

## Article

# A Comprehensive Study on the Expansion of Electric Vehicles in Europe

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**Abstract:** There has been a rapid increase in government efforts to expand electric vehicle markets by deploying fast-charging stations, promoting uptake through greater investment, and by enacting supportive policies. Government support and private investment have contributed to the expansion of electric vehicles in many countries. The aim of this study is to highlight and analyze the most critical aspects of the expansion of the electric vehicle market, regarding technologies, characteristics, advantages and disadvantages, opportunities, and barriers in Europe. Our study analyzes the progress of electric vehicles by reviewing recent literature based on technology, policy, and government measurements. This study provides comprehensive information on electric vehicles and perspectives that are critical to policymakers, car manufacturers, consumers, and the community. To achieve favorable results, governments should invest in developing electric vehicles and battery technologies, provide subsidies, and develop charging infrastructure. Furthermore, by analyzing current EV sales in ten countries around the world, we assess the operating costs of electric vehicles. Overall EV cost of ownership is influenced by grid electricity price, cost of financing, location, carbon tax, wind speed, and solar insolation.

**Keywords:** electric vehicles (EVs); renewable energy; technology; charging stations



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## 1. Introduction

The importance of the environment for future generations has led to a global push to develop clean transportation options to mitigate climate change [1]. In recent years, electric vehicle (EV) sales have increased [2], as EVs have grown in popularity worldwide and provided new opportunities [3]. There is no doubt that EVs can play a key role in the future energy system, which will further accelerate their development [4]. As reported by International Energy Agency (IEA), global sales of EVs doubled to 6.6 million in 2021 from the previous year. In this regard, the development of EVs and associated technology, in particular fast-charging stations, has increased rapidly in previous years [5]. Moreover, significant government support, combined with private investment, has helped with both the uptake of electric vehicles and the development of charging infrastructure worldwide [6].

Following a decade of rapid growth, the global EV market experienced a decline in sales in 2019 due to the outbreak of the COVID-19 pandemic. There was, however, a temporary reduction in EV sales. The US market for EVs is predicted to rise approximately threefold between 2022 and 2028, compared to the world market, demonstrating the importance of EV development for people and governments [7].

There have been several studies related to the development of EVs in recent years, some of which are outlined as follows. For instance, Razmjoo et al. investigated the development of EVs for smart cities. They showed that EVs are able to produce CO<sub>2</sub> reductions, while simultaneously helping to improve transport options for smart cities in the future [8]. Gnann et al. investigated the potential to reduce greenhouse gas emissions using plug-in EVs in Germany in 2020. They showed that both energy prices and the cost of batteries have a large impact on the evolution of the plug-in EV market. Therefore, plug-in EVs were expected to account for between 0.4% and 3% of German passenger car stock by 2020 [9].

In order to deal with severe environmental problems, as well as managing energy systems, Hu investigated the impact of policy on EV diffusion. Policies such as support for infrastructure construction and production subsidies can increase the uptake of EVs to 70% [10]. A long-term EV forecast and its potential impact on the electricity grid were conducted by Kapustin and Grushevenko. It was shown that with heavy government support, 11–28% of the global fleet can be converted to electric cars by 2040 [11]. Mo et al. examined trends and emerging technologies for the development of EVs. There are a number of emerging technologies in the EV development industry that are mentioned in this paper, such as vehicle-to-grid (V2G) systems, smart power distribution, vehicle-to-vehicle networking, wireless charging, and vehicle-to-home (V2H) [12]. They also evaluated the commercialization of EVs in Hong Kong as a key case study. As a first step, they discussed the challenges facing private EV owners, including inadequate access to charging infrastructure and insufficient management of public facilities, as well as difficulties finding suitable repair and maintenance services. Subsequently, they presented the challenges for commercial EVs such as limited commercial models, charging infrastructure, long charging times, and insufficient parking places. Eventually, the authors offered strategies for promoting EVs, including promoting technological innovation, offering incentives for commercial EVs, strengthening stakeholder relationships, creating fast-charging stations, offering active development of commercial EVs, facilitating the installation of charging infrastructure for private EVs, and encouraging the participation of the private sector in promoting fee-based services [13].

