

Received April 2, 2022, accepted May 12, 2022, date of publication May 16, 2022, date of current version May 24, 2022.

Digital Object Identifier 10.1109/ACCESS.2022.3175585

# Comprehensive Assessment of Electric Vehicle Development, Deployment, and Policy Initiatives to Reduce GHG Emissions: Opportunities and Challenges

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**ABSTRACT** Embracing innovative vehicle technology in the transportation sector provides constructive solutions to the rising pollution levels and global warming. Developing Electric Vehicles (EV) with market competency, deploying standardized charging infrastructure in sufficient numbers, and government promotional policies all impact EV adoption and help reduce tail pipe emissions. To determine the key hurdles to EV adoption that still exist in today's market, the comparison between the most preferred EV and the Conventionally Propelled Vehicle (CPV) is deliberated under various parameters like vehicle class, type, specification, performance, pricing etc. The research assessed the countries with the most CPV (China, the USA, Japan, Germany, and India), as well as the expertise and experience of the country (Norway) that pioneered the EV industry, to discover the key policies that will help accelerate EV adoption in their respective regions. Significant findings within the local market and across markets belonging to the countries of concern and research recommendations addressing the issues have been discussed as a result of the study conducted with data obtained from the vehicle manufacturer's website, government statistical institutes, and other affiliated survey organizations, as well as technical reports published online. These qualitative and quantitative findings and recommendations will aid in the creation of EV and charging station designs, as well as the formulation of strategies aimed at generating more cost-effective EV designs that take into account local usage patterns, car kinds, and performance. It also assists legislators in their efforts to streamline EV policy. Consideration of these issues aids in the reduction of greenhouse gas (GHG) emissions.

**INDEX TERMS** Air pollution, electric vehicle, charging station, charging standards, policy.

## I. INTRODUCTION

One of the most essential aspects of every country's economic development is transportation [1]. According to the International Organization of Motor Vehicle Manufacturers: Organization International des Constructeurs Automobiles (OICA), around 917 million automobiles were sold worldwide since 2011 [2]. Asia, Europe, and North America account for

The associate editor coordinating the review of this manuscript and approving it for publication was Francisco Perez-Pinal<sup>1</sup>.

more than 90% of all vehicles sold worldwide. At present, the market is dominated by the Conventionally Propelled Vehicles (CPV) comprising of Internal Combustion (IC) and Compression Ignition (CI) engines [3]. In the last ten years, China and the United States of America (USA) registered 258 and 164 million vehicles, respectively. China, the USA, Japan, India, and Germany are among the countries that have sold more than 30 million vehicles between 2011 and 2020.

According to the World Health Organization (WHO), the reliance on oil by road vehicles has resulted in severe

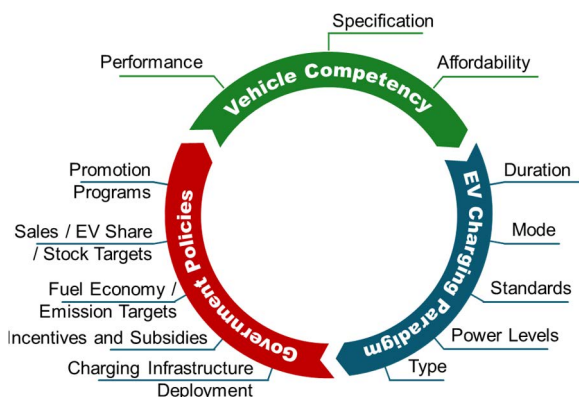


FIGURE 1. Key aspects for market gap analysis.

air pollution [4], [5] with over 91% population exposed to pollution levels over the recommended levels, resulting in 7 million premature deaths every year [6]. Particulate Matter (PM) 2.5 levels in Hotan, China is around  $110.2\mu\text{g}/\text{m}^3$  meanwhile 36 of the top 50 most polluted cities in the world are in India, with PM<sub>2.5</sub> levels ranging from 55.5 to  $150.4\text{g}/\text{m}^3$ , making it unhealthy for living [6], [7]. With an average global temperature increase of  $1.4^\circ\text{F}$  over the century, transportation generates the most  $\text{CO}_2$ , hence, contributes the most to global warming [8], [9]. Strong oil usage, on the other hand, allows reservoirs to drain at a rate of 4 billion tons per year, depleting all known reservoirs by 2053 [10]. Because of growing worries about air pollution levels, global warming, and the rapid depletion of oil supplies, the government has developed stringent vehicle emission rules requirements (Euro IV [11] /Bharat VI [12]) and is looking for alternative fuel cars that are eco-friendly and emission-free [13]. Since China, the USA, Japan, India, and Germany are leading in CPV sales, they have been considered for further investigation in this article.

Electric Vehicle (EV) is the most promising contestant for achieving climate and pollution-related goals [14]. In [15], the major variables that influence customers' intends to use EVs in Malaysia were assessed, while in [16], a few other important elements such as car performance, regulations, and so on were also considered to investigate their impact on EV adoption. EV Opportunities and challenges studies in [17] have suggested that OEMs and battery manufacturers should set up operations in Lithuania to expedite EV adoption. In this article discusses the results of a comprehensive assessment conducted between CPV and EV to identify market gaps and make recommendations for faster and wider EV adoption. The key factors considered that underpin EV uptake are categorized under: a) vehicle competency, b) EV charging paradigm and c) Government Policies concerning EV and are presented in Fig. 1.

The sales data of the countries under consideration were evaluated to determine the most preferred/best-selling vehicle class and category/type classification in the respective

regions. The classification is based on the U.S. Department of Energy's guidelines. In section 2, the competence between CPV and EV has been analyzed in terms of pricing, vehicle specifications, and performance to analyze more about the technical constraints that cause bottlenecks for EV adoption. In section 3, the charging time, access to charging facilities, standardized modalities of power transfer, and other factors available/accepted in the countries covered are thoroughly analyzed, thereby the direct and indirect barriers to a widespread adoption of EVs are identified. The strategies and main aims in the nations of concern were reviewed in section 4 to find the significant variables in their policies that drive EV forward. Before summarizing the work in the conclusion, the article identifies the barriers that still remain in today's EV business, as well as solutions for overcoming these hurdles.

## II. COMPETENCE OF VEHICLE IN CURRENT SCENARIO

### A. AN OVERVIEW OF THE CPV AND EV MARKET

Passenger Cars (PCs) accounted for 40 million in the first three quarters of 2021, up from 37 million in the same period last year [2], [18]. Between 2016 and 2021, China sold 150 million PCs on average, compared to 86 million in the United States. Since, the volume of PCs sale is higher; the research investigation presented in this article shall pertain to the four-wheeler car class. PCs come in a variety of shapes and sizes, including hatchbacks, sedans, Sports Utility vehicles (SUVs), mini-cars, and other types. Customers' preferred vehicle class in a given region can potentially be used to determine usage patterns.

EV registrations increased 41% globally in 2020, exceeding previous records despite the Covid-19 outbreak. During this time, 3.1 million additional EV registrations were reported, increasing the total number of EVs on the road to 10 million. According to the International Energy Agency (IEA), there are around 10.2 million EV-PC stocks available worldwide [19]. Table 1 presents the comparison of pre and post COVID-19 EV sales in the countries of concern. (+) indicates an increase in EV sales whereas (-) signifies a decrease in EV sales due to COVID-19 impact.

According to Acumen Research and Consulting, the EV sector is predicted to increase at a rate of more than 25.6% each year from 2019 to 2026 [20]. Mckinsey estimates that 120 million EVs will be on the road by 2030 [21]. Nearly 17 million EV registrations are reported during 2021. China stands tall followed by Germany and the United States with 0.53 and 0.37 million units respectively. New EV sales registration during 2016 and 2021 is being presented in Fig. 2.

