



Article

Overview of Sustainable Mobility: The Role of Electric Vehicles in Energy Communities

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Abstract: From 2035 onward, the registration of new conventional internal combustion engine vehicles will be prohibited in the European Union. This shift is driven by steadily rising fuel prices and growing concerns over carbon dioxide emissions. Electric vehicles (EVs) are becoming increasingly popular across Europe, and many manufacturers now offer modified models, making pure internal combustion versions unavailable for certain types. Additionally, the comparatively lower operational costs of EVs for end users further bolster their appeal. In the European Union, new directives have been established to define innovative approaches to energy use in Member States, known as energy communities. This article provides a comprehensive overview of the architecture of energy communities, electric vehicles, and the V2X technologies currently on the market. It highlights the evolution of electric vehicle adoption in the EU, contextualizing it within broader energy trends and presenting future challenges and development opportunities related to energy communities. The paper details the diversification of electricity sources among Member States and the share of generated electricity that is utilized for transport.

Keywords: electric vehicles; European Union; battery; vehicle to grid; vehicle to home; energy community



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1. Introduction

The modern automotive industry is no longer just an important industry; it has become a key area for research and development. Driven by evolving consumer preferences and technological advancements, vehicles are now equipped not only with complex driver assistance systems [1–3] but also with a wide range of safety features [1,4–7] and consumer electronics [8–10]. Over the years, the number of vehicles on Europe's roads has increased steadily [11]. The increase in the number of vehicles has boosted industry and various services, and the mobility of the population has also changed dramatically. However, this surge in vehicular traffic has been accompanied by environmental repercussions, including the emission of greenhouse gases such as sulphur dioxide (SO₂), nitrogen oxides (NO_x), carbon monoxide (CO), and particulate matter (PM) into the atmosphere [12,13]. In response to these challenges, the European Union has enacted a directive mandating the cessation of new internal combustion engine-equipped vehicle sales by 2035 [14]. Consequently, several automotive manufacturers have initiated the development of electric models, which are very popular with certain sections of society [15–19]. In general, electric cars offer a promising avenue for mitigating environmental impacts, provided that genuinely green energy sources are utilized for electricity generation [1,20].

The transport sector has the largest environmental footprint among all energy consumers, contributing to over 25% of global energy consumption and greenhouse gas emissions. Within this sector, road transportation alone contributes to more than 70% of emissions [1,21–23]. In the United States, the adoption of plug-in electric vehicles (PEVs) has seen a significant increase, with over 442,000 such vehicles currently in operation

nationwide, marking a notable growth since 2011 [1,24–26]. Conversely, Europe has experienced a fourfold annual increase in PEV sales since their market introduction in 2010, with approximately 60,000 units sold by 2013 [1,19,24]. China, emerging as a frontrunner in EV adoption, has set ambitious targets, aiming for 20% of all new car sales to be electric vehicles by 2025. Additionally, the Chinese government has set a long-term objective for all new vehicle sales by 2035 to comprise “new energy” vehicles, including both pure electric and plug-in hybrid cars [1,27–29].

Unfortunately, alongside the positive features described above, electric vehicles encounter limitations in their adoption. Their market share remains relatively low, hovering around 16% in Europe [30–35], due to several factors, including the following:

- High price;
- Battery capacity issues;
- Lengthy charging times;
- Limited range;
- Insufficient infrastructure, particularly in terms of charging facilities.

Addressing infrastructure development for electric vehicles is crucial. Despite gradual improvements, the availability of charging points for electric vehicles remains a challenge in many European countries and municipalities, deterring potential customers. Moreover, non-domestic electric charging points are often particularly expensive [36–40]. The outbreak of the Russian–Ukrainian war in 2022 significantly revised energy prices in Europe [41,42], prompting many countries to seek alternative energy sources from other countries, e.g., liquefied natural gas (LNG) [43–45]. Consequently, the utilization of renewable energy sources has become more important than ever in the region.

Alongside the expansion of charging infrastructure, it is crucial to acknowledge the challenges faced in larger residential complexes and remote or economically disadvantaged areas. Battery capacity remains a paramount concern for electric vehicles, necessitating a re-evaluation of the role of vehicle batteries.

It is foreseeable that contemporary electric vehicles will become fundamental components of future smart cities [1,46,47]. For smart cities, as well as the aforementioned geographically isolated or economically disadvantaged regions, the concept of energy communities emerges as a potential solution [1,46–48].

Vehicle-to-grid (V2G) and electric vehicles are the focus of extensive scientific and industrial research and technological development. These fields explore the intersection of energy and transport sciences from a new perspective. Not only research institutes but also numerous vehicle manufacturers and energy suppliers are conducting research on this topic. The challenge is multifaceted, aiming not only to reduce greenhouse gas emissions but also to ensure efficient energy storage in vehicles and the balancing and rebalancing of the electricity grid. There are still several open questions regarding the integration of technology and the various solutions proposed by different manufacturers.

Research goals and motivations

The adoption of electric vehicles faces various challenges, such as high initial costs, limited range, and insufficient charging infrastructure. Addressing these challenges could be crucial in accelerating the uptake of electric vehicles. Numerous researchers and manufacturers are currently focused on increasing battery capacity without changing the physical dimensions of the batteries or even improving them [1,49–52]. However, on the governmental and societal fronts, the scarcity of charging infrastructure presents a multifaceted challenge.

This challenge encompasses several factors, such as the following [1,53–56]:

- Outdated electricity grids;
- Space constraints;
- Costly infrastructure development;
- Geographical limitations;
- Aging buildings;

- Reliance on non-renewable energy sources.

The aim of the study is to present the types of electric vehicles, the European Union directives on energy communities, and the evolution of electricity use from renewable energy sources among EU Member States. The study also aims to highlight future challenges for energy communities. These communities leverage surplus generated energy to facilitate EV charging and potentially enable bidirectional energy flow between vehicles and buildings. The study also aims to assess available technologies for implementing such systems [56–62].

The study further aims to highlight current technologies, their limitations, and the solutions already developed. The primary objective is to present the current policy guidance and describe the technology options from the perspective of vehicle manufacturers. In the second part, this paper reviews the current situation and research trends in the European Union concerning the deployment and uptake of such technology, then outlines future development options.

Employing both qualitative and quantitative data, this research seeks to promote the adoption of EVs in areas with inadequate infrastructure. Additionally, it underscores the importance of treating vehicles and buildings as an integrated system in the future. The data used in this study were sourced from the EuroStat database, and more than 230 references were utilized in writing the article.

The significance of the study lies in its comprehensive overview of the current state of electric vehicle (EV) technology and its implications. It provides valuable guidance to engineers, manufacturers, energy suppliers, municipalities, and policymakers regarding the potential impacts of this technology. This research contributes to the ongoing debate on sustainable energy storage, EVs, and the development of electricity grids. Employing mixed methodologies and databases, this paper seeks to answer five key questions to help readers understand the various issues related to the integration of EVs and V2G technologies.

The following questions are to be answered in the research:

1. Is there a correlation between the increase in the number of electric vehicles and CO₂ emissions?
2. To what degree do vehicle manufacturers incorporate vehicle-to-home (V2H) or vehicle-to-grid (V2G) technologies into their model fleets?
3. Has there been an improvement in battery capacity for electric vehicles, and if so, to what extent?
4. How balanced is the distribution of electricity sourced from renewable energy across European Union Member States?
5. What are the scope and scale of research projects focused on vehicle-to-home and vehicle-to-grid technologies in Europe?

2. Energy Communities

2.1. Overview

Energy communities represent collaborative initiatives through which local communities collectively engage in the production, storage, and distribution of renewable energy. These communities play a pivotal role in enhancing energy efficiency and using sustainable energy sources. Guided by EU Directive 2018/2001/EU, which outlines a unified framework for advancing renewable energy utilization across various sectors, energy communities align with binding EU targets for 2030. This directive regulates self-consumption and establishes standardized guidelines governing the integration of renewable energy into the electricity, heating and cooling, and transportation domains. Thus, energy communities serve as endorsed endeavors under the auspices of the European Union to champion the widespread adoption of renewable energy sources and operate within the regulatory framework delineated by directives such as EU Directive 2018/2001/EU [63,64].

The concept of energy communities within the European Union represents a novel construct. It is important to note that at the world level, we are talking about a solution that is more than 25 years old. Under EU directives, Member States are mandated to implement

new regulations concerning energy communities, encapsulated in the following two pivotal rules [63–72]:

- Facilitation of the “prosumer,” representing an active consumer who not only consumes electricity but also contributes surplus energy back into the grid;
- Establishment of the Energy Community as a distinct legal entity.

