j.enconman.2021.114786.
[47] Zhou Y, Cao S, Hensen JLM. An energy paradigm transition framework from negative towards positive district energy sharing networks—battery cycling aging, advanced battery management strategies, flexible vehicles-to-buildings interactions, uncertainty and sensitivity analysis. Appl Energy 2021;288. https://doi.org/10.1016/j.apenergy.2021.116606.
[48] Logan KG, Nelson JD, Brand C, Hastings A. Phasing in electric vehicles: does policy focusing on operating emission achieve net zero emissions reduction objectives? Transport Res Pol Pract 2021;152:100–14. https://doi.org/10.1016/j.tra.2021.08.001.
[49] Kumar GMS, Cao S. State-of-the-Art review of positive energy building and community systems. Energies 2021;14(16). https://doi.org/10.3390/en14165046.
[50] Guo X, Cao S, Xu Y, Zhu X. The feasibility of using zero-emission electric boats to enhance the techno-economic performance of an ocean-energy-supported coastal hotel building. Energies 2021;14(24). https://doi.org/10.3390/en14248465.
[51] Rifat Boynuegri A, Tekgun B. Real-time energy management in an off-grid smart home: flexible demand side control with electric vehicle and green hydrogen production. Int J Hydrogen Energy 2023. https://doi.org/10.1016/j.ijhydene.2023.01.239.
[52] Shafaati Shemami M, Saad Alam M, Asghar MSJ. Fuzzy control assisted vehicle-to-home (V2H) energy management system. Smart Science 2017;6(2):173–87. https://doi.org/10.1080/23080477.2017.1417963.
[53] García-Muñoz F, Díaz-González F, Corchero C. A two-stage stochastic programming model for the sizing and location of DERs considering electric vehicles and demand response. Sustainable Energy, Grids and Networks 2022;30. https://doi.org/10.1016/j.segan.2022.100624.
[54] Chakir A, Abid M, Tabaa M, Hachimi H. Demand-side management strategy in a smart home using electric vehicle and hybrid renewable energy system. Energy Rep 2022;8:383–93. https://doi.org/10.1016/j.egyr.2022.07.018.
[55] Moore EA, Russell JD, Babbitt CW, Tomaszewski B, Clark SS. Spatial modeling of a second-use strategy for electric vehicle batteries to improve disaster resilience and circular economy. Resour Conserv Recycl 2020;160. https://doi.org/10.1016/j.resconrec.2020.104889.
[56] Barone G, Buonomano A, Calise F, Forzano C, Palombo A. Building to vehicle to building concept toward a novel zero energy paradigm: modelling and case studies. Renew Sustain Energy Rev 2019;101:625–48. https://doi.org/10.1016/j.rser.2018.11.003.
[57] Buonomano A. Building to Vehicle to Building concept: a comprehensive parametric and sensitivity analysis for decision making aims. Appl Energy 2020;261. https://doi.org/10.1016/j.apenergy.2019.114077.
[58] Beheshtikhoo A, Pourgholi M, Khazaee I. Design of type-2 fuzzy logic controller in a smart home energy management system with a combination of renewable energy and an electric vehicle. J Build Eng 2023. https://doi.org/10.1016/j.jobe.2023.106097.
[59] Huang P, et al. Investigation of electric vehicle smart charging characteristics on the power regulation performance in solar powered building communities and battery degradation in Sweden. J Energy Storage 2022;56. https://doi.org/10.1016/j.est.2022.105907.
[60] Boddapati V, Rakesh Kumar A, Arul Daniel S, Padmanaban S. Design and prospective assessment of a hybrid energy-based electric vehicle charging station. Sustain Energy Technol Assessments 2022;53. https://doi.org/10.1016/j.seta.2022.102389.
[61] Chacko PJ, Sachidanandam M. An optimized energy management system for vehicle to vehicle power transfer using micro grid charging station integrated Gridable Electric Vehicles. Sustainable Energy, Grids and Networks 2021;26. https://doi.org/10.1016/j.segan.2021.100474.
[62] Sharifi P, Banerjee A, Feizollahi MJ. Leveraging owners' flexibility in smart charge/discharge scheduling of electric vehicles to support renewable energy integration. Comput Ind Eng 2020;149. https://doi.org/10.1016/j.cie.2020.106762.
[63] Bertolini A, Martins MSE, Vieira SM, Sousa JMC. Power output optimization of electric vehicles smart charging hubs using deep reinforcement learning. Expert Syst Appl 2022;201. https://doi.org/10.1016/j.eswa.2022.116995.
[64] shafiei M, Ghasemi-Marzbali A. Electric vehicle fast charging station design by considering probabilistic model of renewable energy source and demand response. Energy 2023;267. https://doi.org/10.1016/j.energy.2022.126545.
[65] Zhou Y, Cao S. Energy flexibility investigation of advanced grid-responsive energy control strategies with the static battery and electric vehicles: a case study of a high-rise office building in Hong Kong. Energy Convers Manag 2019;199. https://doi.org/10.1016/j.enconman.2019.111888.
[66] Gong L, Cao W, Liu K, Yu Y, Zhao J. Demand responsive charging strategy of electric vehicles to mitigate the volatility of renewable energy sources. Renew Energy 2020;156:665–76. https://doi.org/10.1016/j.renene.2020.04.061.
[67] 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. https://doi.org/10.1016/j.est.2022.105241.
[68] Shojaei S, Beiza J, Abedinzadeh T, Alipour H. Optimal energy and reserve management of a smart microgrid incorporating parking lot of electric vehicles/renewable sources/responsive-loads considering uncertain parameters. J Energy Storage 2022;55. https://doi.org/10.1016/j.est.2022.105540.
[69] İnci M, Savrun MM, Çelik Ö. Integrating electric vehicles as virtual power plants: a comprehensive review on vehicle-to-grid (V2G) concepts, interface topologies, marketing and future prospects. J Energy Storage 2022;55:105579. https://doi.org/10.1016/j.est.2022.105579.
[70] Das R, et al. Multi-objective techno-economic-environmental optimisation of electric vehicle for energy services. Appl Energy 2020;257:113965. https://doi.org/10.1016/j.apenergy.2019.113965.