Japan's EV sales have been dropping for few years, while Norway's EV sales have been gradually increasing. EVs are still in their infancy in India, where two and three-wheelers dominate the market. In India, over 6000 EVs were sold in 2021. In China, EV registrations were increasing every

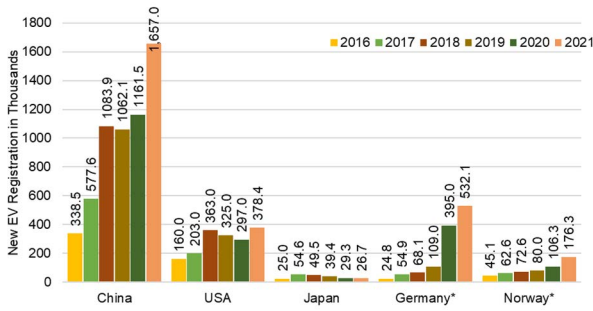


FIGURE 2. New EV registrations during 2016–2021.

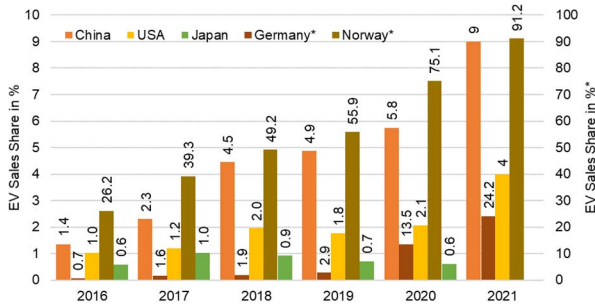


FIGURE 3. EV sales share during 2016–2021.

year, however, the sales share was still less than 6% in 2020. The statistical data for Fig.2 and Fig.3 were collected from the International Energy Agency (IEA) Global EV report for the year 2021 [19] complemented by the European Automobile Manufacturers Association (ACEA) [22], China Association of Automobile Manufacturers [23], European Alternative Fuels Observatory (EAFO) [24], Norwegian Vehicle Statistics [25] and EV world sales database (EV Volumes) [26]. The sales shares for the countries considered are reported in Fig. 3.

Norway’s EV sales share has remained at its best level in the last five years. By 2021, it had risen to 91%. Hence, Norway is also included in the list for analysis as it has set a benchmark in EV sales share. Consumer demand for EVs has increased as a result of substantial technological advancements.

**B. MOST PREFERRED CPVs AND EVs**

The most popular/best-selling models from each vehicle class from the countries investigated have been determined for the recent years [27]–[31] based on sales statistics published online by the automotive association or the vehicle maker to comprehend people’s choice of PC category/type. The top five most popular models have been selected, and the specifications of these models are listed in Table 2. The cost per km for each model from the countries considered is calculated using the fuel price data obtained from Globalpetrolprice.com [32], [33]. Data on the five most popular/best-selling EVs [25], [34]–[39] were obtained from reliable sources and tabulated in Table 3, to assess the competency of EVs currently in the market. The cost/km of

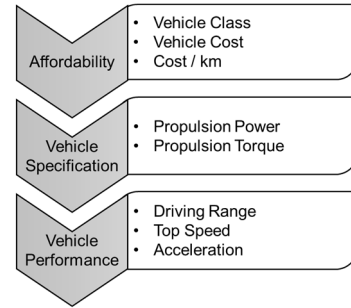


FIGURE 4. Competency analysis for vehicles.

TABLE 1. Pre and post COVID-19 EV sales (in thousands).

Region	Pre COVID-19 Sales (2018)	Post COVID-19 Sales(2021)	Percentage Change
China	1062.1	1657	56 (+)
USA	325	378.4	16.4 (+)
Japan	39.4	26.7	32.23 (-)
Germany	109	523.1	380 (+)
Norway	80	176.3	120 (+)
India	3.6	6.2	72.2 (+)

run for CPV and EV are calculated using equation (1) and (2).

Cost per km for CPV

$$= \frac{\text{Fuel cost / liter}}{\left( \frac{\text{Range}}{\text{Total Tank Capacity}} \right)} \tag{1}$$

Cost per km for EV

$$= \frac{\text{Per Unit Electricity Cost} * \text{Charing Power} * \text{Duration}}{\text{Range}} \tag{2}$$

The vehicle specifications have been taken from the product information page of the Original Equipment Manufacturers (OEMs) as well as reliable online EV databases such as ACEA, CAAM, EAFO, InsideEV, Statista, Kraftfahrt-Bundesamt (KBA), Car Sales Statistics, Society of Manufacturers of Electric Vehicle (SMEV), Autocarpro, WattEV2buy, Clean Technica.

**C. EVs COMPETENCY ANALYSIS**

Current EV models must be able to compete with popular CPVs for faster and wider customer acceptance. Consumer affordability, vehicle specification, and performance requirements are all taken into account [40] when assessing competency, as categorized in Fig. 4.

For generating the necessary tractive power, most of the EVs found in these countries employ Permanent Magnet Synchronous Motors (PMSM), with a few models using AC Induction Motors (ACIM). Customers in the USA prefer Tesla models. Customers in most of the countries considered, prefer Tesla’s Model 3 SR+, which is propelled by a Switch Reluctance Motor (SRM) [41].

**1) AFFORDABILITY**

SUVs and sedans are the most preferred options for EV customers; however the average price of an SUV in the U.S is

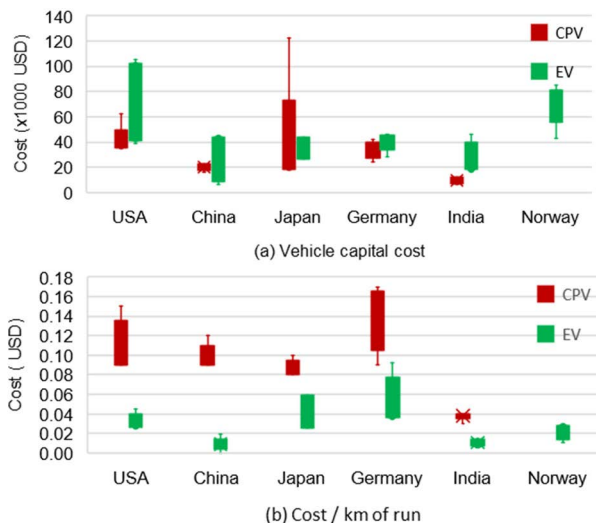


FIGURE 5. Comparison of CPV and EV related costs.

about double that of a CPV-Pickup truck. The average vehicle price gap between the most popular CPV and EV vehicles in Germany and China is less than 25% (Fig. 5 (a)). In India, EVs cost 185 % more than CPVs, whereas the most popular EV in Japan costs less.

Norway and the US have higher EV prices than the rest of the world. The Chinese market has a range of good EVs. EVs and CPVs are expected to reach price parity in 3 to 5 years [42], [43]. EVs have a 60-90% lower operating cost than a CPV [44]. The highest cost per electrical km (Fig. 5. (b)) in Germany is due to the higher cost of gasoline (1.78 USD/liter) and electricity (0.37 USD/kWh). Data from domestic electricity rates in the countries under consideration are used to calculate the cost per km [45]. Commercial electricity in Norway is only 0.052 USD/kWh, compared to 0.239 USD/kWh in Germany. Despite all of the positive aspects, the cost of EVs and the lengthier repayment period must be addressed to increase EV adoption [46].