The European Union has established ambitious targets, aiming for 65% of energy consumption to be sourced from energy communities by 2050. However, this directive has presented challenges at both the local and EU levels [63,65–72]. Establishing energy communities is not solely a legal imperative but also a technical one. Without modern and efficient electricity grids, such initiatives lack viability. Many Member States grapple with inflexible and outdated electricity systems, exemplified by cases in Hungary and Eastern European countries, but Italy also encounters challenges in this regard [63,65–78].

The use of solar panels by the public and the spread of electric cars are presenting unprecedented challenges to electricity grids. In the 21st century, many consumers have transitioned from being mere consumers to also becoming producers of electricity.

Consequently, service providers must adopt new strategies to effectively manage the balance between supply and demand. It is crucial to highlight that in numerous countries, existing electricity grid systems are aging and struggling to adapt to these changes.

Across Europe, a significant portion of the population relies on 230–400 volt systems, commonly referred to as the grid edge, which connects street transformer stations to residential user points. In industrial settings, we see the implementation of digital solutions in high-voltage networks, yet similar advancements are lacking on the residential or user side. This discrepancy often results in service providers being ill-equipped to address fluctuating demands adequately, leading to network congestion and subsequent failures [65–72,79].

Charging electric and plug-in hybrid vehicles presents a significant challenge for households in the 21st century. In addition to vehicles, it is essential to recognize the increasing reliance on electrically powered devices. The COVID-19 pandemic in 2020 precipitated profound shifts in user behaviors, with many employees transitioning to remote work arrangements, commonly referred to as “home offices”. This shift has led to an uptick in electricity demand within residential buildings. Even as the pandemic recedes, numerous companies have opted to retain remote work arrangements or adopt hybrid workflows, further perpetuating the need for electricity within residential spaces [65–72,80].

In many instances, residential and industrial consumers have opted to install solar panels on the rooftops of their buildings or in dedicated areas. However, aging electricity grids struggle to effectively manage the energy generated from these sources, posing safety concerns. To address these challenges, electricity companies have the opportunity to implement smart solutions for the peripheries of the grid. Siemens (Munich, Germany) has responded to these evolving needs by introducing new microgrid solutions, offering a flexible management approach. The system developed by Siemens centrally oversees connected devices such as smart meters, solar panels, and car chargers. Continuous monitoring ensures that network bottlenecks are minimized, even during peak usage periods. Leveraging this technology, the Siemens Campus Microgrid achieves annual carbon dioxide savings of nearly 100 tons [65–72,81–86].

Energy communities are characterized by their flexibility, enabling seamless integration of new consumers and producers. A key aspect of these communities is to foster diverse consumer habits among members. Smart contracts are established among these users to facilitate efficient operation. However, the viability of energy communities solely comprising residential buildings is questionable. In such settings, consumption patterns are largely uniform, with peak periods concentrated in the morning and evening, while energy usage remains low during the day. To achieve balance, it is essential to incorporate consumers with significant daytime energy needs, such as schools, kindergartens, or office buildings. Larger energy communities tend to be more efficient due to their enhanced capacity to balance energy demands [65–72,86,87].

Not all existing solar systems are equipped with energy storage capabilities, resulting in surplus energy being fed back into the grid during periods of non-utilization. This process is inefficient, prompting numerous research endeavors focused on enhancing the storage of solar-generated electricity. The increasing adoption of electric and hybrid vehicles introduces a novel dimension to energy management through vehicle-to-grid (V2G) and vehicle-to-home (V2H) systems. A relevant inquiry arises regarding the potential use of vehicles for electricity storage and system balancing within an energy community [65–72,88].

2.2. Feasibility and Economic Aspects of Energy Communities

The concept of energy communities has been established by the European Union through directives. However, its implementation raises numerous questions, and differences between Member States complicate the widespread adoption of the system.

2.2.1. Integration of Electric Vehicles

When integrating electric vehicles, several technical issues arise, such as the configuration of charging infrastructure, management of grid capacity, and energy demand. During the establishment process, it is essential to evaluate the infrastructural implementation support of energy communities in a local community and the challenges associated with integration. Numerous case studies and project initiatives are available to address these issues [46,61,89].

2.2.2. Economic Opportunities and Regulatory Framework

From an economic perspective, it is crucial to examine the economic challenges, cost savings, and investment requirements. The introduction and integration of electric vehicles lead to increased costs, as the stability of the electric grid can be disrupted, necessitating the replacement of outdated system components. Implementing and expanding this technology requires the development of new business models tailored to the specific characteristics of individual member states. In many cases, local regulations and the regulatory environment need to be reviewed. The planning, dissemination, and implementation of new technologies are often hindered by the slow pace of legal changes. A review of national policies is certainly useful and effective [90–92].

2.2.3. Social and Environmental System

The social integration of electric vehicles is a key issue. Many people have reservations, not only due to the cost but also because of the limited range. Researching and considering social aspects is crucial. These aspects include community involvement, equity, and access to clean, environmentally friendly transportation solutions. It is important to highlight that the spread of electric vehicles can create new jobs, although it might also lead to the loss of old ones. In the long run, public health indicators are expected to improve due to the reduction in local pollutant emissions [93,94].

Researchers and developers play a crucial role in shaping and balancing these points. If any of these aspects is only partially addressed or overlooked, the creation and operation of energy communities will be extremely challenging, if not impossible. In addition to political, legal, and social evaluations, it is important to examine various technical parameters and highlight current technical limitations. The following subsections discuss these aspects in detail.

3. Electric/Intelligent Vehicle Technology and V2X Technologies in the 21st Century

3.1. Types of Electric and Intelligent Vehicles

As discussed in the previous chapters, the European Union has prioritized reducing emissions, making the future use of electric vehicles imperative to achieving this goal. It is important to clarify the main types of electric vehicles and the existing V2X solutions. This information is detailed in Section 3.

3.1.1. Electric Vehicles (EVs)

Electric drives play an important role in our everyday transport. In practice, it is crucial to recognize that pure electric vehicles are not the only type of electric vehicles available.

Several types of electric vehicles are prominent in the market, including the following [95]:

- Battery Electric Vehicles (BEVs);
- Plug-in Hybrid Electric Vehicles (PHEVs);
- Hybrid Electric Vehicles (HEVs);
- Fuel Cell Electric Vehicles (FCEVs);
- Extended-Range Electric Vehicles (ER-EVs).

Plug-in hybrid vehicles (PHEVs) feature batteries that can be charged from the mains, but they also include a conventional internal combustion engine. When the battery is depleted or during longer journeys, the internal combustion engine engages to charge the battery. PHEVs typically have a limited range on electric power alone, making them more suitable for urban environments, where the electric motors are not active during longer journeys or only assist the combustion engine during rapid acceleration. These vehicles can be powered by either petrol or diesel [95].

In contrast, battery electric vehicles (BEVs) operate solely on electric power and do not have an internal combustion engine [95].

Hybrid electric vehicles (HEVs), on the other hand, contain a battery but cannot be charged from external sources. They rely on a combination of an internal combustion engine and electric power, with the battery typically providing power for short distances.

These vehicle types are capable of traveling only a short distance (a few kilometers) on battery power [95,96].

Fuel cell electric vehicles utilize fuel cells to convert hydrogen into electricity. These vehicles boast remarkable efficiency, with the ability to cover distances of 600–700 km on a single hydrogen tank. One significant advantage is their rapid refueling capability, taking just a few minutes, compared to the hours needed for electric vehicles to recharge. Typically, these vehicles incorporate regenerative braking systems, which capture kinetic energy and store it in a battery as electricity. Despite their potential, fuel cell electric vehicles are not yet widely adopted, leaving ample room for further development and research on this technology [95,97].

Extended-range electric vehicles feature series hybrid systems (series-HEV) engineered for extended travel distances. These vehicles incorporate a range-extending generator or auxiliary power unit (APU) that autonomously charges the battery [98,99].

3.1.2. Intelligent Vehicles (IVs) and Autonomous Vehicles (AVs)

Intelligent vehicles are equipped with sensors, communication devices, and various software solutions, with those powered by artificial intelligence being particularly significant. These technologies are designed to enhance the driving experience, safety, and efficiency of vehicles. Vehicle-to-vehicle (V2V) communication protocols are evolving rapidly, enabling vehicles to share information with each other, optimizing journeys, and maximizing energy efficiency [100–103].

Machine learning and artificial intelligence (AI) methods are essential components of modern vehicles. AI solutions find application in diverse areas, including object recognition, route planning, decision-making processes, and energy management systems. Several studies [104–106] have explored how AI tools can augment the capabilities and scope of intelligent and electric vehicles by enabling adaptive predictive functions. Additionally, cyber security concerns are gaining prominence, particularly as vehicles become increasingly connected to infrastructure like buildings [107,108].

Autonomous vehicles capable of navigating and operating without human intervention represent a significant advancement in the automotive sector. These vehicles leverage technologies like LiDAR, radar, and computer vision to perceive and navigate their surroundings. The Society of Automotive Engineers (SAE) has established six levels

of automation, ranging from level 0 (no automation) to level 5 (full automation), providing a framework for categorizing the capabilities of autonomous driving systems [109–111].