[71] Sharifi P, Banerjee A, Feizollahi MJ. Leveraging owners' flexibility in smart charge/discharge scheduling of electric vehicles to support renewable energy integration. Comput Ind Eng 2020;149:106762. https://doi.org/10.1016/j.cie.2020.106762.
[72] Kumar GMS, Cao S. Conversion of metro railway into smart charging zero-emission transportation hub for supporting electric train, shuttle bus, cars and public EV charging station. Energy Convers Manag X 2024;22:100552. https://doi.org/10.1016/j.ecmx.2024.100552.
[73] Huang P, Zhang L. Electric vehicle smart charging characteristics on the power regulation abilities. In: Zhang X, Huang P, Sun Y, editors. Future urban energy system for buildings: the pathway towards flexibility, resilience and optimization. Singapore: Springer Nature Singapore; 2023. p. 171–86.
[74] Mou X, Zhao R, Gladwin DT. Vehicle-to-Vehicle charging system fundamental and design comparison. Presented at the 2019 IEEE international conference on industrial technology (ICIT). 2019.
[75] Cao S. The impact of electric vehicles and mobile boundary expansions on the realization of zero-emission office buildings. Appl Energy 2019. https://doi.org/10.1016/j.apenergy.2019.113347.
[76] Barman P, et al. Renewable energy integration with electric vehicle technology: a review of the existing smart charging approaches. Renew Sustain Energy Rev 2023;183:113518. https://doi.org/10.1016/j.rser.2023.113518.
[77] Zhang G, Dai M, Zhao S, Zhu X. Orderly automatic real-time charging scheduling scenario strategy for electric vehicles considering renewable energy consumption. Energy Rep 2023;9:72–84. https://doi.org/10.1016/j.egyr.2022.11.164.
[78] Liu S, Cao Y, Ni Q, Xu L, Zhu Y, Zhang X. Towards reservation-based E-mobility service via hybrid of V2V and G2V charging modes. Energy 2023;268. https://doi.org/10.1016/j.energy.2023.126737.
[79] Li Z, Shang Y, Lei X, Shao Z, Jia Y, Jian L. An accessible close-loop V2V charging mechanism under charging station with non-cooperative game. Energy Rep 2022;8:1038–44. https://doi.org/10.1016/j.egyr.2022.08.129.
[80] Roudbari A, Nateghi A, Yousefi-khanghah B, Asgharpour-Alamdari H, Zare H. Resilience-oriented operation of smart grids by rescheduling of energy resources and electric vehicles management during extreme weather condition. Sustainable Energy, Grids and Networks 2021;28. https://doi.org/10.1016/j.segan.2021.100547.
[81] Alabi TM, Lu L, Yang Z. Improved hybrid inexact optimal scheduling of virtual powerplant (VPP) for zero-carbon multi-energy system (ZCMES) incorporating Electric Vehicle (EV) multi-flexible approach. J Clean Prod 2021;326. https://doi.org/10.1016/j.jclepro.2021.129294.
[82] Tang H, Wang S. A model-based predictive dispatch strategy for unlocking and optimizing the building energy flexibilities of multiple resources in electricity markets of multiple services. Appl Energy 2022;305. https://doi.org/10.1016/j.apenergy.2021.117889.
[83] Trinko D, Horesh N, Porter E, Dunckley J, Miller E, Bradley T. Transportation and electricity systems integration via electric vehicle charging-as-a-service: a review of techno-economic and societal benefits. Renew Sustain Energy Rev 2023;175:113180. https://doi.org/10.1016/j.rser.2023.113180.
[84] Wu W, Lin Y, Liu R, Li Y, Zhang Y, Ma C. Online EV charge scheduling based on time-of-use pricing and peak load minimization: properties and efficient algorithms. IEEE Trans Intell Transport Syst 2022;23(1):572–86. https://doi.org/10.1109/TITS.2020.3014088.
[85] Zheng S, Huang G, Lai ACK. Coordinated energy management for commercial prosumers integrated with distributed stationary storages and EV fleets. Energy Build 2023;282:112773. https://doi.org/10.1016/j.enbuild.2023.112773.
[86] Daneshzand F, Coker PJ, Potter B, Smith ST. EV smart charging: how tariff selection influences grid stress and carbon reduction. Appl Energy 2023;348:121482. https://doi.org/10.1016/j.apenergy.2023.121482.
[87] Wu Y, Aziz SM, Haque MH. Techno-economic modelling for energy cost minimisation of a university campus to support electric vehicle charging with photovoltaic capacity optimisation. Renew Energy 2023;219:119427. https://doi.org/10.1016/j.renene.2023.119427.

[88] Song A, Zhou Y. A hierarchical control with thermal and electrical synergies on battery cycling ageing and energy flexibility in a multi-energy sharing network. Renew Energy 2023;212:1020–37. https://doi.org/10.1016/j.renene.2023.05.050.
[89] Khalid M, Thakur J, Mothilal Bhagavathy S, Topel M. Impact of public and residential smart EV charging on distribution power grid equipped with storage. Sustain Cities Soc 2024;104:105272. https://doi.org/10.1016/j.scs.2024.105272.
[90] He Z, Khazaei J, Freihaut JD. Optimal integration of vehicle to building (V2B) and building to vehicle (B2V) technologies for commercial buildings. Sustainable Energy, Grids and Networks 2022;32:100921. https://doi.org/10.1016/j.segan.2022.100921.
[91] Zhang L, Sun C, Cai G, Koh LH. Charging and discharging optimization strategy for electric vehicles considering elasticity demand response. eTransportation 2023;18:100262. https://doi.org/10.1016/j.etran.2023.100262.
[92] Xia X, Li P. A review of the life cycle assessment of electric vehicles: considering the influence of batteries. Sci Total Environ 2022;814:152870. https://doi.org/10.1016/j.scitotenv.2021.152870.
[93] Chargepoint. "It's Easy to Charge Wherever You Go." https://www.chargepoint.com/drivers?_gl=1*1k8b0xw*_up*MQ.*_ga*MTM3NzAyODkxNC4xNjgzMzgzMzQw*_ga_R8LZDKZJ1W*MTY4MzM4MzMzOS4xLjAuMTY4MzM4MzMzOS4wLjAuMA.