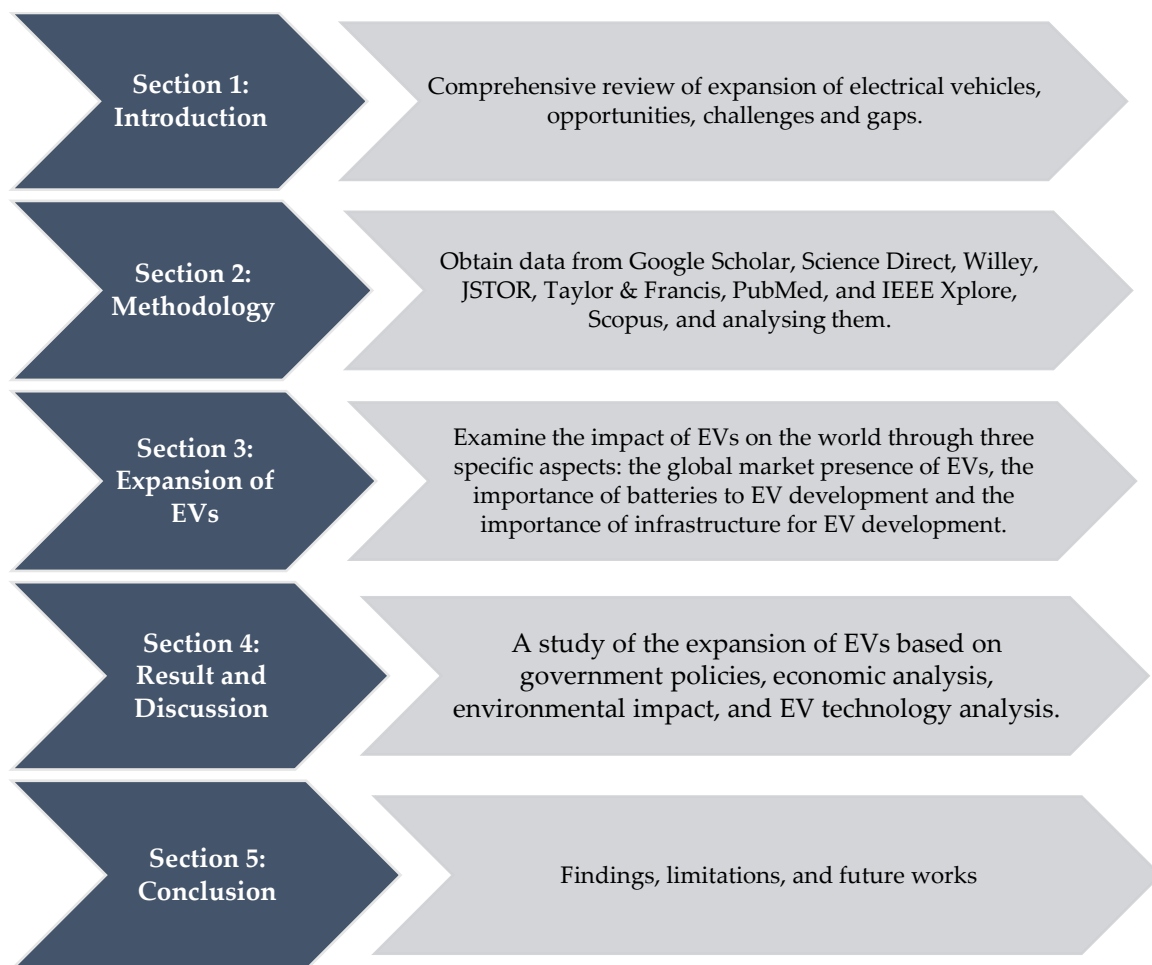
Based on the analysis in [14], there were approximately 7.3 million EV chargers worldwide at the end of 2019, of which 0.9 million were public. Additionally, the number of EVs produced in Europe is expected to increase from about three-quarters of a million in 2019 to more than four million in 2025. Another strand of studies focused on the areas of EV adoption and purchase intentions by customers. For example, Wang et al. (2017) classified policy measures into three categories—financial incentives, public education, and convenience policies—and examined how each of these motivate consumers to adopt EVs [15]. In another study conducted by Lou et al., consumers' attitudes toward new energy vehicles (NEVs) were analyzed statistically, and the effects of NEV policies were identified with a structural equation model (SEM). It was found that consumers prefer hybrid electric vehicles (HEVs) and plug-in electric vehicles (PEVs), however, they are not sufficiently knowledgeable about NEVs and their policies [16]. Javid et al. applied the Norm Activation Model (NAM) to identify travelers' adoption behavior towards EVs in the contexts of pro-social and pro-environmental behaviors in Pakistan. According to their findings, travelers' awareness regarding the social, economic, and environmental perks of EVs contributes to the development of positive personal norms [17].

Previous studies have focused only on specific aspects of EVs, leaving other aspects untouched. This study, however, extends previous studies by examining the most critical aspects of the expansion of the EV market, including technologies, features, advantages/disadvantages, opportunities, and barriers.

Following the previous studies, this research examines the expansion of EVs across the world. A major focus of this study is to examine how well EV expansion relies on proper planning, government strategies, and cooperation between governments in different countries while addressing stakeholder needs. This study contributes to the understanding of EV markets by specifying the key features of EV technologies, and examining the drivers for the expansion of infrastructure, and applications. Moreover, this paper presents the most important policies, strategies, and factors for supporting the development of EVs, by simulating various renewables-based on-grid system scenarios using Homer software. The findings provide critical information for decision-makers, investors, economic agents, and stakeholders. Another novel aspect of this research is that previous studies have typically focused on one key aspect of EV development, while this work simultaneously covers and integrates four important subjects for analysis of EVs: political, economic, environmental, and technological analysis. Finally, the obtained results pinpoint details for each specific area, pinpointing the main problems and suggesting effective solutions.

## 2. Methodology

The expansion of EVs is not easy for governments and policymakers in different countries, but appropriate policies and strategies can overcome existing problems. The purpose of this paper is to find problems and present proper solutions for expanding the use of EVs. The objectives of the literature review are as follows: (1) present a comprehensive overview of EVs and their technologies; (2) identify their characteristics and classify them accordingly; and, (3) determine challenges, advantages/disadvantages, obstacles, opportunities, policies, and solutions. The first step is providing an overview of previous studies and identifying the relative literature. A systematic search was conducted using peer-review papers from scientific databases, books, and Ph.D. dissertations. We considered keywords including electric vehicles (EVs), energy storage, batteries, environment, renewable energy, and policy. We have conducted an exhaustive review of more than 350 publications relevant to EVs using keywords such as expansion, policies, existing problems, and solutions. In this regard, we searched using established scientific databases, such as scientific journals' websites, Web of Science, Scopus, and Google Scholar. In addition, to better understand the concepts of EVs, we examined more than 200 peer-reviewed journals and 150 technical papers. Review articles helped us understand the development of EVs and their new technologies that have come under the spotlight within a short period of time. Moreover, technical articles provided a deeper understanding of applications, effective policies in the development of EVs, opportunities, and barriers in the field. In the next stage, we categorized articles based on their scope, aims, and methodology, and then selected 102 papers with the most relevant concept to EVs. Finally, we identified several significant factors concerning EVs, including their technologies, characteristics, barriers, advantages, and drawbacks. The methodology of this paper is depicted in Figure 1. Following the collection of all relevant papers, the papers were categorized into two groups: technical and review papers, and the methodology used was based on these papers.



**Figure 1.** Research Methodology.

### 3. The Importance of Developing Electric Vehicles

Vehicles powered by electric motors have significant benefits, including less consumption of fossil fuels, lower greenhouse gas emissions, lower fuel costs, and lower maintenance costs. The purpose of this section is to show the importance of EVs in the world. This section contains the following subsections:

- Section 3.1. Participation of EVs in global markets
- Section 3.2. Importance of batteries and battery prices to develop EVs
- Section 3.3. The remarkable role of the infrastructure of EVs