However, unlocking the complete potential of these technologies encounters various challenges. These encompass the necessity of standardized communication protocols, cybersecurity measures, and a robust regulatory framework. Moreover, public acceptance and ethical considerations surrounding the implementation of autonomous vehicles (AVs) and electric vehicles (EVs) are pivotal aspects demanding meticulous consideration. Future research endeavors should prioritize interdisciplinary approaches, amalgamating advancements in artificial intelligence, machine learning, cybersecurity, and renewable energy. These efforts should aim to enhance energy storage capacity while addressing the complex challenges ahead [112–114].

Indeed, collaboration among academia, industry, and government will be imperative to tackle these intricate challenges and to advocate for the adoption of these technologies, as well as the integration of vehicles into smart cities and energy communities. By fostering partnerships and leveraging collective expertise, stakeholders can effectively navigate regulatory hurdles, develop innovative solutions, and facilitate the seamless integration of intelligent transportation systems into urban environments.

3.2. Batteries of Electric Vehicles

Batteries are the most crucial component of electric vehicles, with the following three primary designs [115–117]:

- Cylindrical: In cylindrical batteries, electrodes and separators are stacked, then formed into a cylinder. These batteries are cheap and have a high capacity, but certain configurations may add weight, potentially limiting the vehicle's maximum range.
- Prismatic: Prismatic batteries feature electrodes and separators housed within a rectangular metal casing. They are known for their larger size and may be prone to overheating.
- Pouch: Pouch batteries consist of aluminum foil with a polymer coating and are the most compact in size.

Vehicle batteries utilize various chemistries, including lithium-ion, nickel–metal hybrid, and solid-state batteries. Presently, lithium-ion batteries are the most prevalent, with each type carrying its own set of advantages and drawbacks. Therefore, the selection of a battery largely hinges on the vehicle type [115–117].

The advancement of electric vehicle batteries is a critical concern, aiming to enhance reliability and lifespan, minimize charging durations, and maximize energy storage capacity without augmenting weight and size. Energy density and power density stand as pivotal attributes of batteries. Energy density denotes the amount of energy batteries can contain, where a higher energy density implies prolonged recharging periods yet greater energy storage capabilities. The number of charge and discharge cycles constitutes another crucial aspect. Table 1 delineates the primary battery types, along with their respective characteristics [115–118].

Given the crucial role batteries assume in electric vehicle operation, numerous advancements are underway to enhance their performance. The primary objectives encompass the achievement of swifter charging times and extended range capabilities. Furthermore, to ensure efficient energy utilization, electric vehicles integrate various subsystems aimed at optimizing battery usage [52,119].

While lithium technology presently dominates the vehicle battery landscape, the future potential lies in zinc–air batteries, which could bring about a significant leap in battery capacity [120,121].

Enhancing battery capacity growth is pivotal, with notable variations observed across different markets from 2015 to 2020, as depicted in Table 2. In the United States, where vehicles cater to longer distances, the average battery capacity surpassed that of Europe by 43% and China by 71%, the latter being a market primarily oriented towards urban transport. Notably, vehicles equipped with lower battery capacities entail lower production costs [122].

Table 1. Battery types. Adapted form Ref. [118].

Battery	Specific Energy		Specific Power		Lifetime	
	(W × h)/kg	(W × h)/l	W/kg	W/l	Cycle Number	Year
Lead	30–50	70–120	150–400	350–1000	500–1000	3–5
Nickel-cadmium	40–60	80–130	80–175	180–350	>2000	3–10
Nickel-metal hybrid	60–80	150–200	200–300	400–500	500–1000	5–10
Sodium nickel chloride	80–100	150–175	155	255	800–1000	5–10
Lithium-ion	90–120	160–200	~300	300	1000	5–10
Lithium polymer	150	220	~300	450	<1000	-
Zinc-air	100–230	120–250	~100	120	-	-

Table 2. Battery pack capacity increases in kWh. Adapted form Ref. [122].

	2015	2020
USA	41.2 kWh	70.5 kWh
Europe	30.1 kWh	54.6 kWh
China	24.2 kWh	43.9 kWh

Table 2 demonstrates the variance in growth among markets. Across a 5-year period, the most substantial change occurred in the US market.

3.3. Overview of V2X Technology Solutions

Vehicle-to-everything technology is rapidly evolving. These technologies hold great inventive and reformative potential. They elevate vehicle development and functioning to a new level through integration with buildings and smart cities. Integrating new technology and vehicles into the electric grid can significantly improve energy security and independence. The following subsections explain the fundamentals of existing technology.

3.3.1. Vehicle to Grid (V2G)

Vehicle-to-grid technology stands as a potential energy breakthrough in contemporary times. It is a smart charging technology enabling electric vehicles to inject surplus energy back into the grid. Consequently, vehicle batteries transcend their traditional role, assuming significance as a pivotal energy source and an indispensable component of the grid. This marks the advent of a bidirectional charging system. Tailored to the requirements of the electricity grid, energy can be extracted from the batteries or replenished as dictated by demand fluctuations. The electricity stored in vehicle batteries holds versatile utility, serving various purposes as per necessity [123–125].

The proliferation of electric vehicles, coupled with the ongoing advancements in battery technology and the advent of smart devices, has catalyzed the development of vehicle-to-grid (V2G) technology. This innovative technology enables the provision of additional power to the grid during peak demand periods and serves as a supplementary energy source when renewable resources such as solar or wind are insufficient, such as during periods of low solar irradiance or minimal wind activity. In scenarios where a household relies solely on solar panels, an electric vehicle can serve as a secondary power reservoir when required. Moreover, electric vehicle owners have the potential to optimize their operational costs by selling surplus energy back to the grid operator or other members of the energy community [126–128].

In addition to facilitating local energy sharing, vehicle batteries can actively contribute to grid stability by providing support during peak demand periods, thereby averting overloads and potential safety hazards [129,130].

A fundamental challenge associated with renewable energy sources is their intermittent availability, necessitating supplementary energy procurement from alternative sources during such periods. Traditionally, fossil-fuel power plants have served this purpose in many countries [131,132]. However, electric vehicle batteries hold promise as a plentiful and efficient energy storage solution for the future. Some estimates suggest that by 2030, the global electric vehicle fleet will be more than 350 million, resulting in the same number of batteries. Leveraging vehicle-to-grid (V2G) technology could enable the monetization of vehicle battery storage capacity. It is worth noting that V2G compatibility is a prerequisite for vehicles to participate in such initiatives. Furthermore, V2G technology has the potential to facilitate the integration of other renewable energy sources into the energy system [133–137].

3.3.2. Vehicle to Home (V2H)

Vehicle-to-home (V2H) technology functions similarly to vehicle-to-grid (V2G) systems. With V2H, electric vehicles can supply power to residential homes or buildings, assisting in meeting their electricity requirements. In this scenario, a vehicle's batteries are charged using renewable energy sources, which may include solar or wind power. The energy stored in these batteries can then be utilized to power buildings or facilities during instances of power outages or heightened demand. The implementation of V2H technology necessitates the utilization of a bidirectional charger capable of facilitating the exchange of electricity between the vehicle and the building [124,138,139].

Bidirectional charging is an emerging technology that enables the charging of vehicle batteries while also allowing for the transfer of energy from the same battery back into the grid or buildings rather than solely powering the vehicle. This represents a significant departure from conventional electric vehicle charging methods, which are unidirectional, meaning that energy flows solely from the grid to the vehicle for its operation, without the capability to extract energy from the vehicle for other purposes [140,141].

Electric vehicles typically utilize direct-current (DC) power, which must be converted to an alternating current (AC) in order to be repurposed for other applications such as powering devices, households, or buildings. Bidirectional charging systems necessitate the implementation of intelligent systems to manage this process efficiently [142–145]. Manufacturers like Toyota have developed their own solutions in this regard [146,147].

V2H systems offer users the advantage of storing energy, granting them free access to it and reducing costs, along with several environmental benefits, including a decrease in greenhouse gas emissions [148]. However, it is essential to acknowledge that alongside these advantages, the technology also presents drawbacks. Electric vehicles typically cost more compared to conventional fuel vehicles, although this gap is gradually narrowing year by year [149–152]. Furthermore, the prices of solar smart systems, including vehicle-to-home solutions, remain relatively high and often involve complex installations. Despite these challenges, V2H technology is poised to play a pivotal role in the future. Various policy initiatives, such as the establishment of energy communities, are fostering the development and ongoing adoption of this technology to meet European climate objectives. Anticipated reductions in vehicle and technology costs in the future hold the potential for significant advancements in this field [153–160].