[94] Chen T, et al. A review on electric vehicle charging infrastructure development in the UK. Journal of Modern Power Systems and Clean Energy 2020;8(2):193–205. https://doi.org/10.35833/MPCE.2018.000374.
[95] CLP. "CLP Power Extends Free Charging Service to Encourage Green Motoring." https://services.clp.com.hk/ev/en/article.html?itemid=6ca84e74-f38b-41ea-a2a3-f97bbe65c5d6.
[96] InsideEVs. "Public EV Charging Is Often Free: Observations From ChargePoint." https://insideevs.com/news/342506/public-ev-charging-is-often-free-observations-from-chargepoint/.
[97] Visitbeijing. "How do I charge for charging on public charging piles? State Grid Beijing Electric Power Company authoritative answer." https://www.visitbeijing.com.cn/article/47QriiQKCg4.
[98] Tesla. https://www.tesla.com/en_hk.
[99] libertyinsurance. "Guide to Charging Your Tesla in Hong Kong." https://www.libertyinsurance.com.hk/insuremytesla/blogpost04/Guide-to-Charging-Your-Tesla-in-HK.
[100] leafscore. "How Much Does it Cost to Charge a Tesla in 2023?" https://www.leafscore.com/tesla/how-much-does-it-cost-to-charge-a-tesla/.
[101] SmartCharge. "Charge Your Car at Home!" https://www.smartcharge.com.hk/eng/index.html.
[102] Shell Recharge. "Shell Recharge For Electric Vehicle." https://www.shell.com.hk/en_hk/motorists/shell-recharge.html#iframe=L2Zvcm1zL3NoZWxsX3JlY2hhcmdlX2Zhc3RfY2hhcmdpbmdfc2l0ZQ.
[103] HK Electric. "EV Charging." https://www.hkelectric.com/en/smart-power/ev-charging.
[104] CEM. "Charging in Public or at Home." https://ev.cem-macau.com/en/ChargeAtHomeOrPublic.
[105] Recharge. "Recharge Prices." https://rechargeinfra.com/sv/prices/.
[106] Eonenergy. "The cost of charging an electric car." https://www.eonenergy.com/electric-vehicle-charging/running-costs-and-benefits.html.
[107] Eonenergy. "Park and charge with EasyPark." https://www.eon.dk/in-english/easypark.html.
[108] EnBW. "EnBW makes electromobility easier: New tariff based solely on energy consumed, now available on the largest charging network." https://www.enbw.com/company/investors/news-and-publications/enbw-makes-electromobility-easier-new-tariff-based-solely-on-ene.html.
[109] Fortum. "About Charging an EV." https://www.fortum.com/about-charging-ev.
[110] Fortum. "Pricing list and Terms & Conditions." https://www.fortum.in/list-price-terms.
[111] Elli. "Charge anywhere with Elli." https://www.elli.eco/en/b2c/products/tariffs.
[112] BritishGas. "Electric vehicle (EV) tariffs." https://www.britishgas.co.uk/energy/ev-tariff-home.html.
[113] Octopus. "Get the whole EV package from Octopus." https://octopusev.com/.
[114] EDF. "Everything electric cars." https://www.edfenergy.com/electric-cars.
[115] Clever. "Find your charging solution." https://clever.dk/opladning-uden-abonnement.
[116] Helen. "Electric vehicle charging network." https://www.helen.fi/en/electric-cars/charging-network.
[117] Virta. "Powered By Virta Network - Easy & Everywhere." https://www.virta.global/ev-drivers#:~:text=Virta's%20charging%20service%20has%20a,is%20less%20than%20one%20euro.&text=At%20registration%2C%20you'll%20add,according%20to%20your%20charging%20spending.
[118] Allego. "Introducing new charging tariffs on October 7, 2022." https://www.allego.eu/news/2022/september/new-charging-tariffs-october-2022.
[119] CHAdeMO. "CHAdeMO fast charging for EVs." https://www.chademo.com/#map.
[120] Audi. "Pricelist Audi." https://e-tron.charging-service.audi/o/dcs-api/customer/GB/tariffs/pdf?locale=en_GB.
[121] Audi. "Your tariff to access charge points across Japan." https://e-tron.charging-service.audi/web/en/audi-jp/tariffs.
[122] EVgo. "Discover Pricing on the Go." https://www.evgo.com/pricing/.
[123] Korea Economic Daily. "SK Energy teams up with state-run power supplier for EV charging station." https://www.kedglobal.com/electric-vehicles/newsView/ked202301130015.
[124] InvestKorea. "KEPCO to launch some 1,500 EV charging stations across the country." https://www.investkorea.org/ik-en/bbs/i-465/detail.do?ntt_sn=470615.
[125] Hyundai Motorstudio. "2 List of Rates and Charges for Electric Cars." https://hyundai.motorstudio.co.id/senayan-park/newsrooms/rates-and-charges-for-electric-cars.
[126] Afentoulis KD, Bampos ZN, Vagropoulos SI, Keranidis SD, Biskas PN. Smart charging business model framework for electric vehicle aggregators. Appl Energy 2022;328:120179. https://doi.org/10.1016/j.apenergy.2022.120179.
[127] Knirsch F, Unterweger A, Engel D. Privacy-preserving blockchain-based electric vehicle charging with dynamic tariff decisions. Comput Sci Res Dev 2018;33(1):71–9. https://doi.org/10.1007/s00450-017-0348-5.
[128] M. von Bonin, E. Dörre, H. Al-Khzouz, M. Braun, and X. Zhou, "Impact of dynamic electricity tariff and home PV system incentives on electric vehicle charging behavior: study on potential grid implications and economic effects for households," Energies, vol. 15, no. 3, doi: 10.3390/en15031079.
[129] M. Pasetti, S. Rinaldi, A. Flammini, M. Longo, and F. Foiadelli, "Assessment of electric vehicle charging costs in presence of distributed photovoltaic generation and variable electricity tariffs," Energies, vol. 12, no. 3, doi: 10.3390/en12030499.