## 2) VEHICLE SPECIFICATIONS

Most of the best-selling CPVs in China, Japan, Germany, and India use Front-Wheel Drive (FWD) technology while Rear-Wheel Drive (RWD) is being used in the best-selling CPVs of the USA. Sedans have been the popular CPV type in China, Germany, and Norway. Because of their versatility, pickup trucks and SUVs are popular in the United States. These vehicles are more costly and perform better. The most common Hatchback and Mini type EVs in China are a mix of FWD and RWD. Wuling Hongguang, Great Wall Ora Black Cat, BYD Han EV, and Baojun E200 are among the most popular native EV brands in China. However, in Norway and the US, All Wheel Drive (AWD) based Sedans and SUVs are typically the people’s choice for EVs. Customers in Japan choose compact and hatchback EV for a number of reasons, including road infrastructure architecture and EV pricing.

Even if there is diversity in vehicle class, the power train architecture in German automobiles is more comparable.

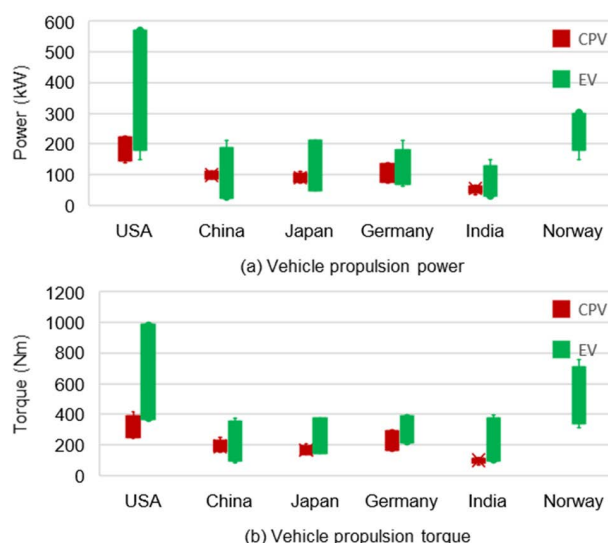


FIGURE 6. Comparison of CPV and EV specifications.

Meanwhile, three of Germany’s top five EVs are hatchbacks. FWD hatchback models dominate the Indian CPV market, whilst EVs are usually SUVs. There is a distinction observed in the vehicle usage patterns between the CPV and EV segments. Although CPV specifications are limited in the US market, EVs with higher power and torque are becoming more popular; nonetheless, these parameters overlap with the most popular CPV in other countries. The most popular EVs in the USA (86% and 98%) and India (50% and 138%) have better power and torque specifications than CPV. The Chinese EV versions have also improved significantly. Norway’s EVs are similar to those in the US. For comparison, the power and torque ranges of the most popular CPVs and EVs are presented in Fig. 6 (a) and (b).

## 3) VEHICLE PERFORMANCE

Chinese EV has the highest average Electrical Driving Range (EDR), followed by US variants as shown in Fig. 7.(a) whereas, few Indian and Japanese EVs have a shorter EDR. The BYD Han EV series offers a range of 605km [150]. In the countries studied, the EDR of an EV is almost 40-65% less than that of a CPV. USA and Germany EVs exhibit a similar EDR to that of those from Norway. The battery capacity in kWh, as well as the vehicle’s energy-efficient design, have an impact on the driving distance [151], [152]. The energy efficiency of an EV is calculated using a ratio of battery capacity to mileage [153]. The Tesla Model X [110], [111] and S [114], [115] are reported to have a 100kWh battery, with the Tesla Model X and the Mercedes-Benz EQC [143]–[145] have an energy efficiency of 228.5 and 226 respectively.

With an average battery capacity of 79.2kWh and 72.2kWh, US and Norway EVs offer an average EDR of 441 and 392km respectively. By increasing the energy density of the batteries, a significant increase in EDR can be accomplished. As a consequence of the current revolution

**TABLE 2. Specifications, capital and running cost of most preferred CPVs by country.**

Region	Car Brand, Model, Drive train, Type	Technical Spec (Lit / Power(kW) / Torque (Nm))/Tank Capacity (Ltrs)	Performance Comparison				Price Range (USD x1000)	Cost / km (USD)	
			Range (kms)	Top Speed (kmph)	Acceleration time for 0-100 kmph (Sec)	Energy Efficiency (Wh/km)			CO <sub>2</sub> Emission (g/km)
China	Nissan Sylphy 1.6 XE FWD, Sedan[47]	1.6 / 94 / 154 / 52	996	190	11.8	457	17 - 19.5	0.09	
China	Volkswagen Lavida Gran III, FWD, Sedan[48]	1.4 / 112 / 250 / 55	725	200	8.3	495	China VI	15 - 21	0.10
China	Toyota Corolla FWD, Sedan[49]	1.2 / 87 / 186 / 50	714	200	9.6	495	128 g/km	17 - 23	0.10
China	Volkswagen Bora, FWD, Sedan[50], [51]	1.5 / 87 / 158 / 51	790	185	11.6	487	Euro -VI	15 - 22	0.09
China	GWM Haval H6 FWD, SUV[52], [53]	1.5 / 112 / 210 / 58	768	180	9*	629	Euro VI	12--16	0.12
USA	Ford, F- XL, RWD, Pickup Truck[54], [55]	3.3 / 216 / 360 / 99	846	209	6.5*	985	336	28 - 37	0.12
USA	Chevrolet Silverado 1500, RWD, Pickup Truck[56]–[58]	3.3 / 216 / 360 / 99	846	209	6.5*	985	336	28 - 37	0.12
USA	Ram 1500 Classic, RWD, Pickup Truck[59], [60]	4.3 / 213 / 415 / 106	721	217	7*	1231	427	29 - 36	0.15
USA	Toyota RAV4 LE, AWD, SUV [61], [62]	3.6 / 227 / 366 / 99	876	169	7.7*	869	331	28 - 45	0.11
USA	Honda CR-V FWD, SUV [63]	2.5 / 151 / 250 / 55	582	209	7.9*	745	207	25 - 36	0.09
Japan	Toyota Yaris L FWD, Hatchback[64], [65]	1.5 / 79 / 140 / 44	560	185	8*	611	215	16 - 19	0.10
Japan	Toyota Raize FWD, SUV [66]–[68]	1 / 73 / 140 / 36	480	0		551		13 - 19	0.09
Japan	Toyota Corolla L FWD, Sedan[49], [69]	1.2 / 87 / 186 / 50	714	200	9.4*	495	128 g/km	17 - 23	0.08
Japan	Honda Fit LX FWD, Hatchback[70]–[73]	1.5 / 95 / 154 / 41	563	185	8.6*	579	232	9 -- 18	0.09
Japan	Toyota Alphard, SUV[74], [75]	2.5 / 112 / 206 / 75	1225	180	11.9*	512	215	68 - 122	0.08
Germany	VW Golf, FWD, Hatchback[76], [77]	1.4 / 110 / 250 / 50	595	224	7.6*	672	228	23 - 24	0.14
Germany	VW Passat FWD, Sedan[78], [79]	2 / 130 / 280 / 71	685	209	5.7*	771	-	22 - 31	0.16
Germany	VW Tiguan FWD, SUV[80], [81]	2 / 137 / 301 / 61	563	201	8.2*	836	319	24 - 38	0.17
Germany	Skoda Octavia FWD, Sedan[82], [83]	1 / 81 / 160 / 50	833	180	10.9*	416	107 g/km	19 - 32	0.09
Germany	Ford Focus, Sedan [84], [85]	1 / 74 / 170 / 46	506	187	12.1	595	107 g/km	26 - 42	0.12
India	Maruti Swift FWD, Hatchback[86], [87]	1.2 / 61 / 113 / 37	592	164	12.7	459	BS-VI	6.8 - 11	0.03
India	Maruti Alto FWD, Hatchback[88], [89]	0.79 / 35 / 69 / 35	533	140	19.0	474	BS-VI	4 -- 6	0.04
India	Maruti Baleno FWD, Hatchback[90], [91]	1.2 / 61 / 113 / 38	520	180	12.4	509	BS-VI	7 -- 12	0.04
India	Maruti WagonR, FWD, Hatchback[92], [93]	1 / 50 / 90 / 32	433	151	18.6	518	BS-VI	6 -- 8	0.04
India	Maruthi Suzuki Dezire FWD, Sedan[94], [95]	1.2 / 66 / 114 / 38	552	140	12.0	482	BS-VI	8 - -12	0.04

\* Acceleration time computed for 0-60 MPH

in battery cell chemistry, manufacturing equipment, and procedures, battery-pack pricing is expected to decrease below USD 100/kWh offering higher energy density [154]. The proliferation of EVs is highly backed up by lower battery prices and improved battery performance [155]. In comparison to CPV, the average top speed of EVs in China

has increased by 11%, whereas, in USA it is increased by 78% (Fig. 7 (b)). The average top speed of EVs from India as well as a handful from China is significantly lower than that of EVs from Norway.