3.3.3. Vehicle to Load (V2L)

Vehicle-to-load (V2L) technology functions similarly to V2G and V2H systems. With V2L, power is drawn from the batteries of electric vehicles and can be directed to external devices such as electric bikes, scooters, camping equipment, and more. This versatile solution holds appeal for many customers, offering added convenience and flexibility. Vehicles equipped with V2L capabilities provide users with the ability to customize battery discharge settings and manage energy usage according to their preferences [124,161–165].

These vehicles come equipped with an onboard charger (OBC), which is responsible for generating sufficient AC and DC power while also ensuring adequate cybersecurity

measures. The evolution of vehicle-to-load (V2L) technology progresses alongside developments in V2G and V2H systems but tries to satisfy a different user experience or habit [164–167].

V2G and V2H represent two of the most innovative and significant research domains in contemporary energy systems. While the two technologies share similarities, they also exhibit notable distinctions. Both V2G and V2H leverage electric vehicle batteries for energy storage. V2G primarily focuses on grid balancing and stabilization, offering potential solutions for peak demand periods. Conversely, V2H utilizes stored energy to power buildings, offering cost-saving benefits to local users. Both systems are compatible with a diverse array of renewable energy sources. However, a common challenge lies in the design and commercialization of standardized charging systems for both technologies. Furthermore, the integration of V2G and V2H into energy communities necessitates a balanced mix of producers, consumers, and storage facilities for optimal effectiveness.

3.3.4. Virtual Power Plants (VPPs)

Virtual power plants (VPPs) integrate diverse energy sources, including solar panels, to optimize energy production and consumption. These systems are engineered to stabilize electricity grids by efficiently allocating energy resources. Operating under the oversight of smart systems, VPPs coordinate multiple energy sources as a unified power plant. Numerous brands and manufacturers are actively pursuing the integration of their electric vehicles with VPPs, with the Volkswagen Group emerging as a key pioneer on this technological frontier [144,168–172].

In summary, vehicle-to-grid (V2G) technology prioritizes grid interactions, enabling electric vehicles to contribute to grid stability. Vehicle-to-home (V2H) systems concentrate on supplying energy to homes or small communities. In contrast, virtual power plant (VPP) systems specialize in coordinating and managing the entire energy ecosystem by integrating diverse energy sources.

3.4. Limits and Challenges

Electric vehicles are the foundation of sustainable transport and a crucial component of the smart cities and energy communities of the future. Despite rapid progress, numerous technical challenges remain. Several studies have identified these challenges, which can be categorized under five main headings.

3.4.1. Standardization Problems and Uncertain Regulations

Current V2G systems lack standardized communication protocols and interaction mechanisms. As a result, V2G systems developed by different vendors struggle to communicate and operate cohesively. This lack of standardization also extends to vehicle charging equipment and battery designs. According to research by the National Renewable Energy Laboratory (NREL, USA), the absence of standardization increases the cost of V2G systems by 10–15% [173–175].

Legal and regulatory frameworks for V2G systems are currently undergoing revisions and preparations across all EU Member States. Various countries, energy suppliers, and network operators employ different regulatory approaches. Studies conducted by the EU indicate that the absence of clear regulations could potentially delay investments by up to several years [176,177].

3.4.2. High Investment Costs and Limited Electric Vehicle Options

The installation of bidirectional charging equipment comes with a high price tag, leading many EV owners to forgo it due to economic concerns. According to research, bidirectional systems can cost anywhere from USD 2000 to 5000 more than conventional charging systems [176–180].

Unfortunately, the current model range does not adequately provide vehicles capable of V2G or V2H technology, as discussed in Section 4. Numerous studies have examined

and attempted to find solutions to the aforementioned problems. Studies have focused on standardizing protocols and optimizing pricing. However, developments in this form are insufficient. The development and sale of inexpensive, reliable bidirectional charging systems are crucial, and vehicle manufacturers must enable V2G or V2H solutions in their models. V2G offers promising solutions to increase the stability of electric grids and integrate renewable energy sources, but numerous regulatory and technical challenges need to be overcome [178–180].

3.4.3. Safety Technology

The security regulatory framework is also a concern and is currently under development. This issue is particularly critical in the event of network failure, when the bidirectional system must be safely disconnected from the grid; or, more generally, the problem is battery degradation. According to a study by the University of Delaware, an EV can store up to 10 kW of energy for a household during a power outage [181–183].

4. Vehicle Manufacturer Solutions

Vehicle manufacturers have recognized the pivotal role of electric vehicles in energy management, integrating them into broader systems such as buildings, electrical grids, or communities. General Motors (GM) has developed a range of solutions for electric energy storage and commercial applications, offering both vehicle-to-home (V2H) and vehicle-to-grid (V2G) solutions [144,169–172,184]. Volkswagen's Elli brand collaborates with utility providers to develop solutions for integrating vehicles into the grid. This partnership focuses on four different areas, namely pricing and user adoption of V2G technology, marketing, reliability, and safety of EV data, to create trust and data security [181–186]. Hyundai Motor Company showcased its vehicle-to-load (V2L) capabilities by powering a hotel in England with a fleet of Hyundai Ioniq 5 vehicles [144,169–172,187]. Volvo Cars enables bidirectional charging in its EX90 model [188], while the Nissan Leaf, introduced in 2017, already features a bidirectional charger [189]. US company Tesla built a so-called power wall in Puerto Rico, supplying electricity to 44,000 homes post hurricane [144,169–172,190].

Today, South Korean manufacturers lead the way in the aforementioned technologies. Two notable models are the Hyundai Ioniq 6 and the Kia EV6, both equipped with a 3.6 kW vehicle-to-load (V2L) system capable of powering electronic devices like laptops and electric bicycles [191,192].

A list of key V2G-, V2H-, and V2L-compliant vehicles (2024, Q1) is presented as follows [193,194]:

- MG ZS EV—V2L;
- MG4—V2L;
- BYD Atto 3—V2L;
- BYD Dolphin—V2L;
- BYD Seal—V2L;
- Hyundai Ioniq 5—V2L;
- Kia EV6—V2L;
- Kia EV9—V2L, V2G, and V2H;
- Kia Niro EV—V2L;
- Genesis GV60, GV70, G80—V2L;
- Nissan Leaf—V2H and V2G;
- Cupra Born—V2H and V2G;
- Mitsubishi Outlander and Eclipse Cross—V2G, V2H, and V2L;
- Volkswagen MEB models (VW ID.4)—V2H;
- Ford F-150 Lighting—V2G.

As indicated by the list, the majority of the vehicles are manufactured in South Korea or China. Prominent European manufacturers like BMW, Volvo, and Porsche are currently in the testing phase for the described technologies. Tesla plans to introduce support for bidirectional charging in its vehicles starting in 2025 [144,169–172,194]. General Motors intends

to incorporate vehicle-to-home functionality as a standard feature in its cars beginning in 2024. This will apply to the following models [194]:

- Chevrolet Silverado EV RST—V2H;
- GMC Sierra EV Denali Edition 1—V2H;
- Chevrolet Blazer EV—V2H;
- Chevrolet Equinox EV—V2H;
- Cadillac Lyriq—V2H;
- Cadillac Escalade IQ (from 2025)—V2H.

The literature review indicates that Asian vehicle manufacturers are already ahead in offering V2G, V2H, and V2X technology in numerous models, with Chinese manufacturers leading the way in implementing these advancements. In contrast, European vehicle models have yet to incorporate this technology, despite directives set forth by the European Union for future standards. On the other hand, US manufacturers are poised to introduce V2G-capable vehicles as early as 2024 and 2025.

This discrepancy may place European vehicle manufacturers at a competitive disadvantage, potentially resulting in long-term negative consequences for the continent and its entire automotive supply chain. The lag in technological adoption poses a significant threat, particularly considering the reliance of many European economies, such as Germany and Eastern European nations like Hungary, on the automotive industry. In an intensely competitive landscape, European manufacturers often rely on components from numerous Far-Eastern suppliers, enhancing productivity but diminishing the presence of European suppliers. This scenario extends to critical components like battery production.

The issue at hand is multifaceted, encompassing stringent environmental regulations imposed on manufacturers in Europe, inadequate communication channels between governments and manufacturers, and the regulatory framework outlined previously, all of which contribute to significant delays. Additionally, challenges such as chip shortages exacerbated by the COVID-19 pandemic further compound these issues.

5. Overview of Electric Vehicle Trends and Technical Solutions in the European Union

In Europe and around the globe, the volume of vehicles traversing roads is steadily increasing. This growth has resulted in a significant uptick in greenhouse gas emissions discharged into the atmosphere. It is crucial to underscore that this surge has not solely been propelled by transportation but also by industrial operations, agricultural practices, and many other human activities [195,196].