[130] Baumgartner N, Kellerer F, Ruppert M, Hirsch S, Mang S, Fichtner W. Does experience matter? Assessing user motivations to accept a vehicle-to-grid charging tariff. Transport Res Transport Environ 2022;113:103528. https://doi.org/10.1016/j.trd.2022.103528.
[131] Rancilio G, Bovera F, Delfanti M. Tariff-based regulatory sandboxes for EV smart charging: impacts on the tariff and the power system in a national framework. Int J Energy Res 2022;46(11):14794–813. https://doi.org/10.1002/er.8183. 10.1002/er.8183.
[132] Belgiawan PF, Dharmowijoyo DBE, Novizayanti D, Farda M, Prasetio EA, Dirgahayani P. Does range or fiscal policies matter on EV adoption in Jakarta Metropolitan Area? Transp Res Interdiscip Perspect 2024;23:101027. https://doi.org/10.1016/j.trip.2024.101027.
[133] Peng Y, Bai X. What EV users say about policy efficacy: evidence from Shanghai. Transport Pol 2023;132:16–26. https://doi.org/10.1016/j.tranpol.2022.12.016.
[134] Mekky MF, Collins AR. The Impact of state policies on electric vehicle adoption -A panel data analysis. Renew Sustain Energy Rev 2024;191:114014. https://doi.org/10.1016/j.rser.2023.114014.
[135] Vidyattama Y, Tanton R, Sinclair D, Schirmer J. Simulating electric vehicle policy in the Australian capital territory. Transport Pol 2024;149:91–9. https://doi.org/10.1016/j.tranpol.2024.01.018.
[136] Mouhy-Ud-Din MA, Azeem F, Memon Z, Arshad J. Comparative techno-economic assessment of electric vehicle charging preferences: a quantitative study for sustainable EV policy in Pakistan. Energy for Sustainable Development 2024;78:101355. https://doi.org/10.1016/j.esd.2023.101355.
[137] Ledna C, Muratori M, Brooker A, Wood E, Greene D. How to support EV adoption: tradeoffs between charging infrastructure investments and vehicle subsidies in California. Energy Pol 2022;165:112931. https://doi.org/10.1016/j.enpol.2022.112931.
[138] Afzal M, et al. Role of blockchain technology in transactive energy market: a review. Sustain Energy Technol Assessments 2022;53. https://doi.org/10.1016/j.seta.2022.102646.
[139] Kumari A, Patel MM, Shukla A, Tanwar S, Kumar N, Rodrigues JJPC. ArMor: a data analytics scheme to identify malicious behaviors on blockchain-based smart grid system. In: GLOBECOM 2020 - 2020 IEEE global communications conference; Dec. 7-11, 2020. p. 1–6. https://doi.org/10.1109/GLOBECOM42002.2020.9348061.
[140] Ersöz OÖ, İnal AF, Aktepe A, Türker AK, Ersöz S. A systematic literature review of the predictive maintenance from transportation systems aspect. Sustainability 2022;14(21). https://doi.org/10.3390/su142114536.
[141] Alkawsi G, Baashar Y, Abbas U D, Alkahtani AA, Tiong SK. Review of renewable energy-based charging infrastructure for electric vehicles. Appl Sci 2021;11(9). https://doi.org/10.3390/app11093847.
[142] A. Kumari et al., "Blockchain-based peer-to-peer transactive energy management scheme for smart grid system," Sensors, vol. 22, no. 13, doi: 10.3390/s22134826.
[143] Adegbohun F, von Jouanne A, Lee K. Autonomous battery swapping system and methodologies of electric vehicles. Energies 2019;12(4). https://doi.org/10.3390/en12040667.
[144] Cui D, et al. Operation optimization approaches of electric vehicle battery swapping and charging station: a literature review. Energy 2023;263. https://doi.org/10.1016/j.energy.2022.126095.
[145] Kumari A, Shukla A, Gupta R, Tanwar S, Tyagi S, Kumar N. ET-DeaL: a P2P smart contract-based secure energy trading scheme for smart grid systems. In: Ieee infocom 2020 - IEEE conference on computer communications workshops (INFOCOM WKSHPS); Jul. 6-9, 2020. p. 1051–6. https://doi.org/10.1109/INFOCOMWKSHPS50562.2020.9162989.
[146] Toglaw S, Aloqaily M, Alkheir AA. Connected, autonomous and electric vehicles: the optimum value for a successful business model. In: 2018 fifth international conference on internet of things: systems, management and security; Oct. 15-18, 2018. p. 303–8. https://doi.org/10.1109/IoTSMS.2018.8554391.
[147] Chen TD, Kockelman KM, Hanna JP. Operations of a shared, autonomous, electric vehicle fleet: implications of vehicle & charging infrastructure decisions. Transport Res Pol Pract 2016;94:243–54. https://doi.org/10.1016/j.tra.2016.08.020.
[148] Fenghui W, Ming Y, Ruqing Y. Dynamic fleet management for cybercars. In: *2006 IEEE intelligent transportation systems conference*, sept; 2006. p. 1246–50. https://doi.org/10.1109/ITSC.2006.1707393. 17-20.

[149] Gonçalves Duarte Santos G, Birolini S, Homem de Almeida Correia G. A space–time-energy flow-based integer programming model to design and operate a regional shared automated electric vehicle (SAEV) system and corresponding charging network. Transport Res C Emerg Technol 2023;147: 103997. https://doi.org/10.1016/j.trc.2022.103997.
[150] Ostermann J, Koetter F. Energy-management-as-a-service: mobility aware energy management for a shared electric vehicle fleet. In: 2016 5th international conference on smart cities and green ICT systems (SMARTGREENS). IEEE; 2016. p. 1–11.
[151] Department for Business, Energy & Industrial Strategy. Electric vehicle smart charging action plan [Online] Available: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1129728/electric-vehicle-smart-charging-action-plan.pdf; 2023.
[152] Volkswagen. "Volkswagen lets its charging robots loose." https://www.volkswagenag.com/en/news/stories/2019/12/volkswagen-lets-its-charging-robots-loose.html.