EVs average top speed in India is lower than that of its CPVs. To a degree, the EV's top speed performance is

**TABLE 3. Specifications, capital and running cost of most preferred EVs by country.**

Region	Brand, Vehicle Model, Drive train, Class	Motor Specification (Type / Power(kW) / Torque (Nm))	Performance Metrics				Price Range (x 1000 USD)	Cost / km Domestic Charging (USD)
			Range (km)	Top Speed (kmph)	Acceleration Time for 0-100 kmph (Sec)	Energy Efficiency (Wh/km)		
China	Wuling Hongguang Mini EV, RWD, Hatchback[96], [97]	PMSM / 20 / 85	170	100	-	81.8	4 - 6	0.01
China	Tesla Model 3 SR+, RWD, Sedan[98], [99]	Tesla L13 SRM / 211 / 375	402.3	225	5.3	136.7	40 - 43	0.02
China	Great Wall Ora Black Cat, FWD, Crossover Sedan[100], [101]	PMSM / 35 / 125	351	102	17.1	94.0	21 - 22	0.01
China	BYD Han EV, FWD, Sedan[102], [103]	PMSyRM / 163 / 330	605	-	7.9	127.3	36 - 44	0.01
China	Baojun E200, Small Car, FWD[104], [105]	PMSM / 29 / 110	250	100	15.8	96.0	9 - 11	0.01
USA	Tesla Model 3 SR+, RWD, Sedan[98], [99], [106], [107]	Tesla L13 SRM / 211 / 375	402.3	225	5.3	136.7	40 - 43	0.03
USA	Tesla Model Y, AWD, SUV[108], [109]	PM / 258 / 527	425	217	5.1	176.5	60 - 65	0.03
USA	Tesla Model X Performance, AWD, SUV[110], [111]	FD - SRM, 193kW, 330Nm RD - ACIM 375kW, 660NM / 568 / 990	437.7	250	2.9	228.5	100 - 105	0.05
USA	Chevrolet Bolt EV, FWD, Hatchback[112], [113]	PMSM / 150 / 360	417	145	6.9	158.3	38 - 39	0.03
USA	Tesla Model S Performance, AWD, Sedan[114], [115]	FD -L13 PMSM, 193 / 330 RD - ACSM 375/ 650	525	250	2.6	190.5	95 - 100	0.03
Japan	Nissan LEAF S, FWD, Hatchback[116], [117]	EM 57 PMSM / 110 / 320	243	144	7.9	164.6	32 - 44	0.05
Japan	Mitsubishi Minicab i- MiEV RWD[118], [119]	PMSM / 49 / 145	160	135	15.9	100.0	22 - 27	0.03
Japan	Tesla Model 3 SR+, RWD, Sedan[98], [99], [106], [107]	Tesla L13 SRM / 211 / 375	402.3	225	5.3	136.7	40 - 43	0.06
Germany	VW-e-Up, FWD, Hatchback[120]-[122]							0.09
Germany	Tesla Model 3 SR+, RWD, Sedan[98], [99], [106], [107]	Tesla L13 SRM / 211 / 375	402.3	225	5.3	136.7	40 - 43	0.04
Germany	VW ID3, RWD, Hatchback[123]-[125]	APP 310 BLDC / 150 / 310	420	160	8	138.1	33 - 44	0.04
Germany	Hyundai Kona Electric FWD, SUV[126], [127]	Siemens PMSM / 150 / 395	415.2	167	7.6	154.1	38 - 46	0.04
Germany	Renault Zoe R110, FWD, Hatchback[128], [129]	R110 PMSM / 80 / 225	395	135	11.4	131.6	38 - 40	0.06
India	Tata Nexon EV, FWD, SUV[38], [130], [131]	PMSM / 94.5 / 245	317	120	9.3	95.3	19 - 23	0.01
India	MG ZS Excite FWD, SUV[132], [133]	ACSM / 105 / 353	263	140	8.5	169.2	29 - 34	0.02
India	Hyundai Kona Electric FWD, SUV[126], [127]	Siemens PMSM / 150 / 395	415.2	167	7.6	-	38 - 46	0.01
India	Tata Tigor EV, FWD, Sedan[134]-[136]	ACIM / 30 / 105	156	80	18.84*	137.8	17 - 18	0.01
India	Mahindra e-Verito, FWD, Sedan[137]-[139]	ACIM / 31 / 91	181	86	11.2*	117.1	18 - 19	0.01
Norway	VW ID.4, RWD, SUV [140], [141]	APP 310 BLDC / 150 / 310	402	160	8.5	191.5	59 - 70	0.02
Norway	Tesla Model 3 SR+, RWD, Sedan[98], [99], [106], [107]	Tesla L13 SRM / 211 / 375	402.3	225	5.3	136.7	40 - 43	0.01
Norway	Audi e-Tron 55 Quattro, AWD, SUV [142]	FD – ACIM (Axially Parallel Synchronous Motor) / 100 / 230 RD – ACIM (Coaxial Synchronous Rear Motor) / 130 / 310	357	210	6.8	198.9	84 - 85	0.03
Norway	Mercedes Benz EQC, AWD, SUV[143]-[145]	Dual ACSM / 300 / 760	354	180	5.1	226.0	68 - 77	0.03
Norway	Polestar 2 Long Range, AWD, Sedan[146]-[149]	Dual PMSM / 300 / 660	442.6	225	4.9	176.2	64 - 69	0.02

respectable. EVs from the USA and Norway are faster than EVs from other countries in reaching 100km/h meanwhile the

majority of the EVs in the study are faster than their CPVs. In Fig. 7 (c), CPV\* denotes the time it takes to accelerate

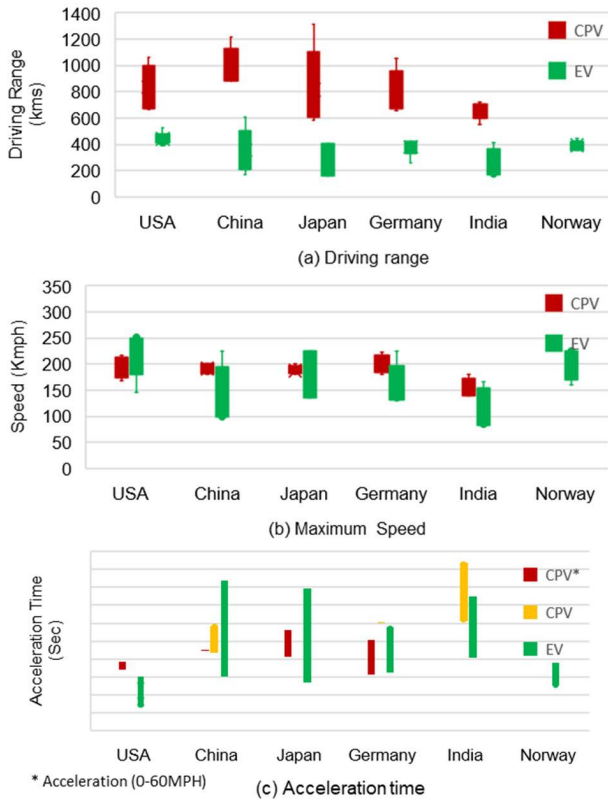


FIGURE 7. Comparison of CPV and EV performances.

from a standstill to 60mph, whereas, CPV and EV denote the time it takes to accelerate from a standstill to 100km/hr. In terms of top speed, acceleration time, power, and torque parameters, the EV looked impressive. EV has a far lower operating cost than CPV. To enhance EV adoption, issues like driving range, capital costs, and vehicle usage patterns should also be addressed.