On the roads of Europe, one encounters both petrol and diesel vehicles, with diesel-powered vehicles not limited to trucks or heavy-duty vehicles but also prevalent among many passenger cars. Electric cars have emerged as a particularly promising alternative for mitigating greenhouse gas emissions. In both Europe and the US, the adoption of electric vehicles gained significant momentum following the Volkswagen diesel scandal in 2015. This scandal implicated Volkswagen and other manufacturers in tampering with emissions measurement software [197,198]. Not only have electric vehicles experienced a surge in popularity, but several major cities in Europe have initiated bans on vehicles equipped with outdated internal combustion engines as part of efforts to ameliorate air quality [199,200]. The ban to be enacted in 2035 by the European Union is expected to further propel the proliferation of electric vehicles, aided by advancements in battery technology [14]. Figure 1 illustrates the escalating trend in the sales of electric vehicles across Europe.

The expansion of electric vehicles promises a substantial reduction in carbon emissions over the medium and long terms. In response, many manufacturers have undergone revisions to their model lineups, discontinuing certain models and implementing bans on diesel engines, with some offering only hybrid-powered options. Unlike conventional vehicles, electric vehicles produce no local emissions, thus mitigating local pollution. Crucially, ensuring that the electricity utilized to charge these vehicles is sourced from renewable energy outlets is imperative [202,203]. On average, the carbon dioxide emissions per kilometer of new vehicles in the EU have decreased, as shown in Figure 2. The correlation between

Figures 1 and 2 is readily apparent. As vehicle manufacturers introduced products with new powertrains, the prevalence of conventional internal combustion vehicles declined, with many customers opting for electric vehicles over older, worn-out models. The beneficial outcomes of this transition are evident in Figure 2.

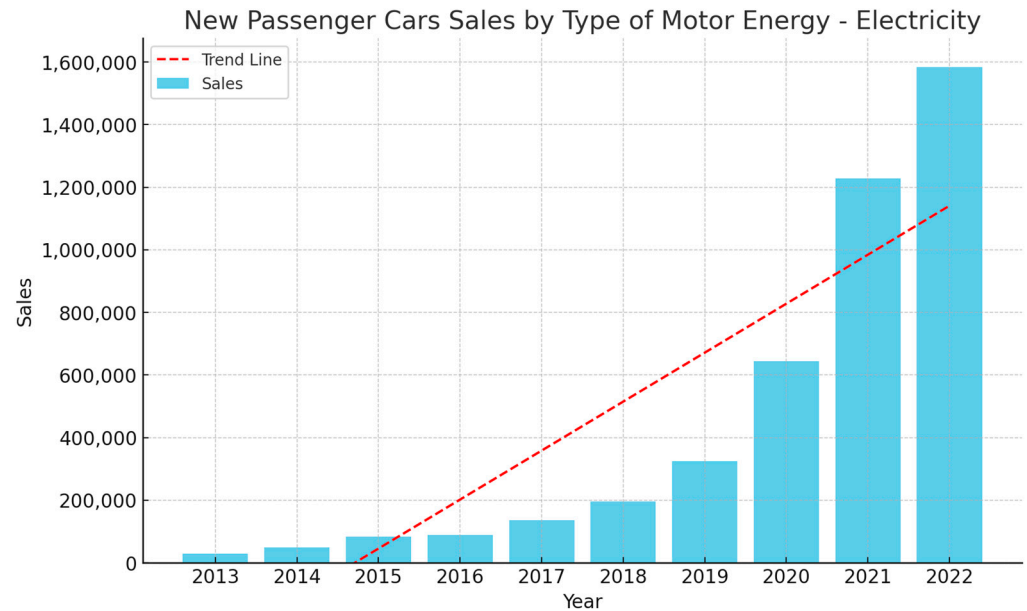


Figure 1. Number of new passenger electric vehicles in the EU [201] (data from EuroStat, Available online: https://ec.europa.eu/eurostat/databrowser/view/road_eqr_carpda_custom_10888778/default/table?lang=en (accessed on 7 April 2024)).

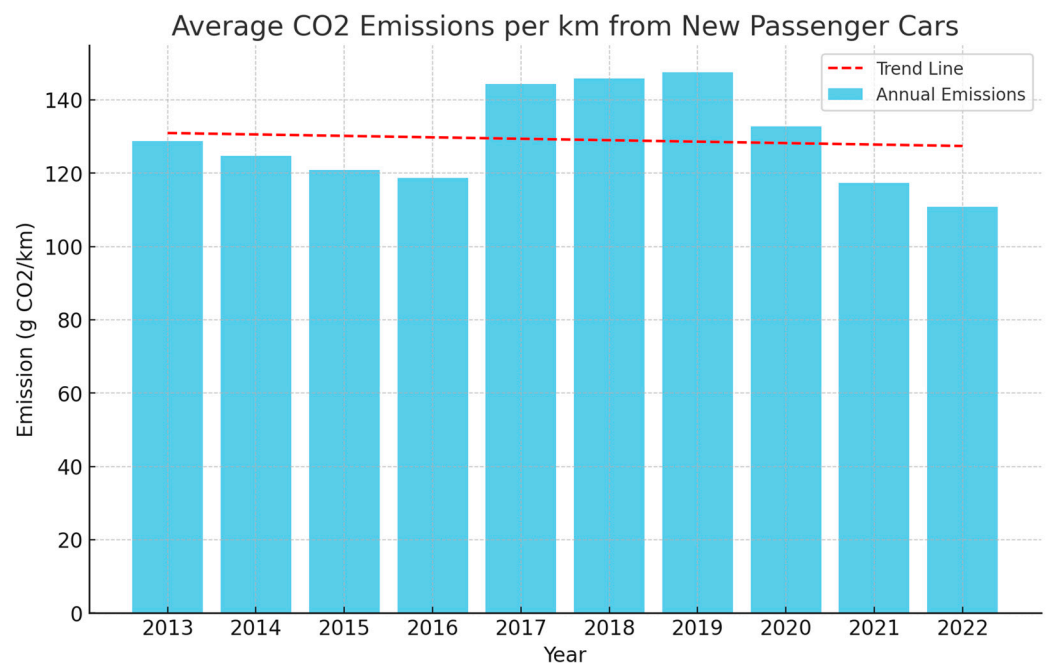


Figure 2. Changes in CO₂ emissions per km in the EU [204] (data from EuroStat, Available online: https://ec.europa.eu/eurostat/cache/metadata/en/sdg_12_30_esmsip2.htm (accessed on 7 April 2024)).

Electric vehicles offer a more cost-effective mode of transportation compared to conventional vehicles due to their simpler mechanics and reduced maintenance requirements [205,206]. Many governments are actively promoting the adoption of electromobility

through various incentives and subsidies. These initiatives aim to reduce the initial purchase cost, lower the total cost of ownership, and decrease operating expenses, rendering electric vehicles a compelling choice over traditional counterparts. In addition to direct price reductions, governments may offer tax incentives and other perks to vehicle owners, such as special schemes and free parking [207,208]. These incentives play a pivotal role in reshaping consumer preferences with respect to electric vehicles. However, the availability of charging infrastructure remains a critical concern, typically addressed through government funding. These concerted efforts have resulted in substantial growth in the electric vehicle market, particularly in China [209,210].

Infrastructure for Electric Vehicles

The infrastructure for electric vehicles comprises a multifaceted system encompassing battery chargers and swap stations, as well as the electrical grid and its associated control mechanisms. Research efforts are particularly concentrated on charging infrastructure. Despite a gradual increase in the number of public charging points across Europe, insufficient availability remains a pervasive issue (see Figure 3). Data on private charging points are not as readily available [211–214].

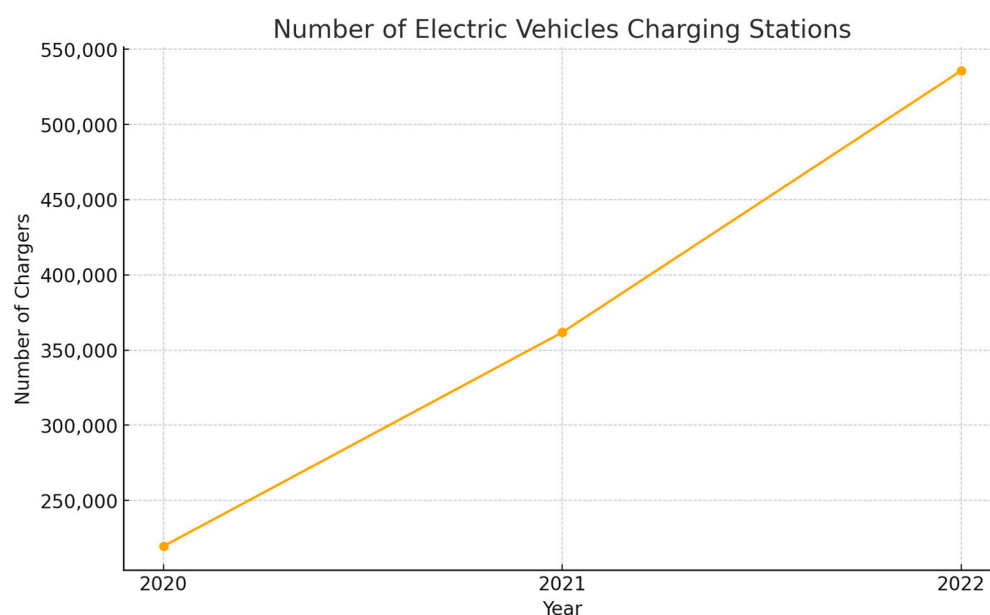


Figure 3. Number of public electric vehicle charging stations in the EU [213] (data from Statista, Available online: <https://www.statista.com/statistics/955443/number-of-electric-vehicle-charging-stations-in-europe/> (accessed on 7 April 2024)).