[153] Volkswagen Group News. "Initial contact: The mobile charging robot – Presenting a vision." https://www.volkswagen-newsroom.com/en/press-releases/initial-contact-the-mobile-charging-robot-presenting-a-vision-6736.
[154] Hyundai Motor Group. "Hyundai Motor Group Shows Newly Developed Automatic Charging Robot for Electric Vehicles." https://www.hyundai.com/worldwide/en/company/newsroom/-0000016986.
[155] Ford Media Center. "Ford trials robot charging station designed to give disabled drivers a much needed helping hand." https://media.ford.com/content/fordmedia/feu/en/news/2022/07/20/ford-trials-robot-charging-station-designed-to-give-disabled-dri.html.
[156] PwC. "Can Autonomous Electric Vehicles accelerate the low carbon transition?" https://www.pwc.co.uk/services/sustainability-climate-change/insights/autonomous-electric-vehicles.html.
[157] James Arbib TS. Rethinking Transportation 2020-2030 2017.
[158] Ercan T, Onat NC, Keya N, Tatari O, Eluru N, Kucukvar M. Autonomous electric vehicles can reduce carbon emissions and air pollution in cities. Transport Res Transport Environ 2022;112. https://doi.org/10.1016/j.trd.2022.103472.
[159] Binod Vaidya HTM. Connected autonomous electric vehicles as enablers for low-carbon future. Research Trends and Challenges in Smart Grids 2019. https://doi.org/10.5772/intechopen.84287.
[160] Stephens JGTS, Chen Y, Lin Z, Liu C, Gohlke D. Estimated bounds and important factors for fuel use and consumer costs of connected and automated vehicles. 2016. U.S.
[161] Yao Z, Wang Y, Liu B, Zhao B, Jiang Y. Fuel consumption and transportation emissions evaluation of mixed traffic flow with connected automated vehicles and human-driven vehicles on expressway. Energy 2021;230. https://doi.org/10.1016/j.energy.2021.120766.
[162] Wadud Z, MacKenzie D, Leiby P. Help or hindrance? The travel, energy and carbon impacts of highly automated vehicles. Transport Res Pol Pract 2016;86: 1–18. https://doi.org/10.1016/j.tra.2015.12.001.
[163] Vasebi S, Hayeri YM. Air emission impacts of low-level automated vehicle technologies in U.S. metropolitan areas. Transp Res Interdiscip Perspect 2020;7. https://doi.org/10.1016/j.trip.2020.100194.
[164] Archdaily. "Hackcity: Calling on 100 Architects to Co-build a Future City With Autonomous Moving Vehicles." https://www.archdaily.com/991492/official-launch-of-pixcity-announced-calling-on-city-hackers-across-the-world-to-collaborate-on-improving-future-human-habitat.
[165] Kassens-Noor E, et al. Sociomobility of the 21st century: autonomous vehicles, planning, and the future city. Transport Pol 2020;99:329–35. https://doi.org/10.1016/j.tranpol.2020.08.022.
[166] Bezai NE, Medjdoub B, Al-Habaibeh A, Chalal ML, Fadli F. Future cities and autonomous vehicles: analysis of the barriers to full adoption. Energy and Built Environment 2021;2(1):65–81. https://doi.org/10.1016/j.enbenv.2020.05.002.
[167] Dlugosch O, Brandt T, Neumann D. Combining analytics and simulation methods to assess the impact of shared, autonomous electric vehicles on sustainable urban mobility. Inf Manag 2022;59(5). https://doi.org/10.1016/j.im.2020.103285.
[168] Iacobucci R, McLellan B, Tezuka T. Costs and carbon emissions of shared autonomous electric vehicles in a Virtual Power Plant and Microgrid with renewable energy. Energy Proc 2019;156:401–5. https://doi.org/10.1016/j.egypro.2018.11.104.
[169] Waseem M, Sherwani AF, Suhaib M. Integration of solar energy in electrical, hybrid, autonomous vehicles: a technological review. SN Appl Sci 2019;1(11). https://doi.org/10.1007/s42452-019-1458-4.
[170] Al Wahedi A, Bicer Y. A case study in Qatar for optimal energy management of an autonomous electric vehicle fast charging station with multiple renewable energy and storage systems. Energies 2020;13(19). https://doi.org/10.3390/en13195095.
[171] Dean MD, Gurumurthy KM, de Souza F, Auld J, Kockelman KM. Synergies between repositioning and charging strategies for shared autonomous electric vehicle fleets. Transport Res Transport Environ 2022;108. https://doi.org/10.1016/j.trd.2022.103314.
[172] Yi Z, Smart J. A framework for integrated dispatching and charging management of an autonomous electric vehicle ride-hailing fleet. Transport Res Transport Environ 2021;95. https://doi.org/10.1016/j.trd.2021.102822.
[173] Vosooghi R, Puchinger J, Bischoff J, Jankovic M, Vouillon A. Shared autonomous electric vehicle service performance: assessing the impact of charging infrastructure. Transport Res Transport Environ 2020;81. https://doi.org/10.1016/j.trd.2020.102283.
[174] Jameel F, Chang Z, Huang J, Ristaniemi T. Internet of autonomous vehicles: architecture, features, and socio-technological challenges. IEEE Wireless Commun 2019;26(4):21–9. https://doi.org/10.1109/MWC.2019.1800522.
[175] Zhuge C, Wang C. Integrated modelling of autonomous electric vehicle diffusion: from review to conceptual design. Transport Res Transport Environ 2021;91: 102679. https://doi.org/10.1016/j.trd.2020.102679.
[176] Lam AYS, Yu JJQ, Hou Y, Li VOK. Coordinated autonomous vehicle parking for vehicle-to-grid services: formulation and distributed algorithm. IEEE Trans Smart Grid 2018;9(5):4356–66. https://doi.org/10.1109/TSG.2017.2655299.
[177] Todorovic M, Simic M, Kumar A. Managing transition to electrical and autonomous vehicles. In: *21st international Conference on knowledge - Based and intelligent Information and engineering systems (KES)*, Aix marseille univ, st charles campus, marseille, France, sep 06-08, vol. 112. AMSTERDAM: Elsevier Science Bv, in Procedia Computer Science; 2017. p. 2335–44. https://doi.org/10.1016/j.procs.2017.08.201. 10.1016/j.procs.2017.08.201. [Online]. Available:.