**D. FINDINGS**

- In most of the countries studied, differences in vehicle class could be identified. The variation will have an impact on car usage patterns and will slow the EV adoption.
- In India, the cost of an EV is more than 185 % than that of a CPV, whereas in Germany and China, the price difference is less than 25%. EV pricing is greater in Norway and the U.S. than in the rest of the countries.
- Operating cost of EV is 60-90% lower than CPV.
- EVs with better power and torque specifications than CPV are available in US and India.
- Chinese EVs have a greater EDR, while only a few Indian and Japanese EVs have a lower EDR. Overall, the EDR of an EV is almost 40-65% lower than that of a CPV. Meanwhile, these vehicles’ top speeds and acceleration are comparable.

**III. EV CHARGING PARADIGM**

Charging time and access to charging infrastructure are other crucial factors in accelerating EV adoption. The battery

chemists, capacity, charging rate, and charging power level all have an impact on charging time. These factors are rampant in today’s EV industry [156]. Table 4 shows the battery specifications, as well as the maximum charging power and charging time for the most popular EVs in each of the countries being studied. EVs of the USA and Norway are configured with higher kWh batteries to offer a longer range, whereas in Japan and India the batteries of lower capacity are installed to facilitate short distance rides and keep the vehicle price affordable. Presently Tesla uses a battery capacity of 100kWh.

Wuling Hong Guang Mini EV uses a 13.9kWh battery whereas Mitsubishi Minicab MiEV Cab uses a 16kWh battery. These vehicles offer a driving range of about 170 and 160km for a single charge. EVs use Lithium-ion based batteries with few NCM, Polymer, NCR, LiFePO4, Ternary types of batteries, etc., [157]. As China is leading the EV battery market along with South Korea, the USA, and Poland [158], it could provide EVs with higher battery capacity at competent pricing. Contemporary Amperex Technology Co Ltd (CATL) which is the world’s largest EV battery manufacturer located in China, is developing a new type of battery that avoids using nickel and cobalt [159].

**A. POWER TRANSFER MODES**

Electric Vehicle Supply Equipment (EVSE) provides the necessary power required for the EV’s onboard batteries. EVSE can be categorized based on the technologies employed for power transfer, rating, location, accessibility, and associated framework. Using conductive wires or contactless techniques, charging power can be transmitted to the on-board EV batteries [160]. Static charging approaches allow vehicles to be charged while they are stationary, whereas dynamic charging allows vehicles to be charged while they are in motion.

Although the dynamic mode of power transfer reduces the on-board battery requirement and the EV’s initial cost [161], [162], it necessitates modernizing road infrastructure. The various techniques of charging power transfer and their accompanying standards are classified in Fig. 8.

Active research and development are carried out in Wireless Charging Technique (WCT) with standards are being developed, whereas, Conductive Charging Technique (CCT) is fully established, with standards set and in place. These technologies, as well as the research gaps, are recognized and discussed in the following subsections.

**1) WIRELESS CHARGING POWER TRANSFER**

WCT is being investigated as a way to avoid the terminal-dependent CCT allowing power transfer while the vehicle is in motion (dynamic) [162]–[164]. WCT as shown in Fig. 9 delivers charge transfer that is safe, convenient, adaptable, and self-directed [165].

Dynamic WCT reduces the need for expensive on-board batteries while increasing driving range [166]. Intensive research is carried out to improve the power transfer

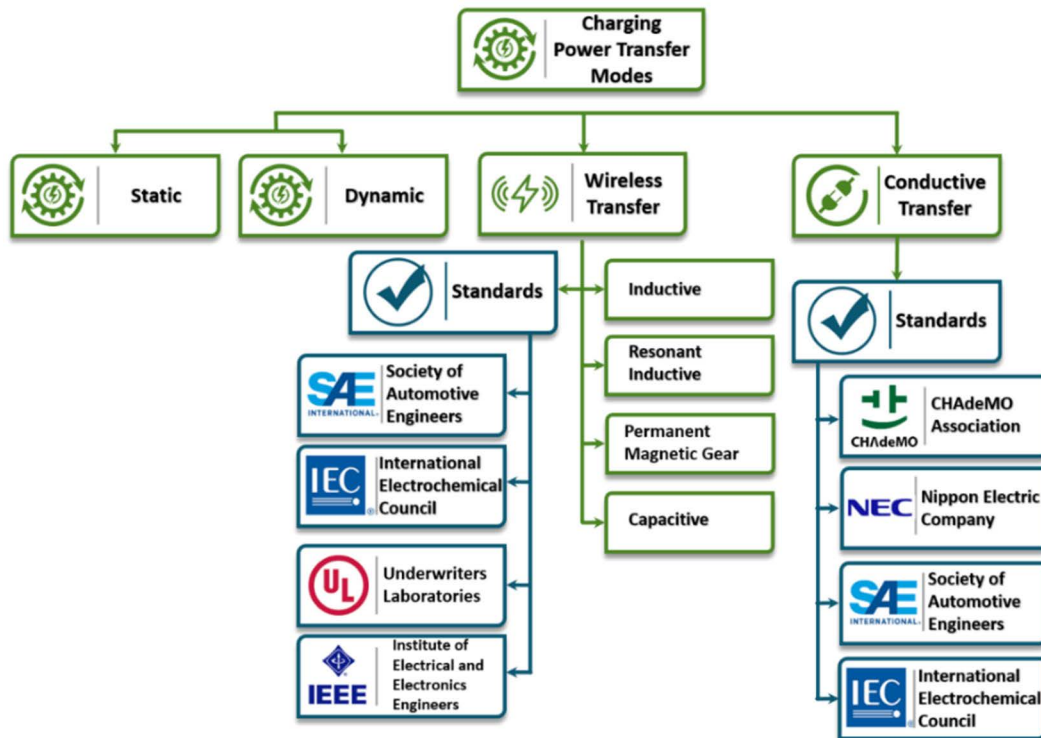


FIGURE 8. Classification of charging power transfer modes and standard.

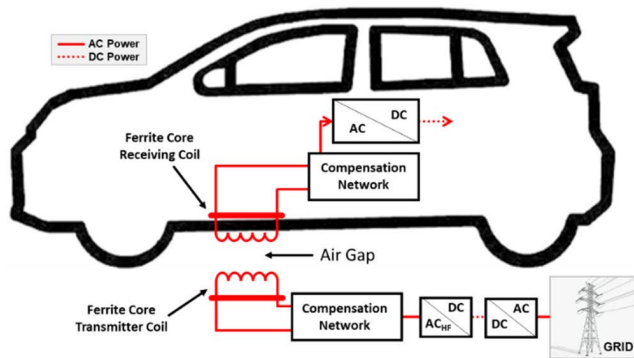


FIGURE 9. Block diagram of wireless charging system.

efficiency by addressing the air gap and coil misalignment challenges concerning dynamic WCT. The usual air gap between the transmitter and receiver in a smaller passenger automobile may range from 150 to 300mm. The air gap may be greater for larger cars. Since 2018, cabs in Norway have been employed with wireless charging [167]. Standards for WCT have been proposed and developed by the Society of Automotive Engineers (SAE), the Institute of Electrical and Electronics Engineers (IEEE), and Underwriters' Laboratories (UL). The WCT standards and their definitions are tabulated in Table 5. SAE charging specifications for Wireless power transfer for EVs and their classes are presented in Table 6. Inductive, Resonant Inductive, Permanent Magnetic Gear, and Capacitive methods for wireless power

transfer have piqued the interest of academic and industrial researchers. High-frequency AC ( $AC_{HF}$ ) is provided as an input to the ferrite core transmitting coil by converting the power frequency AC from the grid using AC-DC and DC-AC converters.