#### 3.1. Participation of Electric Vehicles in the Global Markets

The rapid growth of vehicle ownership resulted in some critical issues such as energy security risk [18], environmental pollution [19], and rising greenhouse gases (GHG) emissions [20]. As a solution to the above challenges, EVs are becoming more popular [21]. Fortunately, these years, with regard to both governments' and people's positive attitudes, financial incentives, and fossil fuel problems especially for the future, EVs have found an essential role in the world markets [22]. In this regard, governments have offered various incentives in many countries to promote the diffusion of EVs [23]. Consequently, EV manufacturing and charging infrastructure is expanding every day. Different countries around the world, such as the US [24], China [25], India [26], Norway [27], the UK [28], Australia [29], and Germany [30], are implementing plans to develop EVs, and EV markets, to improve transportation and reduce CO<sub>2</sub> emissions. Despite the COVID-19 pandemic, EV ownership has increased impressively worldwide over the last three years. In 2020, global EV sales reached three million, which accounted for 4.1% of global automobile

sales. In 2021, global EV sales had a remarkable growth rate of 108%. Over 6.6 million EVs were sold, roughly 9% of the global automobile market, tripling from two years prior to that [31]. This illustrates that EV sales are increasing year by year [32]. According to research, with 3.4 million registrations and around 53% of global EV sales, China is the world's largest market for EVs. As reported by Canalys, in 2021, over 3.2 million EVs were sold in Mainland China—half of all EVs sold worldwide [33]. Europe has the second-largest stock of electric cars in the world after China. The European Union registered 2.3 million cars in 2021, which accounted for 34% of the worldwide stock. The growth rate of EV sales in Europe was 64.3% in 2021, which is an impressive increase. Additionally, the United States has the third-largest market for electric cars. Figure 2 [34], displays the passenger electric vehicle sales from 2015 to 2022. According to a report by Bloomberg NEF, global sales of electric passenger vehicles in 2022 will reach 10.5 million, about four million above 2021 levels.

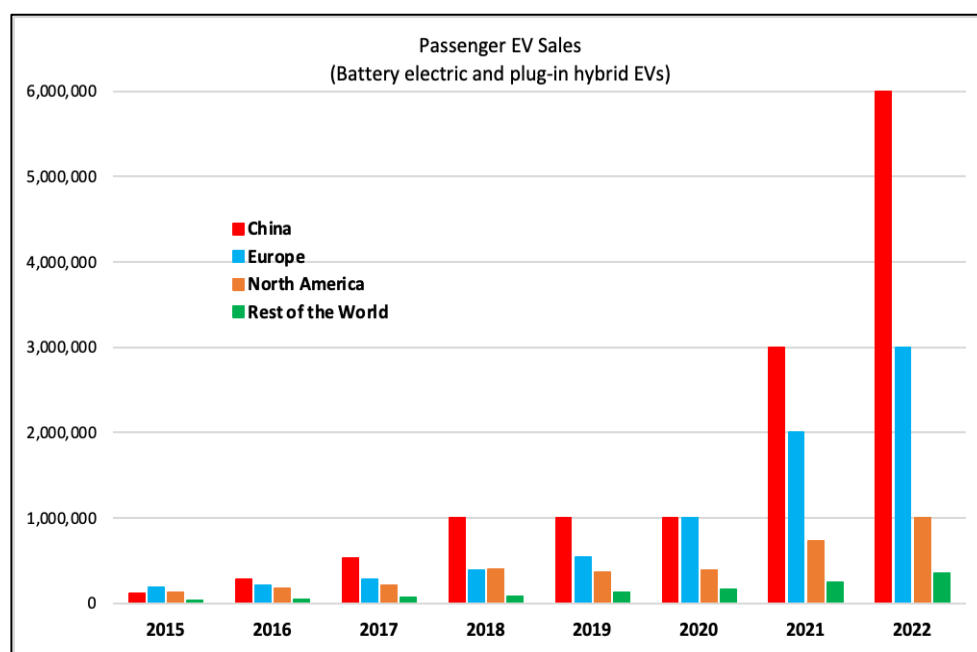


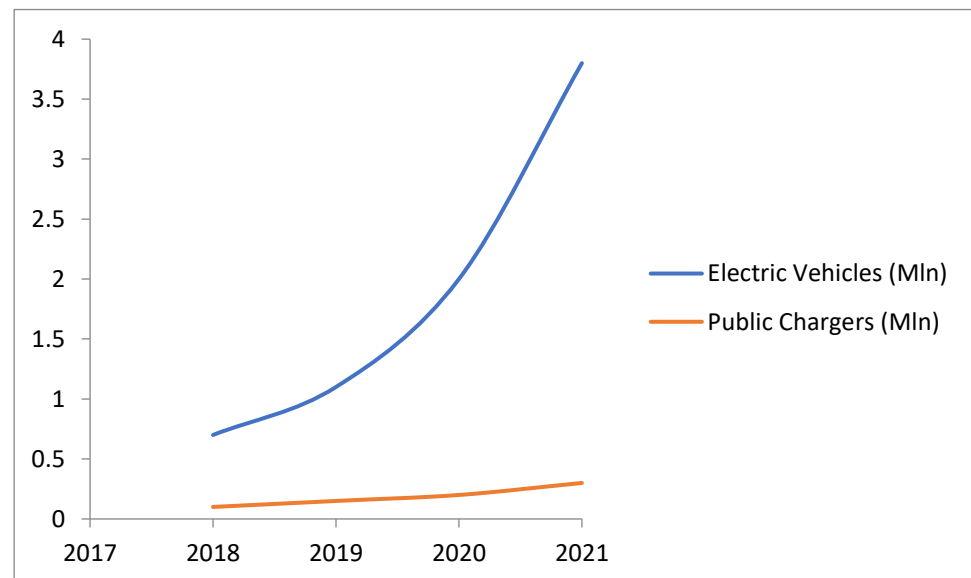
Figure 2. Passenger electric vehicle sales from 2015 to 2022 [34].

### 3.2. Importance of Battery and Battery Prices to Develop EVs

In order to develop EVs that provide efficiency and energy savings, the battery is the most important component. Indeed, there are no EVs without batteries. It is obvious that investors and customers are interested in the energy-saving features of EVs. The development of batteries for EVs is, therefore, crucial [35]. There are different types of battery chemistries used in EVs, such as Lithium-ion (most popular), Lead-Acid, Nickel-Cadmium, Nickel-metal hydride, and Nickel-iron. Also, the use of several other types of batteries is being investigated, such as the Iron-air battery, Aluminium-air battery, or Vanadium redox flow battery [36–41]. EVs are often still unable to meet all of their energy and power needs for all required conditions, despite advancements in battery technology. EVs regularly operate with non-monotonic consumption of energy, which is accompanied by frequent changes during the battery discharging process, which can be harmful to the electrochemistry of the battery. In this regard, coupling the battery with a supercapacitor may be a practical solution. The supercapacitor in this design can provide the required energy excess. Electrical engineering is also very important when designing the architecture of the corresponding hybrid system [42]. In addition, the development of commercialized lithium-ion batteries with benefits such as safety, lifetime, energy density power, and cost requirements of the EV economy has allowed for greater development of EVs [43,44].