Presently, four distinct charging standards exist, each characterized by varying performance and charging times. While slow chargers are more cost-effective to install, they are less favored by users. The widespread implementation of Level 3 and Level 4 chargers is crucial for all EU countries [1,215,216].

Level 1 and Level 2 chargers typically require 2 to 8 h to fully charge batteries, operating within the range of 110 to 240 volts. On the other hand, Level 3 systems, also referred to as fast chargers, utilize 480 volts, enabling a quicker recharge time of 20 to 40 min [1,215,216].

The development of charging stations should consider alternative approaches, including integrating storage solutions and tapping into renewable energy sources. By doing so, charging points can potentially operate independently of the local conventional electricity grid, particularly when paired with intelligent systems. These integrated solutions offer opportunities to stabilize the electricity grid and optimize electricity pricing [1,215,216].

For heavy-duty electric vehicles (HDVs), a viable solution could entail replaceable batteries or electric road systems. Battery replacement presents a cost-effective option in such scenarios [217,218].

The infrastructure necessary for charging demands meticulous planning. Upgrading aged electricity grids necessitates costly capacity expansions. Additionally, in major urban centers, urban planning must consider the proliferation of electric vehicles, their influence on traffic flow, and parking requirements. A distinct strategy for vehicle charging and maintenance is imperative. In sizable residential complexes, simultaneous charging by numerous residents, potentially reaching up to a thousand vehicles, poses safety risks [53,211,212].

Primary charging methods encompass the following components [1,219]:

- Conductive charging:
 - a. AC Charging;
 - b. DC Charging;
- Inductive charging;
- Battery swap.

6. Electric Vehicle Implementation in Energy Communities

The integration of electric vehicles into energy communities holds significant promise. These vehicles offer grid flexibility and can function as storage batteries, aiding in grid operations. Despite the advantages, drawbacks such as accelerated battery wear and the need for vehicle owners to commit to using their vehicles as energy storage devices should be acknowledged [71,220,221]. Precise strategies are necessary for electric vehicles, as many manufacturers advise against charging batteries beyond 80% or discharging them below certain levels [222]. A technical challenge lies in determining whether utilizing batteries up to 85% capacity would substantially affect their lifespan and how this increased capacity could benefit an energy community.

In summary, the integration of electric vehicles into energy communities is associated with several positive impacts, as follows [71,220,221]:

- Reductions in greenhouse gas emissions;
- Improved air quality;
- Absence of local emissions;
- Enhanced energy independence, reducing reliance on energy imports;
- Cost reduction;
- Improved resilience of the existing electricity network;
- Increased sustainability;
- Utilization of renewable energy sources and their integration into the existing electricity grid.

6.1. Energy Policy, Consumption, and Production in the European Union

The European Union's energy policy prioritizes energy security and the adoption of renewable energy sources, with increasing consideration given to addressing climate change in policy decisions. The 20/20/20 target, established in 2009, marked a significant initial milestone. It mandated Member States to increase their share of renewable energy to 20%, reduce greenhouse gas emissions by 20%, and enhance energy efficiency by 20%. Successfully meeting these targets prompted EU leaders to set new climate objectives for 2030, aiming to cut greenhouse gas emissions by 55% [223–225].

The Russian invasion of Ukraine prompted a shift in EU energy policy, leading to the introduction of REPowerEU, which underscores energy security and relies extensively on renewable energy sources. The European Renewable Energy Directive (RED) serves as a legal framework for renewable energy development, establishing common rules and targets for all Member States. RED II, effective from 2021, aims to elevate the utilization of renewable energy sources to 40% by 2030. It introduced guarantees of origin to certify energy from renewable sources [223–225].

Between 2004 and 2022, the proportion of renewable energy in the EU doubled. Figure 4 provides a comprehensive depiction of the share of energy derived from renewable sources in each EU Member State in 2022 [226].

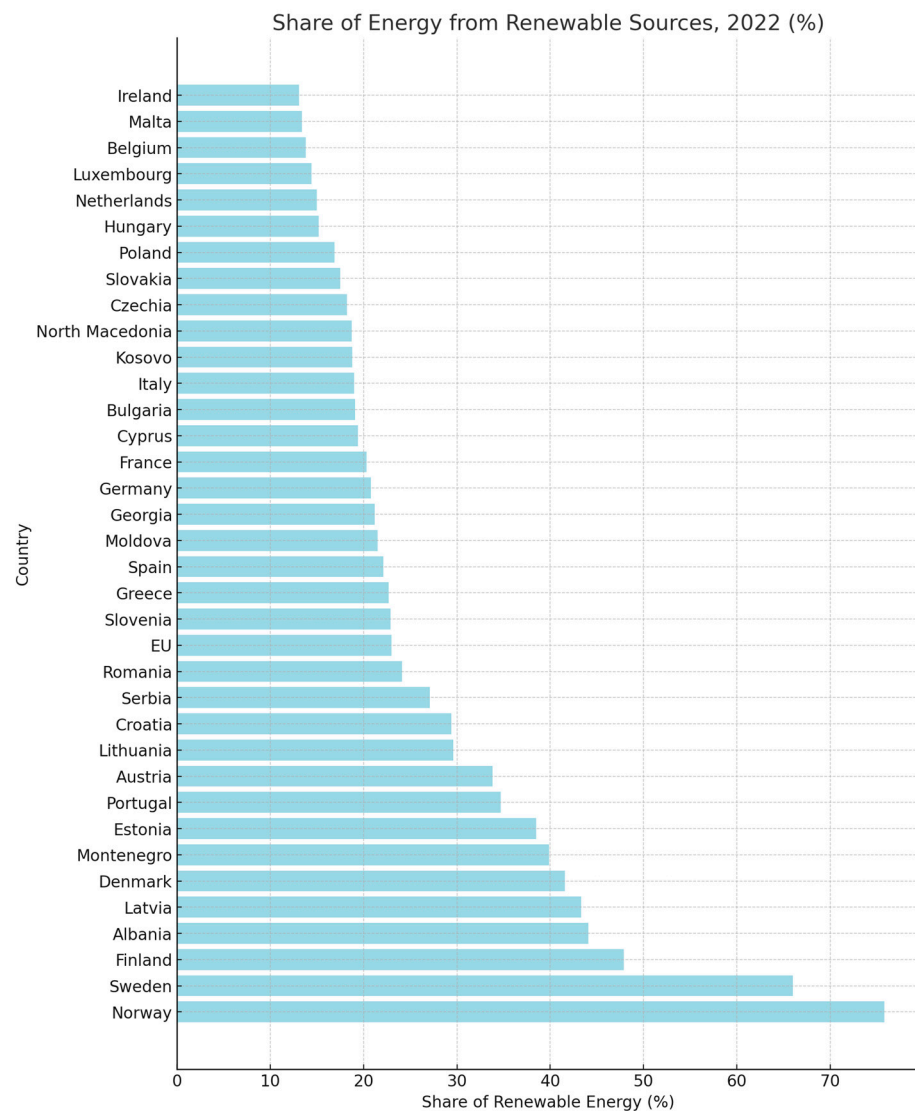


Figure 4. Share of energy from renewable sources in 2022 (%) [226,227] (data from EuroStat, Available online: https://ec.europa.eu/eurostat/databrowser/view/nrg_ind_ren/default/table?lang=en (accessed on 26 March 2024)).

The 2030 EU target stands at 42.5%. However, in 2022, only Sweden (66%), Finland (47.9%), and Latvia (43.3%) had managed to surpass this goal. Sweden and Finland achieved their remarkable performance primarily through the utilization of hydro and wind power, while Latvia relied mainly on hydroelectricity. Conversely, Ireland (13.1%), Malta (13.4%), Belgium (13.8%), and Luxembourg (14.4%) exhibited the lowest proportions of renewables in 2022 among the Member States [226,227].

Figure 4 illustrates the overall utilization of renewable energy sources, while Figure 5 depicts the proportion of renewable energy among total electricity consumption.