[178] Liang Y, Dong H, Li D, Song Z. Adaptive eco-cruising control for connected electric vehicles considering a dynamic preceding vehicle. eTransportation 2024; 19:100299. https://doi.org/10.1016/j.etran.2023.100299.
[179] Dong H, Zhuang W, Wu G, Li Z, Yin G, Song Z. Overtaking-enabled eco-approach control at signalized intersections for connected and automated vehicles. IEEE Trans Intell Transport Syst 2024;25(5):4527–39. https://doi.org/10.1109/TITS.2023.3328022.
[180] Dong H, Zhuang W, Chen B, Yin G, Wang Y. Enhanced eco-approach control of connected electric vehicles at signalized intersection with queue discharge prediction. IEEE Trans Veh Technol 2021;70(6):5457–69. https://doi.org/10.1109/TVT.2021.3075480.
[181] Kumari A, Tanwar S. A data analytics scheme for security-aware demand response management in smart grid system. In: 2020 IEEE 7th Uttar Pradesh section international conference on electrical, electronics and computer engineering (UPCON); 27-29 Nov. 2020, 2020. p. 1–6. https://doi.org/10.1109/UPCON50219.2020.9376458.
[182] Vdovic H, Babic J, Podobnik V. Automotive software in connected and autonomous electric vehicles: a review. IEEE Access 2019;7:166365–79. https://doi.org/10.1109/ACCESS.2019.2953568.
[183] Damaj IW, Serhal DK, Hamandi LA, Zantout RN, Mouftah HT. Connected and autonomous electric vehicles: quality of experience survey and taxonomy. Vehicular Communications 2021;28:100312. https://doi.org/10.1016/j.vehcom.2020.100312.
[184] A. Biswas and H.-C. Wang, "Autonomous vehicles enabled by the integration of IoT, edge intelligence, 5G, and blockchain," Sensors, vol. 23, no. 4, doi: 10.3390/s23041963.
[185] Abou-zeid H, Pervez F, Adinoyi A, Aljlayl M, Yanikomeroglu H. Cellular V2X transmission for connected and autonomous vehicles standardization, applications, and enabling technologies. IEEE Consumer Electronics Magazine 2019;8(6):91–8. https://doi.org/10.1109/MCE.2019.2941467.
[186] Iacobucci R, Bruno R. Cascaded model predictive control for shared autonomous electric vehicles systems with V2G capabilities. In: 2019 IEEE international conference on communications, control, and computing technologies for smart grids (SmartGridComm); Oct. 21-23, 2019. p. 1–7. https://doi.org/10.1109/SmartGridComm.2019.8909735.
[187] Iacobucci R, McLellan B, Tezuka T. Optimization of shared autonomous electric vehicles operations with charge scheduling and vehicle-to-grid. Transport Res C Emerg Technol 2019;100:34–52. https://doi.org/10.1016/j.trc.2019.01.011.
[188] Zhang Y-T, Hu M-B, Chen Y-Z, Shi C-L. Cooperative platoon forming strategy for connected autonomous vehicles in mixed traffic flow. Phys Stat Mech Appl 2023; 623:128828. https://doi.org/10.1016/j.physa.2023.128828.
[189] Yoo Y, Chen T, Jang K, Kim I. Impact on platooning of autonomous vehicles using macro to micro simulations. Procedia Computer Science 2023;220:235–42. https://doi.org/10.1016/j.procs.2023.03.032.
[190] Mersky AC, Samaras C. Fuel economy testing of autonomous vehicles. Transport Res C Emerg Technol 2016;65:31–48. https://doi.org/10.1016/j.trc.2016.01.001.
[191] Kumari A, Tanwar S. RAKSHAK: resilient and scalable demand response management scheme for smart grid systems. In: 2021 11th international conference on cloud computing. Data Science & Engineering (Confluence); Jan. . p. 309–14. https://doi.org/10.1109/Confluence51648.2021.9377139.
[192] Electreon. "Our wireless charging technology." https://electreon.com/technology.
[193] Qualcommhalo. "Wireless charging for electric vehicles." chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.qualcomm.com/content/dam/qcomm-martech/dm-assets/documents/qch_faq_flyer_jan_2012_final.pdf.
[194] Witricity. "The Electric Car Unplugged." https://witricity.com/wp-content/uploads/2022/05/The-Electric-Car-Unplugged-Final.pdf.
[195] INDUCTEV. "Powering commercial mobility systems with clean energy." https://www.inductev.com/.
[196] Autovoltek. "Automated Home EV Charging. Smart, affordable, convenient." https://chargerobot.com/.
[197] VOLTERIO. "REDEFINING CHARGING." https://www.volterio.com/#tf-about.
[198] Gaussin. "We are the next generation of zero-emission, smart and connected vehicles." https://www.gaussin.com/.
[199] ABB. "EV Charging Solutions." https://new.abb.com/ev-charging.
[200] Siemens. "Siemens to deliver charging stations for electric buses to Denmark." https://press.siemens.com/global/en/pressrelease/siemens-deliver-charging-stations-electric-buses-denmark.
[201] Siemens. "Simply reliable: On-board pantographs for eBuses." https://www.siemens.com/global/en/products/energy/medium-voltage/solutions/emobility/charging-pantograph.html.

[202] Siemens. "Dynamic charging infrastructure." https://www.mobility.siemens.com/global/en/portfolio/road/ehighway.html.
[203] Heliox. "Scalable charging solutions for E-Bus fleets start here." https://www.heliox-energy.com/solutions/e-bus.
[204] Heliox. "Different Electric Buses, One Rapid Charging System by Heliox." https://www.heliox-energy.com/case-studies/different-electric-buses-one-rapid-charging-system-by-heliox.
[205] Heliox. "Amsterdam's Public E-Bus Network – A Challenging Proposition." https://www.heliox-energy.com/case-studies/amsterdams-public-e-bus-network-a-challenging-proposition.