### 3.3. The Critical Role of Infrastructure in Supporting Deployment of EVs

Without a doubt, the lack of adequate and suitable charging infrastructure is one of the main challenges to the development of EVs in different countries [45]. A robust network of charging stations is essential for electric car drivers. Fortunately, the charging infrastructure of EVs is currently being developed in many countries. Considerable efforts towards the development of EV charging infrastructure have been carried out to implement effective indicators in the community, such as energy demand management from EVs, managing energy intensity, and considering environmental impacts such as charger's intensity distribution and carbon intensity [46,47]. Therefore, the development of residential charging, electrified public transportation through electric buses, and public charging in electrified highways can be useful for every country, and in densely populated areas will also play a key role over the next decades to reduce air pollutants [48]. However, Williams et al. [49] analyzed the infrastructure and technology requirements in California, and concluded that simply using the most technologically advanced types of energy supply now available will not be enough. They demonstrated that transportation and other sectors will need to be converted largely to electrical systems, which would make decarbonized electricity the dominant form of energy supply. It means transformation will require technologies that are not yet commercialized, and intensive public-private and interindustry coordination at every stage of the process. Figure 3 [50] shows the number of public chargers, and the number of EVs in European countries between 2018 to 2021. As can see in this figure, there has been a remarkable increase in both public chargers and number of EVs in these countries, despite all European countries dealing with the COVID pandemic during these years.



**Figure 3.** Number of public chargers, and number of EVs (EU-27).

## 4. Result and Discussion

In this section, the development of EVs based on PEST (Political, environmental, social, and technological) analysis is investigated. This section contains the following subsections:

- Section 4.1. Expansion of EVs based on government policy
- Section 4.2. Economic analysis of EV development
- Section 4.3. Expansion of EVs based on environmental considerations
- Section 4.4. Technological analysis of EV development
- Section 4.5. Findings and recommendations



#### 4.1. Expansion of EVs Based on Government Policy

The EV market is an increasingly important aspect of the automotive industry. Globally, EVs will replace fossil fuel vehicles in the future. Therefore, having proper policies for their development is critical and fruitful. Policies such as government subsidies, investment in research especially for batteries, utilization of new technology, congestion charge exemptions, incentives to purchase and use EVs, improvement of charging infrastructure (and innovation in charging infrastructure such as rapid charging stations) will be required [51,52]. In order to increase the popularity of EVs, governments are implementing policies that support their use. Despite this, there are still issues to be resolved. From a political perspective, the expansion of EVs is easy due to their environmental friendliness (when EV batteries and electricity are sustainably sourced) and public support. Therefore, it only requires investments, attention to consumer preferences, a few cultural changes, and the expansion of road infrastructure (the availability of charging points is an important factor in expanding electric vehicles). Through appropriate policies and strategies, governments should emphasize the development of EVs and the reduction of fossil fuel vehicles [53,54]. In addition, Ryan and LaMonaca believe public charging infrastructure is an important enabler of the deployment of EVs, and has a better effect on national EV market share than financial incentives. Their findings show that additional charging stations resulted in a better impact on EV market share compared with consumer incentives, according to their research [55].

#### 4.2. Economic Analysis of EV Development

EV development faces a number of challenges, one of which is demonstrating the economic benefits of EVs. Indeed, economic analysis of EVs for both investors and buyers is essential and should be taken into account. As long as they believe that EVs do not provide economic benefits, they will never develop them, own them, or recommend them to anyone else [56]. Manufacturers believe and prove that EVs reduce fuel consumption and provide economic benefits in the form of additional disposable income that creates jobs and improves the economy. The economic benefits of EVs are greater than those of conventional gas or diesel cars. Electric automobiles can help improve fuel economy, enhance energy security, reduce fuel costs, create jobs, and mitigate greenhouse gas emissions. Also, EVs can play a crucial role in the green economic transition that is necessary for economic development. With their contribution to improving air quality in cities, we can reach a zero-emission world. Another economic advantage of electric cars is their lower maintenance costs. Compared to traditional fuel cars, they have fewer parts that result in less damage so you can save more on operating costs. Over the life of the vehicle, an EV will cost significantly less than a diesel or petrol car [57]. EVs also have significantly better performance than conventional fuel-powered cars because their acceleration is very high. Due to the decreased use of fossil fuels, EVs receive government grants and tax incentives to improve efficiency, reduce production costs, and decrease electricity costs, which results in lower prices for EVs [58]. In 2021, a study was conducted in Ethiopia about the economic feasibility of EV charging including PV/Wind/Diesel/Battery Hybrid Energy. The findings of this research indicate that the feasible configuration of Solar Photovoltaic/Diesel Generator/ZnBr battery systems has the lowest net present cost with values of \$2.97 M, \$2.72 M, and \$2.85 M and that the cost of energy (COE) in Addis Ababa, Jijiga and Bahir Dar is \$0.196, \$0.18 and \$0.188. It shows that electric vehicles can be developed, with due consideration of all calculations [59].

#### 4.3. Expansion of EVs Based on Environmental Considerations

The emissions from fossil fuels that cause climate change harm our planet as well as our health. A great solution is to reduce fossil fuel consumption by introducing new modes of transportation, such as EVs [60]. EVs are generally regarded as a promising and effective solution to reduce air pollution in cities, as they help optimize environmental management more efficiently [61]. Therefore, governments' investment in the expansion of

EVs, zero-emissions technologies (renewable energy), and hydrogen as a sustainable fuel is a viable alternative due to EVs' long-term environmental benefits. Thereby, countries are looking for innovations in EVs [62]. Although electric vehicles have many advantages, such as reducing fossil fuel consumption, their large lithium-ion batteries require a lot of materials and energy to manufacture, meaning that they can still contribute to global warming, as do gasoline cars. This suggests that we need sustainable materials to have a healthy environment [63,64]. South Korea has appropriate policies in the clean energy movement such as EVs. For example, this country in 2017, when they purchase an electric car, offered tax reductions and government subsidies to their citizens. A total of 133 electric cars were registered in 2017, in Suwon city, composed of 20 city government vehicles and 113 privately owned vehicles. This was almost 0.03% of the total registered cars in this city and 44.3% of the city policymakers' goal [65]. Also, it can be added that in the interest of the Indian government solving issues of energy security, air pollution, and climate changes, special attention has been paid to plug-in electric vehicle (PEV) deployment; however, there are some problems, such as high land rent prices and the lack of land availability in Indian cities for the establishment of charging infrastructure [66].