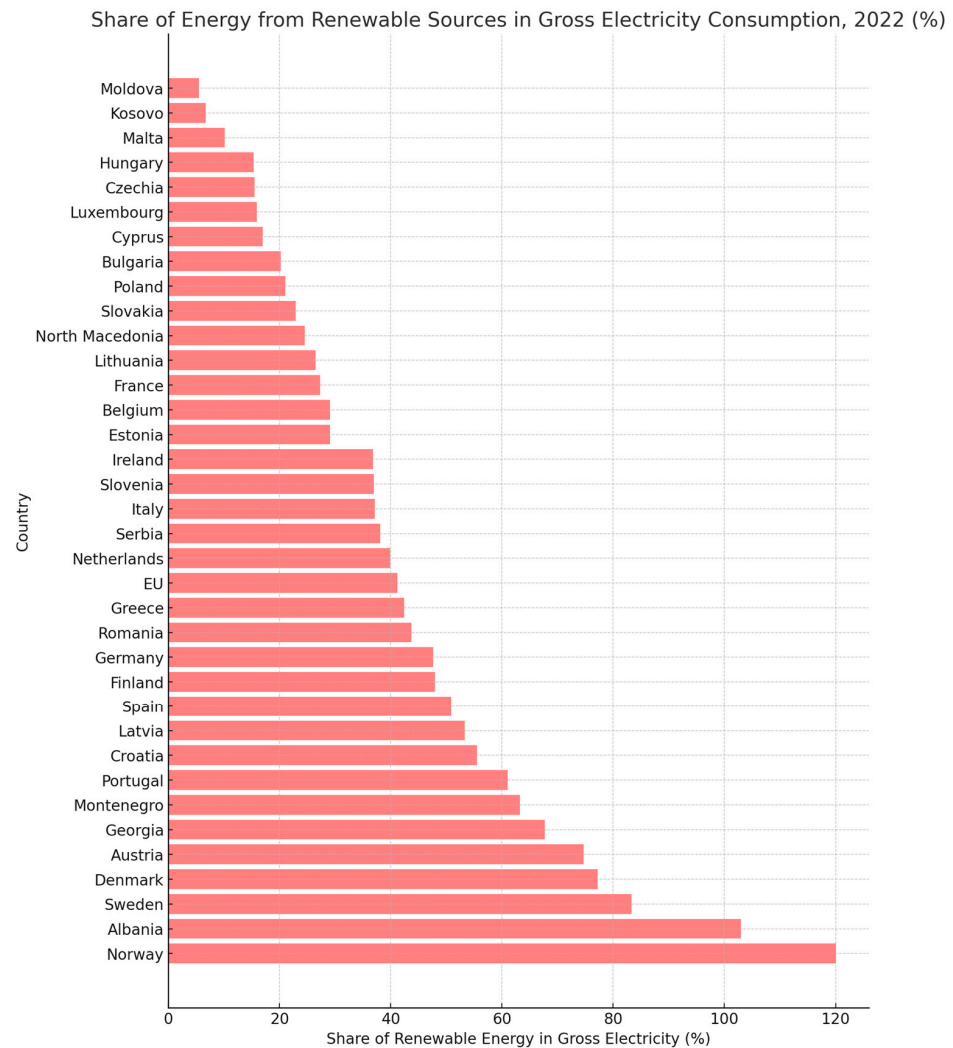


Figure 5. Share of energy from renewable sources in gross electricity consumption in 2022 [%] [226,227] (data from EuroStat, Available online: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Renewable_energy_statistics#Share_of_renewable_energy_more_than_doubled_between_2004_and_2022 (accessed on 26 March 2024)).

According to EU Directive 18/2001, electricity generated by water and wind energy must be harmonized, taking into account annual weather variations. Figure 5 provides an overview of these statistics. From 2012 to 2022, there was a significant surge in electricity production from renewable sources, primarily driven by wind and solar energy. In 2022, renewable energy accounted for 41.2% of gross electricity consumption—up from 37.5% in 2021 [226,227]. The percentage distribution of renewable electricity generation is outlined in Table 3.

Table 3. Distribution of renewable energy sources in electricity generation [226].

Renewable Energy Source	%
Wind energy	37.5%
Hydro power	29.9%
Solar energy	18.2%
Solid biofuel	6.9%
Other renewable sources	7.5%

The most remarkable growth has been observed in solar PV systems, rising from 7.4 TWh in 2008 to 210.3 TWh in 2022 [226].

Data indicate that 9.6% of renewable energy sources were utilized in transportation as of 2021, as depicted in Figure 6. EU Member States have collectively established a target of 29% by 2030 [226].

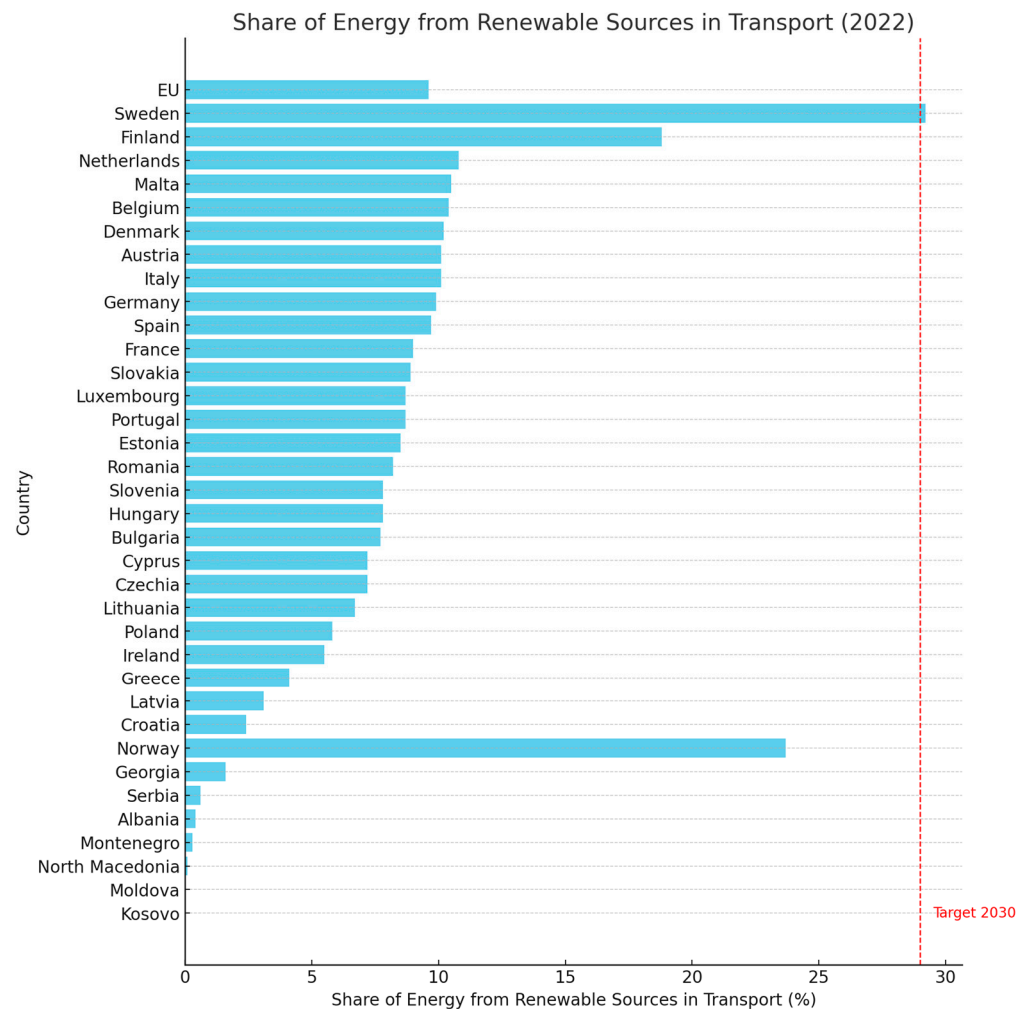


Figure 6. Share of energy from renewable sources in transport in 2022 [%] [226,227] (data from EuroStat, Available online: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Renewable_energy_statistics#Share_of_renewable_energy_more_than_doubled_between_2004_and_2022 (accessed on 26 March 2024)).

Renewable energy sources in the transport sector have shown gradual growth, increasing from 1.6% in 2004 to 9.6% in 2022. There exists significant divergence among Member States, with Sweden leading, at 29.2%, and Croatia lagging behind, at 2.4%. Notably, EFTA member Norway distinguishes itself with a substantial 23.7% utilization rate. In the domain of heating and cooling, renewable sources contribute significantly, accounting for 24.8% in 2022 compared to a mere 11.7% in 2004. This surge has been propelled by various industrial and domestic applications, including the widespread adoption of heat pumps [226,227].