[206] Zhang TZ, Chen TD. Smart charging management for shared autonomous electric vehicle fleets: a Puget Sound case study. Transport Res Transport Environ 2020; 78:102184. https://doi.org/10.1016/j.trd.2019.11.013.
[207] Shaikh PW, Mouftah HT. Intelligent charging infrastructure design for connected and autonomous electric vehicles in smart cities. In: 2021 IFIP/IEEE international symposium on integrated network management (IM); 2021. p. 992–7.
[208] Adnan N, Nordin SM, Saleh MF, Sanyal S. Smart charging management for autonomous vehicles: a smart solution for smart cities & societies: covid 19. In: Smart charging solutions for hybrid and electric vehicles; 2022. p. 341–59.
[209] Rozman M, et al. Smart wireless power transmission system for autonomous EV charging. IEEE Access 2019;7:112240–8. https://doi.org/10.1109/ACCESS.2019.2912931.
[210] Kodeeswaran S, Gayathri MN, Kannabhiran A, Sanjeevikumar P. Chapter 16 - autonomous and electric vehicles charging schemes without an operator. In: Rashid MH, editor. Handbook of power electronics in autonomous and electric vehicles. Academic Press; 2024. p. 257–77.
[211] Lee U, Kang N, Lee YK. Shared autonomous electric vehicle system design and optimization under dynamic battery degradation considering varying load conditions. J Clean Prod 2023;423:138795. https://doi.org/10.1016/j.jclepro.2023.138795.
[212] Huang K, Zhou P, Liu Z, Tang T, Zhang H, Jiang W. The calculation and distribution of CAV carbon emissions on urban transportation systems: a comparative analysis of renewable and non-renewable energy sources. Renew Energy 2024;230:120884. https://doi.org/10.1016/j.renene.2024.120884.
[213] Li Y, Li X, Jenn A. Evaluating the emission benefits of shared autonomous electric vehicle fleets: a case study in California. Appl Energy 2022;323:119638. https://doi.org/10.1016/j.apenergy.2022.119638.
[214] Le Hong Z, Zimmerman N. Air quality and greenhouse gas implications of autonomous vehicles in Vancouver, Canada. Transport Res Transport Environ 2021;90:102676. https://doi.org/10.1016/j.trd.2020.102676.
[215] Zhang H, Sheppard CJR, Lipman TE, Zeng T, Moura SJ. Charging infrastructure demands of shared-use autonomous electric vehicles in urban areas. Transport Res Transport Environ 2020;78:102210. https://doi.org/10.1016/j.trd.2019.102210.
[216] Bauer GS, Greenblatt JB, Gerke BF. Cost, energy, and environmental impact of automated electric taxi fleets in manhattan. Environmental Science & Technology 2018;52(8):4920–8. https://doi.org/10.1021/acs.est.7b04732.
[217] Iacobucci R, McLellan B, Tezuka T. Modeling shared autonomous electric vehicles: potential for transport and power grid integration. Energy 2018;158: 148–63. https://doi.org/10.1016/j.energy.2018.06.024.
[218] Weiss J, Hledik R, Lueken R, Lee T, Gorman W. The electrification accelerator: understanding the implications of autonomous vehicles for electric utilities. Electr J 2017;30(10):50–7. https://doi.org/10.1016/j.tej.2017.11.009.
[219] Ireshika MAST, Rheinberger K, Lliuyacc-Blas R, Kolhe ML, Preißinger M, Kepplinger P. Optimal power tracking for autonomous demand side management of electric vehicles. J Energy Storage 2022;52:104917. https://doi.org/10.1016/j.est.2022.104917.
[220] Yumiki S, et al. Autonomous vehicle-to-grid design for provision of frequency control ancillary service and distribution voltage regulation. Sustainable Energy, Grids and Networks 2022;30:100664. https://doi.org/10.1016/j.segan.2022.100664.
[221] Monios J, Bergqvist R. Logistics and the networked society: a conceptual framework for smart network business models using electric autonomous vehicles (EAVs). Technol Forecast Soc Change 2020;151:119824. https://doi.org/10.1016/j.techfore.2019.119824.
[222] Kester J, Noel L, Zarazua de Rubens G, Sovacool BK. Promoting Vehicle to Grid (V2G) in the Nordic region: expert advice on policy mechanisms for accelerated diffusion. Energy Pol 2018;116:422–32. https://doi.org/10.1016/j.enpol.2018.02.024.
[223] HONDA. "Honda installs new bi-directional chargingn technology at European R&D centre." https://hondanews.eu/eu/en/cars/media/pressreleases/124178/honda-installs-new-bi-directional-charging-technology-at-european-randd-centre.
[224] Jain S, et al. Blockchain and autonomous vehicles: recent advances and future directions. IEEE Access 2021;9:130264–328. https://doi.org/10.1109/access.2021.3113649.
[225] Bedi G, Venayagamoorthy GK, Singh R, Brooks RR, Wang K-C. Review of internet of things (IoT) in electric power and energy systems. IEEE Internet Things J 2018; 5(2):847–70. https://doi.org/10.1109/jiot.2018.2802704.
[226] ElSayed M, Foda A, Mohamed M. Autonomous drone charging station planning through solar energy harnessing for zero-emission operations. Sustain Cities Soc 2022;86. https://doi.org/10.1016/j.scs.2022.104122.
[227] Liu P, Fan WD. Exploring the impact of connected and autonomous vehicles on mobility and environment at signalized intersections through vehicle-to-infrastructure (V2I) and infrastructure-to-vehicle (I2V) communications. Transport Plann Technol 2021;44(2):129–38. https://doi.org/10.1080/03081060.2020.1868088.
[228] Kumari A, Golyan A, Shah R, Raval N. Introduction to data analytics. In: *Recent Trends and future Direction for data analytics*, (advances in systems analysis, software engineering, and high performance computing; 2024. p. 1–14. ch. [chapter 1].
[229] Golyan A, Panchal S, Vaghasiya D, Parekh H. Data ethics and privacy. In: *Recent Trends and future Direction for data analytics*, (advances in systems analysis, software engineering, and high performance computing; 2024. p. 259–68. ch. [chapter 11].