#### 4.4. Technological Analysis of EV Development

There are four main types of EVs, including plug-in hybrid electric vehicles (PHEV), hybrid electric vehicles (HEV), fuel cell electric vehicles (FCEV), and battery electric vehicles (BEV) [67]. In each of them, the role of technology and innovation is not hidden. Therefore, the utilization of new technology and innovation results in higher uptake by consumers [68]. Figure 4 which is drawn based on the results of reference [67,68], shows four main types of EVs.

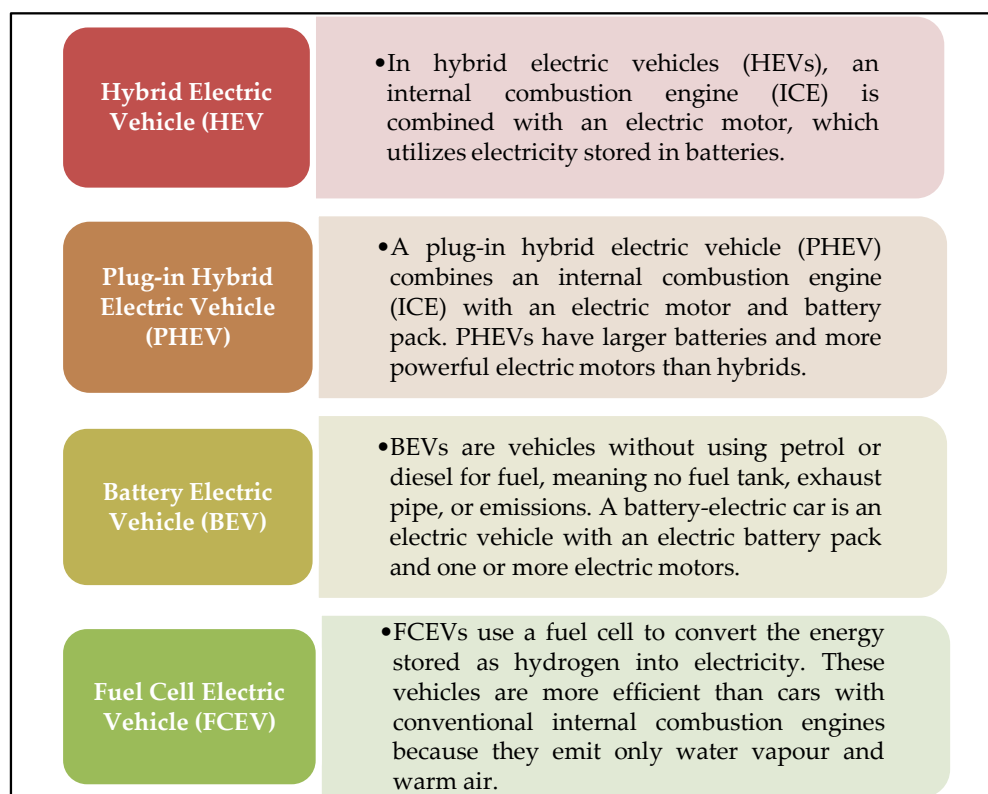


Figure 4. Type of Electric Vehicles [67,68].



Therefore, key technologies regarding charging of batteries, and electric motors to improve EVs' efficiency, reliability, and safety are important [69]. Mercedes, Volkswagen, and Ford are all attempting to further develop the technology of EVs [70–72]. Moreover, the statistics of EV patents in the last 30 years show that the number of patents increased rapidly and reached its historical peak in 2012 was more than 20,000 patents [73]. In addition, many countries have introduced new energy vehicles (NEVs) as an alternative to conventional cars in order to reduce their dependence on oil. For example, as the world's largest automotive market, China has reduced the consumption and import of oil to promote NEVs. Additionally, European countries, the US, and Japan have a remarkable plan for developing technologies for NEVs [74,75]. In this regard, developing advanced technologies related to EVs such as vehicle-to-grid (V2G), vehicle-to-infrastructure (V2I), batteries, vehicle-to-vehicle (V2V), integration of artificial intelligence (AI) and V2X, vehicle-to-pedestrian (V2P), and mechanisms, and communication technologies to face different users are increasing [73].

#### 4.5. EV Charging Stations

Table 1 lists the top ten countries in Europe in terms of electric car sales in 2020 [76]. Grid electricity price [77], interest rate [78], selected station in the country, geographical coordinates, altitude from sea level, carbon tax [79–89], average annual wind speed, and average annual solar radiation are other parameters presented in Table 1. The station under study was selected as the capital of each country. The data in Table 1 are input to HOMER software for technical-economic-environmental-energy simulation over 25 years. The methodology of the performed simulations as well as the schematic of the studied systems (wind and solar) are given in Figures 5 and 6. As can be seen, the systems under study are connected to the national electricity grid and also use batteries as a backup [90].

**Table 1.** European countries with the highest EV sales in 2020.

| Country     | Capital    | Grid Price (\$/kWh) [77] | Interest Rate (%) [78] | GMT | Coordinates          | Elevation (m) | Carbon Tax (\$/Tonnes) [79–89] | Annual Average Wind Speed (m/s) | Annual Average Solar Radiation (kWh/m <sup>2</sup> -Day) |
|-------------|------------|--------------------------|------------------------|-----|----------------------|---------------|--------------------------------|---------------------------------|--|
| Norway      | Oslo       | 0.141                    | 0.75                   | +2  | 59°54' N<br>10°44' E | 17            | 57.52                          | 2.5                             | 2.75   |
| Iceland     | Reykjavik  | 0.140                    | 3.75                   | 0   | 64°08' N<br>21°56' W | 61            | 32.16                          | 6                               | 2.10   |
| Sweden      | Stockholm  | 0.176                    | 0.25                   | +2  | 59°19' N<br>18°47' E | 44            | 122.21                         | 3.6                             | 2.87   |
| Netherlands | Amsterdam  | 0.199                    | 0                      | +2  | 52°22' N<br>4°45' E  | −4            | 96.48                          | 5                               | 3.03   |
| Finland     | Helsinki   | 0.179                    | 0                      | +3  | 60°10' N<br>24°56' E | 56            | 82.55                          | 3.9                             | 2.73   |
| Denmark     | Copenhagen | 0.344                    | −0.6                   | +2  | 55°40' N<br>12°34' E | 28            | 164.21                         | 3.8                             | 2.91   |
| Switzerland | Bern       | 0.206                    | −0.75                  | +2  | 46°56' N<br>7°26' E  | 540           | 130                            | 4.3                             | 3.52   |
| Portugal    | Lisbon     | 0.239                    | 0                      | +1  | 38°43' N<br>9°9' W   | 95            | 25.5                           | 3.7                             | 4.86   |
| Germany     | Berlin     | 0.331                    | 0                      | +2  | 52°31' N<br>13°24' E | 47            | 64.31                          | 3.9                             | 2.74   |
| Luxembourg  | Luxembourg | 0.221                    | 0                      | +2  | 49°36' N<br>6°7' E   | 376           | 21.44                          | 3.5                             | 3.01   |