On the receiving end,  $AC_{HF}$  is converted into a stable DC supply for charging the on-board batteries. Transmission efficiency is improved by using series and parallel compensation circuits on the transmission and receiving ends [180], [181]. The use of a ferrite plate at both ends reduces detrimental leakage flux and improves flux distribution. Inductive type WCT requires the embedding of charging coil in the road which acts as transmitter coil as well as on the vehicle which acts as receiving coil. The power transfer occurs between these coils according to the principle of mutual inductance/magnetic coupling. Operating frequency which ranges from 10kHz to 150kHz, mutual inductance, and the distance between these coils determine the amount of power transfer meanwhile, this type of technology works at an efficiency of 97% [182], [183]. Vehicle occupants being exposed to a higher level of magnetic field emission, the occurring resonance inductive energy resulting in the risk of inference with the nearby vehicle systems, the associated space requirement for embedding the coils and its associated components both on the vehicle as well as on the roadside, additional thermal management due to high power transfer levels and additional cost are some of the issues that need to be addressed in case of inductive type WCT. The potential risk of a driver being exposed to the magnetic field is reduced



TABLE 4. EV battery specification and charging requirement.

Region	Brand, Vehicle Model, Drive train, Class	Battery Specifications (Type / Capacity / Voltage / Energy Density)	AC		DC	
			OBC Max. Power Rating (kW)	Min. Charging Time (hrs)	Max. Power (kW)	Min. Charging Time (hrs)
China	Wuling Hongguang Mini EV, RWD, Hatchback[96], [97], [168]–[171]	Li-Ion / 13.9 / 96 / -	1.7	9.0	-	-
China	Great Wall Ora Black Cat, FWD, Crossover Sedan[100], [101]	Li-Ion / 33 / 350 / -	3.5	10.5	88	0.4
China	BYD Han EV, FWD, Sedan[102], [103]	Li-Ion (LFP) Blade Battery / 77 / - / -		-	205	0.4
China	Baojun E200, Small Car, FWD[104], [105], [172], [173]	Huating LiFePO4 / 24 / 93 / 99	2.7	10.0	-	-
USA	Tesla Model Y, AWD, SUV[108], [109]	Li-ion NCR21700A / 75 / - / -	11.0	7.6	165	0.5
USA	Tesla Model X Performance, AWD, SUV[110], [111]	Panasonic, Li-Ion / 100 / 350 / 243	22.0	5.1	120	0.9
USA	Chevrolet Bolt EV, FWD, Hatchback[112], [113]	LG Chem Li Ion / 66 / 350 / -	7.2	10.2	55	1.3
USA	Tesla Model S Performance, AWD, Sedan[114], [115]	Panasonic Li-Ion NCR 18650A / 100 / 400 / -	22.0	5.1	200	0.6
Japan	Nissan LEAF S, FWD, Hatchback[116], [117]	ASEC Li-Ion / 40 / 350 / 224	6.6	6.7	50	0.9
Japan	Mitsubishi Minicab i- MiEV RWD[118], [119], [174]–[177]	Li-Ion / 16 / - / -	3.7	4.8	50	0.4
Germany	VW-e-Up, FWD, Hatchback[120]–[122]	Li-Ion / 36.8 / - / -	3.7	11.1	40	1.0
Germany	VW ID3, RWD, Hatchback[123]–[125]	Li-Ion / 58 / - / -	11	5.9	100	0.6
Germany	Renault Zoe R110, FWD, Hatchback[128], [129]	Renault & LG Chem Z.E.50 Li-Ion / 52 / 400 / 168	22	2.6	41	1.4
India	Tata Nexon EV[38], [130], [131]	Li-Ion / 30.2 / - / -	3.9	8.5	34	1.0
India	MG ZS Excite FWD, SUV[132], [133]	CATL Li-Ion / 44.5 / - / -	6.6	7.5	76	0.7
India, Germany	Hyundai Kona Electric FWD, SUV[126], [127]	Li-Poly LG Chem NCM 622 / 64 / 356 / -	7.2	9.9	80	0.9
India	Tata Tigor EV, FWD, Sedan[134]–[136]	Li-Ion / 21.5 / - / -	2.1	11.5	12	2.0
India	Mahindra e-Verito, FWD, Sedan[137]–[139]	Li-Ion / 21.2 / - / -	2	11.5	16	1.5
Norway	VW ID.4, RWD, SUV[140], [141]	Li-Ion NCM712 / 77 / - / -	11	7.8	150	0.6
Norway	Audi e-Tron 55 Quattro, AWD, SUV[142], [178], [179]	Li-Ion / 71 / 396 / -	11	7.2	150	0.5
Norway	Mercedes Benz EQC, AWD, SUV[143]–[145]	Li-Ion / 80 / 405 / -	11	8.1	112	0.8
Norway	Polestar 2 Long Range, AWD, Sedan[146]–[149]	Li-Ion / 78 / - / -	11	7.9	150	0.6
China, USA, Japan, Germany, Norway	Tesla Model 3 SR+, RWD, Sedan[98], [99], [106], [107]	Li-Ion (Tesla & Panasonic) LCR21700A / 55 / 360 / 146	11	5.6	160	0.4

by increasing the gap between the transmitter and receiver coils [184], [185]. A higher rate of energy transmission at high quality even with weaker magnetic fields for a long distance is possible with Resonance Inductive WCT. This can be performed when both the coils are operated at the resonant frequency with the help of additional components on the receiver and transmitter sides [185]. In addition to the transmitting and receiving coils, the Permanent Magnetic Gear type WCT uses magnets on the transmitter and receiver sides. The permanent magnets rotate at synchronous speed while the transmitter coil is powered by an AC supply.

Variation of the electric field is used in transferring power in the capacitive type WCT technique using coupling capacitors. The amount of power transfer relies on the frequency (100 to 600 kHz), coupling capacitor size, the air gap between the transmitter and receiver. Due to the low capacitance rating (picofarad) for short distance (in centimeters) power transfer, the power density is 20 times lesser when compared to Inductive type WCT (~40kW/m<sup>2</sup>) [186]. The power

TABLE 5. Standards for wireless charging.

Standards	Definition
UL subject 2750	Outline of Investigation for WEVCS.
SAE J2836/6	Use case for PEV wireless charging communication
SAE J2847/6	Communication between wireless EV charger and the onboard EV receiver
SAE J1773	Inductively coupled EV charging
IEC 61980-1 Cor.1 Ed.1.0	General requirements for EV WCT
IEC61980-2	A specific requirement for Communication between EV and WCT infrastructure
IEC61980-3	IEC 61980-3: Magnetic field type WCT system specific requirements
IEC 62827-2 Ed.1.0	WCT-Management: Multiple Device Control Management
IEC 63028 Ed.1.0	WCT-Air Fuel Alliance Resonant Baseline System Specification.

transfer capability is around 92% [187]. Power transfer happens when the transmitter and receiver are synchronized. Failure of synchronization may occur due to frequency

**TABLE 6.** SAE (J2954) wireless charging standard.

Class	Specifications		
	Max. Power Input (kW)	Min. Efficiency (%)	Frequency (kHz)
I	3.7	Above 85 %	5
II	7.7	under the aligned	
III	11	condition	
IV	22		

**TABLE 7.** Comparison between various wireless charging techniques.

Parameters	Technologies			
	Capacitive	Inductive	Permanent Magnet	Resonant Inductive
Operating Frequency Range (kHz)	100-600	10-50	0.05-0.5	10-150
Size / Volume	Low	Med	High	Med
Power Level	Low	Med-High	Med-Low	Med-Low
Cost	Cheap	Medium	Costly	Medium

mismatch, uncertain and dynamic variation in the loading condition [188]. At higher frequencies, the system suffers more loss due to skin effects. As the electric field easily passes through the metal surfaces of the vehicle, shielding becomes difficult. Keeping human health and safety in concern, considerable research to maintain EMC and EMI standards are required in the WCT technique. Comparison between various WCTs in terms of operating frequency, volume, power level, and cost are presented in Table 7.