The data illustrate an imbalance in the utilization of renewable energy sources among EU Member States, reflecting varied energy policies across the continent. This diversity stems from factors such as geographical characteristics and economic development levels. Notably, eastern (formerly socialist) countries lag behind in renewable energy utilization, as depicted in the graphs.

6.2. Vehicle-to-Home (V2H) and Vehicle-to-Grid (V2G) Initiatives in Europe

Research and development endeavors focusing on vehicle-to-home (V2H) and vehicle-to-grid (V2G) technologies are widespread globally. The majority of these projects are concentrated in North America and Europe. In 2018, Europe accounted for over half of such research initiatives, which is attributable to robust government backing and EU directives regarding climate change. The volume of development projects continues to grow steadily. Table 4 provides an overview of several V2G/V2H/V2X projects in Europe [228–231].

Table 4. V2X projects in Europe. Adapted from Ref. [230].

Country	Year	Project
The Netherlands	2014	Smart solar charging
Denmark	2016	Parker
France	2017	Grid Motion
Germany	2018	Re-dispatch V2G
Switzerland	2020	Equigy
The Netherlands	2021	Vehicle-to-grid and/or vehicle-to-home round-trip efficiency
Italy	2023	Stellantis Fast Reserve

The V2G Repository [229] includes 18 vehicle-to-grid projects being developed in Europe. This abundance of ongoing research highlights the considerable attention being given to the development of vehicle-to-home (V2H) and vehicle-to-grid (V2G) technologies. Notably, it is not just governmental bodies and research institutions driving these initiatives; automotive manufacturers like the Volkswagen Group are actively involved. Volkswagen, for instance, is integrating this technology into its ID model lineup [186,232].

The integration of electric vehicles into the power grids has become a pivotal area of research, offering promising avenues for the management of vehicles alongside buildings and, eventually, smart cities. However, this development encounters numerous challenges, including variations in the proportion of electricity generated from renewable sources across EU Member States and disparities in the condition of the electricity grid. In addition to addressing issues related to generation and local infrastructure, the deployment of smart meters and the implementation of incentives to encourage vehicle owners to transition from conventional to electric vehicles are crucial aspects that require further exploration due to their potential social impacts. Currently, there are just over 50 V2X (vehicle-to-everything) projects in progress worldwide, with half of them underway in Europe [231].

7. Discussion and Future Research Recommendations

The research objectives outlined in this article have been successfully addressed and answered.

1. Is there a correlation between the increase in the number of electric vehicles and CO₂ emissions?

Data provided by EuroStat indicate a significant increase in the number of newly registered vehicles in the European Union. There are various factors contributing to this surge, including government subsidies offering more favorable pricing for vehicles, tax incentives, and the impending ban on the registration of internal combustion engines by 2035. Additionally, many cities across Europe have already implemented restrictions on outdated internal combustion engine vehicles, further driving the shift towards electric alternatives. An analysis of Figures 1 and 2 clearly illustrates this trend, with average CO₂ emissions per kilometer steadily declining for new vehicles. Looking ahead, it would be beneficial to explore the average age of vehicles in the EU and their emissions in light of the introduction of new electric vehicles.

2. *To what degree do vehicle manufacturers incorporate vehicle-to-home (V2H) or vehicle-to-grid (V2G) technologies into their model fleets?*

Research highlights the significant innovation of vehicle-to-home and vehicle-to-grid technologies. Energy communities, as outlined by the European Union, are expected to play a pivotal role in the future (Section 2). Research on these technologies is currently in the testing or experimental phase, showing very promising results (Section 6). While most European manufacturers are still focusing on ensuring stable operation from the vehicle side, many manufacturers from the Far East already have vehicles capable of providing V2X solutions to users. US car manufacturers are set to enter the market with V2H and V2G models starting from 2024 and 2025 (Section 4).

3. *Has there been an improvement in battery capacity for electric vehicles, and if so, to what extent?*

Between 2015 and 2020, there was a significant increase in the battery capacity of electric vehicles. It is worth noting that manufacturers have tailored their models to different markets where they will be sold. The topic of batteries and capacity changes is discussed in Section 3.2. Driving and user habits vary between markets, such as the USA, Europe, and China. Typically, vehicles in the US are used for longer distances, resulting in the greatest capacity growth there. Growth in Europe and China has been more moderate compared to the US. A valuable research opportunity lies in examining the different battery markets for V2G and V2H systems. Leveraging user habits for more efficient battery utilization presents an excellent opportunity for machine learning (AI) methods.

4. *How balanced is the distribution of electricity sourced from renewable energy across European Union Member States?*

The European Union has established various directives that Member States must comply with in order to achieve the 2050 climate targets. Data provided by EuroStat highlight significant disparities among Member States regarding the utilization of renewable energy sources and electricity production (Section 6). Scandinavian countries exhibit a higher proportion compared to Eastern European nations, indicating a need for improvement. Diversified energy mixes should be developed by studying the geographical and geological potential of each Member State in the case of renewable energy sources.

5. *What are the scope and scale of research projects focused on vehicle-to-home and vehicle-to-grid technologies in Europe?*

The establishment of energy communities is mandated for the Member States of the European Union. The development of these communities, along with the implementation of electric vehicles, presents a range of significant technical challenges, including grid balancing, grid modernization, deployment of smart systems, and energy sharing among community members. There are over 50 official projects worldwide focused on vehicle-to-home and vehicle-to-grid technologies, with nearly half of them located in Europe, particularly in Western Europe (Section 6). To enhance European energy security and independence, there is a need to increase the number of research projects. Ensuring the stability of the technology across the vehicle manufacturing, service provision, and construction sectors is crucial for the effective integration of vehicles into energy communities or smart cities. Research efforts should also address larger buildings and complexes.

The extensive use of over 200 peer-reviewed references underscores the thoroughness of this study in addressing the raised questions. It highlights the significance of integrating vehicles into energy communities while revealing a substantial competitive disadvantage faced by European nuclear manufacturers compared to their counterparts. Infrastructure development emerges as a crucial concern within the European container industry.

The imperative for European manufacturers to enhance V2X development for future progress cannot be overstated. Moreover, robust network development is indispensable for energy suppliers.

This study, drawing from extensive databases and a literature review, underscores the intricate and multi-faceted nature of development in this domain, including the following aspects:

- The development of electric vehicles capable of V2X technology;
- Electricity network development;
- Expansion and promotion of renewable energy sources in the Eastern EU Member States;
- Harmonized regulatory frameworks and standards.

Aligning these potentials is imperative to enable the effective functioning of energy communities. The development of regulations transcends mere technicality; it represents a multifaceted political endeavor, necessitating the concerted effort of each EU Member State.

8. Conclusions

This article describes the main features of electric vehicles and an important EU directive aimed at fostering the development of energy communities. It also explores the possibilities of integrating vehicles into buildings, the electrical grid, and other installations.

Furthermore, this study delves into electric vehicle batteries and the evolution of the number of charging points across Europe. It notes the continuous increase in the number of newly registered electric vehicles in the European Union.

The integration of electric vehicles into smart cities holds the potential to create sustainable and efficient urban environments with lower operating costs, reduced greenhouse gas emissions, and improved air quality. Government support plays a crucial role in expanding the adoption of battery-powered vehicles, offering the opportunity to integrate vehicles into tram networks or buildings.

However, the utilization and deployment of these technologies face several challenges, including high initial costs, varying quality and condition of electrical network systems, and disparities in infrastructure among EU Member States.

This article discusses forward-looking vehicle-to-home (V2H) and vehicle-to-grid (V2G) technologies, drawing a comparison with the current state of vehicle manufacturer models. It points out that V2H and V2G technologies are predominantly available in models from Asian manufacturers, with European and US manufacturers lagging behind in this aspect. This discrepancy could pose a problem from the European perspective, potentially impacting economic competitiveness, energy independence, and energy security.

Furthermore, this article highlights the differences in the use of renewable energy sources among EU Member States. The presented graphs illustrate significant differences between countries.

The development of V2G and V2H systems is deemed crucial for achieving climate protection objectives and ensuring energy security. Most of the research in this field is conducted in Europe, particularly in Western Europe.

The study brings to light compelling political and social dilemmas that transcend mere technical or technological remedies. These issues are poised to have a myriad of social ramifications, the ultimate outcomes of which remain uncertain. While car-sharing solutions have gained traction and acceptance, the prospect of communal energy sharing poses a similar question: will society embrace energy sharing within communities? The ongoing transition from internal combustion engine vehicles to electric vehicles in Europe is progressing swiftly but is not without its challenges. In addition to infrastructure gaps, many individuals' lifestyles are ill-suited for slow charging or limited ranges. Moreover, the lack of uniformity and differing speeds of regulation across EU Member States exacerbate these difficulties.

For future advancements and research endeavors, a sociological inquiry is imperative. This entails examining the adaptability and receptiveness of users, establishing a cohesive regulatory framework, and addressing technological hurdles to ensure progress.

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