Table 2 shows equations governing the different parts of wind-grid and solar-grid systems. The information on pollutants produced by the national electricity grid is given in Table 3.

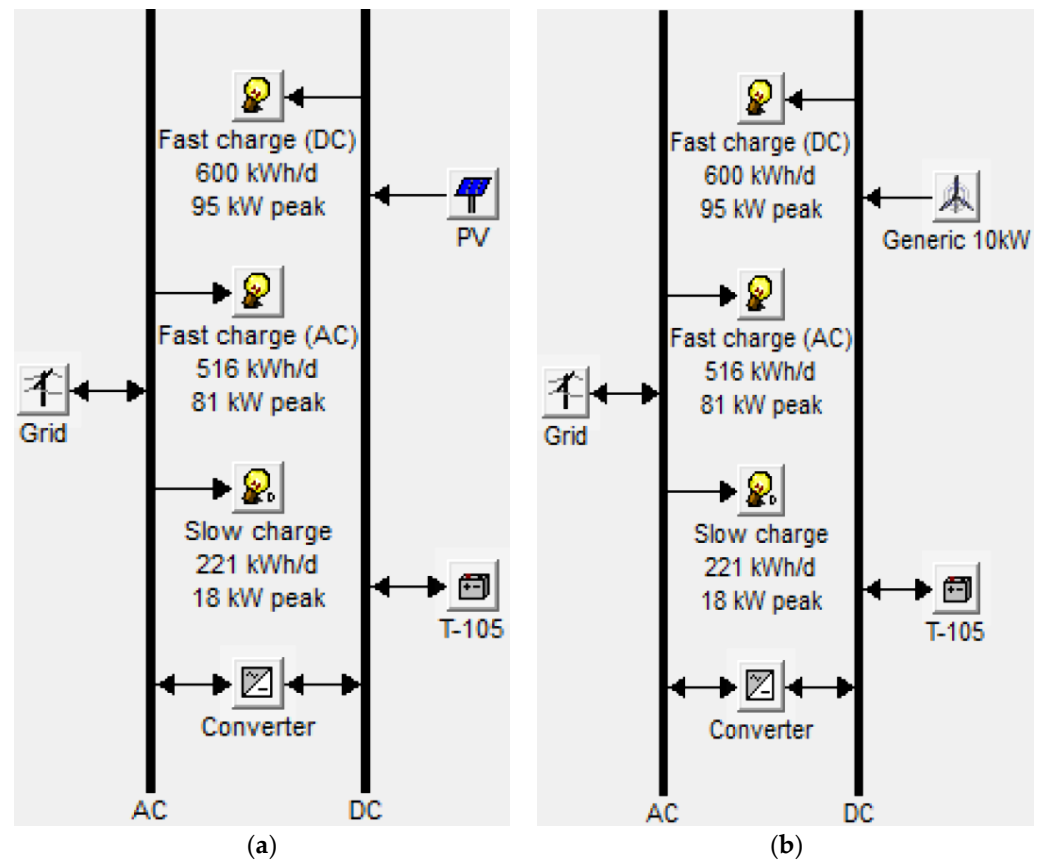


Figure 5. Schematic of systems under study in HOMER (a) Solar-based system (b) Wind-based system.

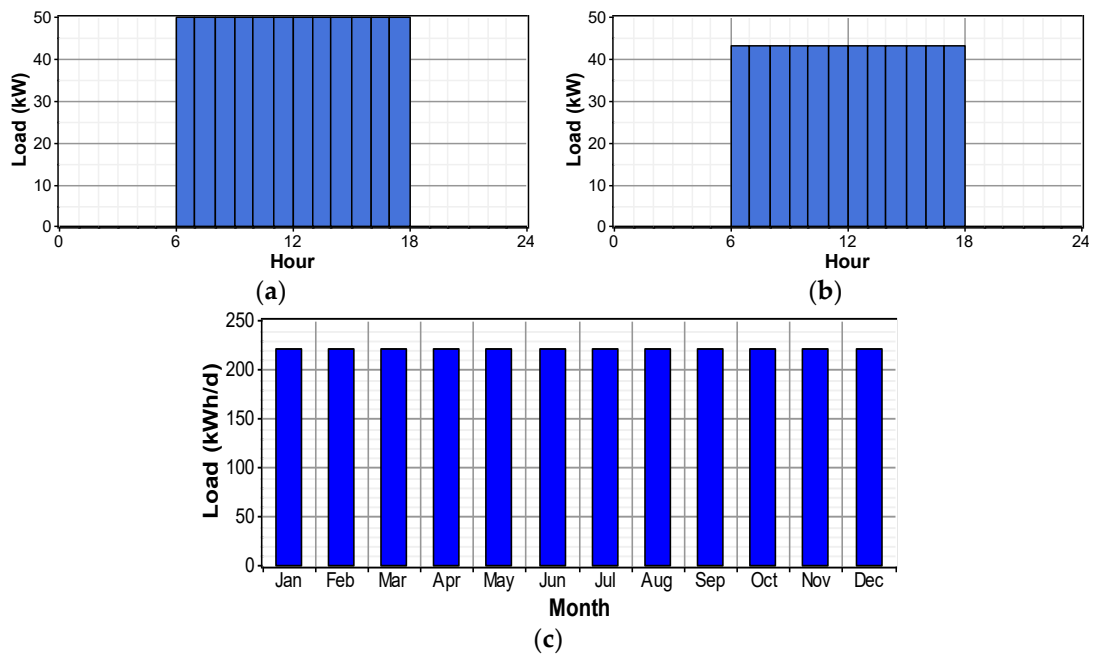


Figure 6. Electricity profile: (a) DC fast charge, (b) AC fast charge, (c) AC slow charge.