WiTricity Corporation, Qualcomm Halo, Hevo Power I, Bombardier Primove, Siemens, and BMW are working in developing WCT techniques for leading EV passenger car manufacturers whereas, Momentum Dynamic and Conductix-Wampfler are working to develop WCT for Industrial Fleet and buses. Evatran group is developing contactless charging solutions for passenger EVs.

## 2) CONDUCTIVE CHARGING POWER TRANSFER

Conducting cables are used to transfer charging power to the on-board EV batteries. The live conductors make sliding contact with the moving vehicle from the top, side, or bottom in the dynamic CCT [189]. Because of the wide range of vehicle heights, overhead supply feed to EVs is difficult to install. Though this type does not affect the road surface, the fall of the pillars that support the live overhead cables poses a significant risk to road users. When electricity is supplied from the sides, only cars in the outermost lane of multi-lane highways can be powered. Overtaking can impair the vehicle's power flow, therefore it's not always possible. Dirt, water, ice, and other debris accumulating on the track impede the supply provided from the bottom [190]. Dynamic CCT for EV allows limited on-board storage capacity allowing the vehicle to exit the track/lane during an emergency condition.

Static CCT allows EVs to be charged in various locations, such as at home, at work, in public, etc., with restricted

charging power. It permits low-power residential charging and high-power public charging. Almost 80% of EVs are charged overnight at home [13], with consumption charged at domestic rates. Private charges at homes accounted for 7 million (40GW) and 2.5 million (15GW) at workplaces, according to estimates. By 2030, private charges at residences will be 140 million, and private charges at work will be 50 million, totaling 670GW of installed charging capacity and 235TWh of electricity in the sustainable development scenario.

With additional electrical installations, Public Charging Stations (PCS) enable slow (charging power below 22kW) and fast (charging power above 22kW) charging. By 2030, the Sustainable Development Scenario predicts that more than 20 million public slow chargers and nearly 4 million public fast chargers would have been deployed, equating to 150GW and 360GW of installed capacity, respectively. In 2030, they will provide 155TWh of electricity. Fast charging is performed with a DC source, while slow charging is performed with single and three-phase AC sources [191]. When using AC power for charging via On-Board Chargers (OBC), a longer charge time is necessary. Fig. 10 shows the comparison of the OBC ratings of EVs in the nations assessed.

During the time of article preparation, OBC in German and American EVs has enough power handling capacity to allow the on-board batteries to charge quickly, however, OBC in India is on the low side. China's Wuling Hongguang Mini EV has the lowest OBC rating of 1.7kW, followed by India's Mahindra e-Verito with 2kW. Tesla allows its Model S to charge at 22kW using the OBC. Only low-power home charging via OBC is available on a few of the most popular EVs. The Renault Zoe R110 in Germany has a maximum OBC rating of 22kW, allowing the 55kWh battery to be charged in 3 hours. Dedicated charging points with appropriate outlets can provide up to 7.4 kW of power for charging the EV in the customer's premises. Higher power levels necessitate specialized equipment on the consumer's premises. The maximum power rating of OBC is limited because of cost and thermal limits, which influences the charging time. Few OEMs allow bypassing the OBC and charging the internal battery to facilitate fast charging. The EVSE performs rectification and DC regulation in conjunction with the on-board Battery Management System (BMS). Recent advances in charging technology enable charging at 250kW and attaining full charge in few minutes. The charging speed offered by various sources and the duration of charging were categorized [192] and shown in Fig. 11.

Standards for static CCT have been well defined and realized to enable the safety of electrical utilities, EV, and human operators along with facilitating interoperability with the help of additional conversion adapters to ensure PCS EV compatibility and battery performance [13], [193], [194]. Table 8 contains information on such standards as well as a description of them.

TABLE 8. Standards corresponding to conductive charging technique.

Standards	Definition
UL 2594	EVSE Standard for Charging using OBC (Input AC voltage < 600V, 50 or 60 Hz, Output)
SAE J1772	EV/PHEV Conductive Charge Coupler
SAE J2847/1	AC Charging
SAE J2847/3	Reverse Power Flow
SAE J2847/2	DC Charging – Revised
SAE J2836/5	Customer Preference Communication Use Cases
ISO 6469	Electrically Propelled Road Vehicles Package
ISO 6469-1:2019	Safety Requirements for Rechargeable Energy Storage System
IEC 61851-1: 2010	General equipment (Conductive EVCS – Part 1)
IEC 61851-21: 2001	Conductive connection requirement between EV and an AC / DC Supply (Conductive EVCS – Part 21)
IEC 61851-22: 2001	AC Charging (Conductive EVCS – Part 22)
IEC 61851-23: 2014	DC Charging (Conductive EVCS – Part 23)
IEC 61851-21-2.	EMC requirement for DC EVCS
IEC 61851-21-1: 201X	EV OBC EMC requirement for conductive connection to AC / DC supply (Conductive EVCS Part 21-1). Not applicable to industrial trucks off-road vehicles, rail, trolley busses. Provides testing condition of EV or the nominal voltage range, specific testing methods and requirements on LF and HF immunity as well as emission phenomena. Also guides the integration of the charging station into the test setup.
IEC 61851-21-2: 201X	EMC requirement and operating condition during testing for Off-Board components and equipment providing the charging power by conductive/wireless means (Input up to 1kV AC or 1.5kV DC and Output up to 1kV AC or 1.5kV DC). Provides immunity (LF and HF) performance criteria as well as emission requirements as well as radiated emission in case of CCT for frequencies 20-185kHz and 150kHz -1GHz even 18GHz.
IEC 61851-21-2: 201X (Annex A)	Provides an example of test setup to measure disturbances on ports providing DC charging power through conductive means
IEC 61851-21-2: 201X (Annex B)	Test for measuring radiation disturbance due to keyless entry.
IEC 61851-21-2: 201X (Annex C)	Load conditions for terminals of CPT ports
IEC 61851-21-2: 201X (Annex D)	Voltage transient disturbances from DC charging equipment
IEC 61851-21-2: 201X (Annex E)	Voltage surge and EFT/B test setup for DC charging equipment

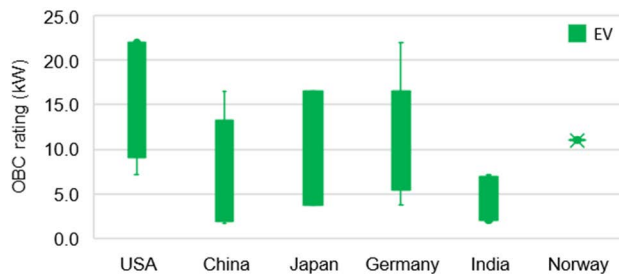


FIGURE 10. Comparison of OBC rating.

EV charging in U.S.A (particularly in North America) is standardized by the Society of Automotive Engineers (SAE) and the professional association known as the Institute of Electrical and Electronics Engineers (IEEE). These standards have been adopted for AC charging of EVs in Japan. Meanwhile, for DC charging, Japan EV manufacturers and Tokyo Electric Power Company collaborated in developing the standard called CHArge de Move (CHAdeMO). Standards developed by International Electro technical Commission (IEC) are followed to a larger extent in the European continent. Standardization Administration of China (SAC) the Chinese Nation committee of the ISO and IEC has developed Guobiao (GB/T) for standardizing AC and DC charging in China.