[230] Saberi-Beglar K, Zare K, Seyedi H, Marzband M, Nojavan S. Risk-embedded scheduling of a CCHP integrated with electric vehicle parking lot in a residential energy hub considering flexible thermal and electrical loads. Appl Energy 2023; 329. https://doi.org/10.1016/j.apenergy.2022.120265.
[231] Axsen J, Bhardwaj C, Crawford C. Comparing policy pathways to achieve 100% zero-emissions vehicle sales by 2035. Transport Res Transport Environ 2022;112. https://doi.org/10.1016/j.trd.2022.103488.
[232] Santos G, Smith O. Electric vehicles and the energy generation mix in the UK: 2020–2050. Energy Rep 2023;9:5612–27. https://doi.org/10.1016/j.egyr.2023.03.114.
[233] Peiseler L, Cabrera Serrenho A. How can current German and EU policies be improved to enhance the reduction of CO2 emissions of road transport? Revising policies on electric vehicles informed by stakeholder and technical assessments. Energy Pol 2022;168. https://doi.org/10.1016/j.enpol.2022.113124.
[234] Yang A, Liu C, Yang D, Lu C. Electric vehicle adoption in a mature market: a case study of Norway. J Transport Geogr 2023;106. https://doi.org/10.1016/j.jtrangeo.2022.103489.
[235] Taiebat M, Xu M. Synergies of four emerging technologies for accelerated adoption of electric vehicles: shared mobility, wireless charging, vehicle-to-grid, and vehicle automation. J Clean Prod 2019;230:794–7. https://doi.org/10.1016/j.jclepro.2019.05.142.
[236] Johnsen D, Ostendorf L, Bechberger M, Strommenger D. Review on smart charging of electric vehicles via market-based incentives, grid-friendly and grid-compatible measures. World Electric Vehicle Journal 2023;14(1). https://doi.org/10.3390/wevj14010025.
[237] Sechilariu M, Molines N, Richard G, Martell-Flores H, Locment F, Baert J. Electromobility framework study: infrastructure and urban planning for EV charging station empowered by PV-based microgrid. IET Electr Syst Transp 2019; 9(4):176–85. https://doi.org/10.1049/iet-est.2019.0032.
[238] Mustafa MA, Zhang N, Kalogridis G, Fan Z. Smart electric vehicle charging: security analysis. In: 2013 IEEE PES innovative smart grid technologies conference (ISGT); Feb. 24-27, 2013. p. 1–6. https://doi.org/10.1109/ISGT.2013.6497830.
[239] Tirunagari S, Gu M, Meegahapola L. Reaping the benefits of smart electric vehicle charging and vehicle-to-grid technologies: regulatory, policy and technical aspects. IEEE Access 2022;10:114657–72. https://doi.org/10.1109/ACCESS.2022.3217525.
[240] Chamberlain K, Al-Majeed S. Standardisation of UK electric vehicle charging protocol, payment and charge point connection. World Electric Vehicle Journal 2021;12(2). https://doi.org/10.3390/wevj12020063.
[241] Wolbertus R, Jansen S, Kroesen M. Stakeholders' perspectives on future electric vehicle charging infrastructure developments. Futures 2020;123. https://doi.org/10.1016/j.futures.2020.102610.
[242] Jones PB, Levy J, Bosco J, Howat J, Van Alst JW. The future of transportation electrification: utility, industry and consumer perspectives [Online]. Available: https://emp.lbl.gov/publications/future-transportation-electrification; 2018.
[243] 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. https://doi.org/10.1016/j.est.2022.105241.
[244] Acharya S, Dvorkin Y, Pandzic H, Karri R. Cybersecurity of smart electric vehicle charging: a power grid perspective. IEEE Access 2020;8:214434–53. https://doi.org/10.1109/access.2020.3041074.
[245] Ghaderi A, Nassiraei AAF. The economics of using electric vehicles for vehicle to building applications considering the effect of battery degradation. In: Iecon 2015 - 41st annual conference of the. IEEE Industrial Electronics Society; Nov. . https://doi.org/10.1109/IECON.2015.7392654. 003567-003572.
[246] Englberger S, Hesse H, Kucevic D, Jossen A. A techno-economic analysis of vehicle-to-building: battery degradation and efficiency analysis in the context of coordinated electric vehicle charging. Energies 2019;12(5). https://doi.org/10.3390/en12050955.
[247] Gschwendtner C, Sinsel SR, Stephan A. Vehicle-to-X (V2X) implementation: an overview of predominate trial configurations and technical, social and regulatory challenges. Renew Sustain Energy Rev 2021;145. https://doi.org/10.1016/j.rser.2021.110977.
[248] Goudkamp J. "Automated vehicle liability and AI," james Goudkamp,'Automated vehicle liability and AI'in ernest lim and phillip morgan. In: The cambridge handbook of private law and artificial intelligence. Forthcoming: CUP; 2023.
[249] Delmonte E, Kinnear N, Jenkins B, Skippon S. What do consumers think of smart charging? Perceptions among actual and potential plug-in electric vehicle adopters in the United Kingdom. Energy Res Social Sci 2020;60. https://doi.org/10.1016/j.erss.2019.101318.
[250] Lu S, Han B, Xue F, Jiang L, Qian K. Multi-objective optimization of EV charging and discharging for different stakeholders. CSEE Journal of Power and Energy Systems 2023;9(6):2301–8. https://doi.org/10.17775/CSEEJPES.2020.02300.

[251] Kubli M. EV drivers' willingness to accept smart charging: measuring preferences of potential adopters. Transport Res Transport Environ 2022;109. https://doi.org/10.1016/j.trd.2022.103396.
[252] Kester J. Insuring future automobility: a qualitative discussion of British and Dutch car insurer's responses to connected and automated vehicles. Research in Transportation Business & Management 2022;45. https://doi.org/10.1016/j.rtbm.2022.100903.
[253] Ahmadian A, Sedghi M, Elkamel A, Fowler M, Aliakbar Golkar M. Plug-in electric vehicle batteries degradation modeling for smart grid studies: review, assessment and conceptual framework. Renew Sustain Energy Rev 2018;81:2609–24. https://doi.org/10.1016/j.rser.2017.06.067.