**Table 2.** Governing equations.

| Parameter                      | Equation   | Reference |
|--------------------------------|--|-----------|
| Wind turbine output power      | $P_{WTG} = \frac{\rho}{\rho_0} \times P_{WTG, STP}$  | [91]      |
| PV cell output power           | $P_{PV} = Y_{PV} \times f_{PV} \times \frac{H_T}{H_{T,STC}}$   | [92]      |
| Battery maximum power          | $P_{batt.cmax} = \frac{\text{Min}(P_{batt.cmax.kbm}, P_{batt.cmax.mcr}, P_{batt.cmax.mcc})}{\eta_{batt.c}}$  | [93]      |
| Electricity exchange with grid | $C_{grid,energy} = \sum_i \sum_j^{rates} \begin{cases} E_{net \text{ grid purchases},i,j} \cdot C_{power,i} & \text{if } E_{net \text{ grid purchases},i,j} \geq 0 \\ E_{net \text{ grid purchases},i,j} \cdot C_{sellback,i} & \text{if } E_{net \text{ grid purchases},i,j} < 0 \end{cases}$ | [94]      |
| Total net present cost (NPC)   | $\text{Total NPC} = \frac{C_{ann,total}}{(1+i)^N}$   | [95]      |
| Levelized cost of electricity  | $LCOE = \frac{C_{ann,total}}{E_{Load \text{ served}}}$   | [96]      |

**Table 3.** Information on production pollutants.

| Item      | Properties  |
|-----------|---|
| Grid [97] | Carbon dioxide: 632 g/kWh, Sulfur dioxide: 2.74 g/kWh, Nitrogen oxide: 1.34 g/kWh |

Figure 6a shows the daily electrical charge for fast DC charging, and Figure 6b depicts the daily electrical charge for fast AC charging. Moreover, Figure 6c illustrates the daily electrical charge for slow AC charging. HOMER V2.81 software uses daily or hourly variability in synthesizing artificial data. The “Random Variability” inputs for the “electric load” allow the user to add randomness to the load data to make it more realistic. HOMER V2.81 software assembles the year-long series of load data from the daily profiles. Then, in each time step, it multiplies the value in that time step by a perturbation factor  $\alpha$ :

$$\alpha = 1 + \delta_d + \delta_{ts} \quad (1)$$

HOMER V2.81 software randomly draws the time-step perturbation value every time step from a normal distribution with a mean of zero and a standard deviation equal to the time-step-to-time-step variability (Timestep) input [98].

Table 4 also provides information on the capital price, replacement, and operating and maintenance (O&M) of equipment used, their size, and other functional specifications.

The results of the simulations performed using HOMER 2.81 software, are provided in Table 5. According to the results, the lowest and highest prices per kWh of electricity generated by the PV-grid scenario are \$0.164 (Norway) and \$0.386 (Denmark), respectively. For electricity generation by wind turbine-grid scenario, these prices are \$0.093 (Iceland) and \$0.422 (Denmark), respectively. As a general conclusion, Denmark has the highest cost for the construction of EV charging stations by wind and solar energies. The reason for this can be related to the high penalty of pollutants for electricity on the grid. The average prices per kWh of electricity generated for PV-grid and wind turbine-grid scenarios for the countries under study are \$0.236 and \$0.246, respectively. Furthermore, the wind turbine-grid scenario is economically preferable to the PV-grid scenario only in Iceland and the Netherlands. Conversely, in other countries, the PV-grid scenario is more cost-effective than the wind turbine-grid scenario. This is due to the appropriate wind speed situation in these two countries. Also, the use of wind and solar energies is economically necessary for other countries and scenarios, except in Norway, where the only-grid system is a priority.

**Table 4.** Wind-solar-electricity grid system equipment data studied in the present work.

| Equipment                  | Cost (\$) |             |     | Size (kW) | Other Information   |
|----------------------------|-----------|-------------|-----|-----------|---|
|                            | Capital   | Replacement | O&M |           |   |
| Converter [99]             | 200       | 200         | 10  | 0–100     | Lifetime: 10 years<br>Inverter Efficiency: 90%<br>Rectifier Efficiency: 85% |
| Battery Trojan T-105 [100] | 174       | 174         | 5   | 0–25      | Lifetime: 845 kWh<br>Nominal specs: 6 V, 225 Ah                             |
| Generic 10 kW DC [101]     | 6118      | 6118        | 35  | 0–10      | Lifetime: 19 years<br>Hub height: 25 m                                      |
| Solar PV [102]             | 1000      | 1000        | 5   | 0–100     | Lifetime: 25 years<br>Derating factor: 80%                                  |

**Table 5.** Simulation results for renewable-based on-grid scenarios for 10 European countries.

| Country         | Component  | LCOE (\$/kWh) | Renewable Fraction (%) | PV/Wind Production (kWh/Year) | Net Purchases from Grid (kWh/Year) | Emission (kg/Year) |
|-----------------|--|---------------|------------------------|-------------------------------|------------------------------------|--------------------|
| Norway          | PV (100 kW), Converter (80 kW)                       | 0.164         | 20                     | 101,254                       | 412,158                            | 260,484            |
| Norway *        | Wind turbine (100 kW), 10 Battery, Converter (80 kW) | 0.197         | 1                      | 1262                          | 525,158                            | 331,900            |
| Iceland         | PV (100 kW), Converter (80 kW)                       | 0.165         | 14                     | 71,768                        | 445,280                            | 281,417            |
| Iceland         | Wind turbine (100 kW), Converter (80 kW)             | 0.093         | 43                     | 250,653                       | 271,584                            | 171,641            |
| Sweden          | PV (100 kW), Converter (80 kW)                       | 0.226         | 20                     | 104,481                       | 408,299                            | 258,045            |
| Sweden          | Wind turbine (100 kW), 5 Battery, Converter (80 kW)  | 0.250         | 11                     | 56,753                        | 465,976                            | 294,497            |
| The Netherlands | PV (100 kW), Converter (80 kW)                       | 0.231         | 20                     | 103,380                       | 409,913                            | 259,065            |
| The Netherlands | Wind turbine (100 kW), Converter (80 kW)             | 0.191         | 29                     | 162,766                       | 358,020                            | 226,269            |
| Finland         | PV (100 kW), Converter (80 kW)                       | 0.209         | 19                     | 100,069                       | 413,630                            | 261,414            |
| Finland         | Wind turbine (100 kW), 5 Battery, Converter (80 kW)  | 0.218         | 14                     | 76,155                        | 445,832                            | 281,766            |
| Denmark         | PV (100 kW), Converter (80 kW)                       | 0.386         | 20                     | 105,365                       | 407,318                            | 257,425            |
| Denmark         | Wind turbine (100 kW), 5 Battery, Converter (80 kW)  | 0.422         | 13                     | 67,431                        | 454,520                            | 287,257            |
| Switzerland     | PV (100 kW), Converter (80 kW)                       | 0.242         | 24                     | 122,280                       | 388,704                            | 245,661            |
| Switzerland     | Wind turbine (100 kW), Converter (80 kW)             | 0.255         | 18                     | 95,934                        | 424,954                            | 268,571            |
| Portugal        | PV (100 kW), 10 Batteries, Converter (70 kW)         | 0.194         | 32                     | 162,976                       | 344,761                            | 217,889            |
| Portugal        | Wind turbine (100 kW), 5 Battery, Converter (80 kW)  | 0.247         | 12                     | 63,852                        | 458,717                            | 289,909            |
| Germany         | PV (100 kW), Converter (80 kW)                       | 0.332         | 18                     | 95,144                        | 418,479                            | 264,479            |
| Germany         | Wind turbine (100 kW), 5 Battery, Converter (80 kW)  | 0.347         | 14                     | 73,389                        | 448,270                            | 283,306            |
| Luxembourg      | PV (100 kW), Converter (80 kW)                       | 0.211         | 20                     | 101,857                       | 411,329                            | 259,960            |
| Luxembourg      | Wind turbine (100 kW), 5 Battery, Converter (80 kW)  | 0.236         | 10                     | 50,665                        | 472,302                            | 298,495            |

\* This is not the top economic scenario.

According to the results of Table 5, the highest percentage of renewable electricity production, at 43%, is related to Iceland and the wind turbine-grid scenario, which produces 250,653 kWh of wind power annually. The lowest rate of 1% (1262 kWh of annual electricity) corresponds to Norway and the wind turbine-grid scenario. High wind speeds in Iceland and low wind speeds in Norway are the reasons for this. Also, the lowest and highest annual CO<sub>2</sub> emissions are about 172 tons (wind turbine-grid scenario in Iceland) and 332 tons (wind turbine-grid scenario in Norway), respectively.

## 5. Conclusions

The importance of emission reductions and energy savings, together with various related issues, has largely driven the development of the EV market to date. Actually, expanding the use of EVs is a logical and practical action that can be taken by governments. Worldwide, EV popularity has increased, resulting in different opportunities, while EVs will play an increasingly important role in the future power grid. In 2019 the global EV market experienced a decline in sales due to the economic impact of the COVID-19 pandemic. However, this was a temporary phenomenon. There is no doubt that as the number of EV models available increases and become available on the market, the production volume will rise as well. On the other hand, famous companies such as Tesla, Nissan, Ford, Honda, Fiat, Tata, and Toyota have many plans to overcome current hurdles and become leading manufacturers in the EV industry. Governments and investors will need a positive view of regulatory policies and competition in this field, while paying attention to consumer sentiment. Currently, EV manufacturers are working to provide a high level of customer satisfaction by paying attention to their financial concerns and emphasizing the energy and running cost savings that EVs can offer.

The aim of this study is to shed light on the most important aspects of EV technologies, opportunities, characteristics, advantages/disadvantages, and barriers in Europe. We comprehensively discussed EVs and the perspectives of different countries in relation to expanding them. Based on the results, it can be concluded that there are different drivers for policymakers and car manufacturers in the development of EVs. For example, the expansion of EVs needs new technology, especially for batteries, fast-charging stations, suitable investments, government support for EV manufacturers, affordable prices for consumers, government subsidies, funding for battery research, congestion charge exemptions, incentives to purchase EVs, and improvement of charging infrastructure. Innovations in charging technology and increased charging stations are necessary in the near term in order to attract drivers. EVs have been developed and promoted by countries such as China, the U.S., the UK, France, Germany, India, Italy, Sweden, Hong Kong, Australia, and Japan despite all the problems mentioned. In these countries, companies such as Tesla, Mercedes, Volkswagen, and Ford are producing new technologies to mitigate these problems, developing advanced technologies related to EVs, including vehicle-to-infrastructure (V2I), vehicle-to-grid (V2G), integrating artificial intelligence (AI), batteries, vehicle-to-vehicle (V2V), vehicle-to-pedestrian (V2P), mechanisms, and communication technologies to handle a wide range of users. Although, the batteries available now, being one of the main components of electric vehicles, cannot always meet the possible energy requirements of future EV needs, remarkable progress has been achieved regarding different types of batteries in electric vehicles, such as Lithium-ion (most popular), Acid batteries, Nickel-Cadmium batteries, Nickel-metal hydride batteries, and Nickel-iron batteries. On the other hand, research on new types of batteries such as Aluminium-air, Vanadium redox, iron-air battery are continuing. Governments must pay close attention to providing the EV charging infrastructure required for the widespread use of EVs by private citizens, and commercial and industrial users. Our future is closely linked to the development of EVs, and we must be looking forward to new types of EVs, as they surely will have positive effects on our lives. However, converting the vehicle fleet to electric cars is complicated and needs suitable policies. The successful development of EVs is critically dependent on factors such as consumer adoption of EVs, charging price and time, and charging infrastructures.

Additionally, consumers' preference for affordable vehicles with large driving ranges and high operating efficiency signals to manufacturers that battery technology must continue to be improved. This combination of government policy, consumer demand and preferences, ongoing technological developments, and environmental concerns will undoubtedly be the main drivers for the rapid expansion of EV markets in every country over the coming decades. In addition, regarding limitations of this study and possible future works, it can be stated that financial support for EVs development is one of the most important factors that governments can be involved with. Most governments are concerned about investing in EVs, but it is still not clear which policies will be most effective in which locations, nor how much investment in EV development will be required. Future studies could investigate the effectiveness of a wide range of policies after they have been implemented and in place for longer periods of time, could review the ongoing development of batteries made from non-rare metals and the associated price trajectory of batteries and EVs, could examine the mass-market appeal of EVs as more EV models become available, and could investigate the optimal co-development of networks of EV chargers as EV driving ranges evolve.

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