China has adopted the standards of IEC for AC charging [193]. It is made mandatory to conform to GB / T 20234.3 – 2015 standards for new EV vehicles launched in China [195]. The charging standards in India are being

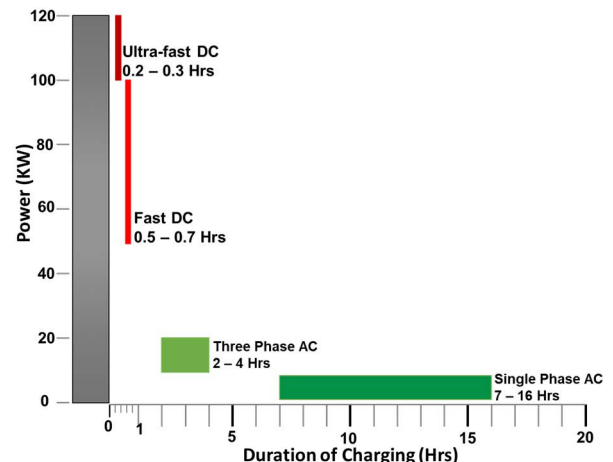


FIGURE 11. EV charging speed and duration.

adopted from IEC as well as from GB/T and modified according to the local market (Type 2 AC Mains, Bharat DC-001, and Bharat AC001). Three dedicated standards have been developed for DC fast charging: a) Combined Charging System (CCS) [196], b) CHArge de Move (CHAdeMO) [197], and c) Supercharger (Tesla Vehicles) [198]. Mostly all these standards have been developed around the National Electrical Code (NEC) article 625 by National Fire Protection Association (NFPA) and have been presented in Table 9. EVs are commonly charged via OBC using AC power at levels 1 and 2. Level 3 charging is used in PCS. The SAE standard divides AC charging power into three categories in

the United States, with 1.4kW being the lowest, whereas, AC charging power in China starts at 3.7kW. To represent the charging power rating, European developers prefer the term “Mode,” while American developers prefer the term “Level.” Table 9 compiles the standards adopted in different nations that are documented in [13], [196], [199]–[207], electrical specifications, charging speed, and the location of EVSE. The compilation is based on the SAE-J1772 standard and the classification described by William Tods [192], to eliminate ambiguities. CCS 1 at SAE Level 3 DC provides 240 kW charging in the public domain of the USA. The CHAdeMO Association and the China Electricity Council are working jointly on a next-generation ultra-high-power charging standard (up to 900 kW), called “ChaoJi” [208], [209]. By communicating with the car’s BMS, the latest version of EVSE could vary the charging power level depending on the battery rating.

Standards also define the specification of the plug/connector and the inlet used for EV charging [210]. Table 10 provides the information about the plug/connector and the inlet. American and Japanese vehicles come with Type 1 inlets; meanwhile, Type 2 inlet is more common on European vehicles. A maximum charging current of 32A at 7kW is prescribed for Type 1 connectors. Type 2 connectors can be used for both single and three-phase charging (Semi-Fast – 22kW(3 × 32A) and Fast Charging - 43 kW (3 × 63 A)). Tesla’s single proprietary connector is used for charging the Tesla vehicles at Level 1, 2, and Fast DC charging [203], [211].

All EVSEs used in America, as well as dedicated fast AC charging EVSEs, use fixed cables (absence of plug and socket) at the supply side meanwhile the private and European versions, use plugs with sockets to connect the cable with the EVSE. It’s important to remember that the plug’s rating is not the same as the charging rating.

The charging power defines the maximum safe charging power available in the market for charging the battery, whereas the plug rating specifies the maximum safe operational power. Due to the inherent nature, dynamic power level variation, and the bidirectional power flow, CHAdeMO and the Combined Charging Standard (CCS) are preferred by most EV users. Bradley Berman [212] records the release of the third version of CHAdeMO.

Japan and China are working together to develop a new high-power DC fast charging standard “ChaoJi” which is compatible with CHAdeMo, GB/T, US-CCS1, Euro – CCS2, and Tesla fast charging. DC fast charging of Tesla cars is performed at Tesla’s Superchargers with their indigenous connectors as well as with CHAdeMO adapters. Special SAE J1772 and IEC 62196-2 adapters are available to charge the Tesla cars in the US and Europe markets respectively. The protocol used to establish communication between the EV’s BMS and the EVSE differs as well. This also causes a problem with PCS EV compatibility. However, because OEMs are unable to comply with all of the criteria, this standardization has made it hard for drivers to choose an EV

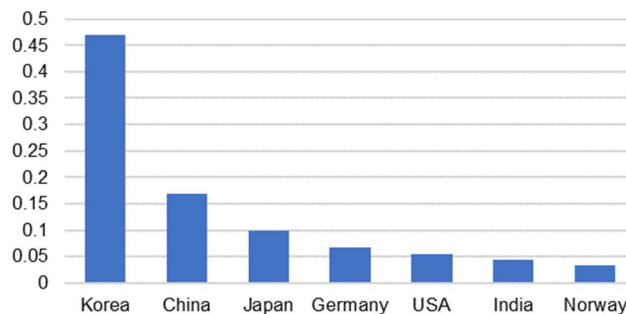


FIGURE 12. EVSE to EV ratio for 2020 Ref: [192].

model and a charging station for recharging. By upgrading regionally available well-established AC and DC standards, CCS is striving to create a global coordinated framework. As a result, EVs will only need a single charging interface that can handle both AC (slow and fast) and DC charging. Automakers from the US and Europe have concluded to provide the users the flexibility to charge the vehicle either from an AC or a DC power source using a single connector. The CCS type 1 connector is made by combining the AC SAE J1772 coupled with 2 extra DC pins for fast charging in the US region and the AC IEC 62196-2 connector for fast charging in the European region. SAE has also endorsed CCS which is widely accepted in North America [199]. This would also reduce the amount of space needed to put a charging port on the car, as well as the time spent looking for a compatible charging station.

### B. EVSE MARKET SCENARIO

For the last six years, the IEA reported stock of 1.012 million fast public chargers and 2.7 million slow public charges [19]. China has the most publicly accessible slow (1.2 million units) and fast (0.78 million units) chargers in the world followed by Europe. Installation of fast chargers is at a higher rate in Europe. Korea leads the ratio with 0.47, based on the Alternative Fuel Infrastructure Directives (AFID) recommendation of one PCS for 10 EVs, whereas the ratio [192] for the countries considered is shown in Fig. 12. The lowest EVSE per EV ratios are found in countries with the highest EV sales share. For longer distance trips, a well-organized charging network has to be in place.

### C. EV BATTERY RELATED CHALLENGES

Because of their higher specific power and energy density, Li-Ion batteries are dominating the EV industry[213], [214]. The battery charge/discharge capacity has a big impact on EV acceleration and charging time, and it’s heavily influenced by the battery operating temperature [215]. The batteries perform better when the operating temperature ranges between 25° C and 40° C meanwhile its useful life is affected when the temperature exceeds 50° C [216]. Fast charging also reduces the useful battery life as more heat is generated during the charging process. Using both active and

**TABLE 9. Charging standards, power level, and location of EVSE.**

Standards	Power Source	Region	SAE J1772 Level	Phase	Voltage (V)	Max. Current (A)	Power (kW)	Charging Speed	Location of EVSE
SAE J1772	AC	U.S.A	1	1	120	12 - 16	1.4 – 1.92	Slow	Home
SAE J1772	AC	U.S.A	1	1	240	16	3.7	Slow	Home, Workplace
SAE J1772	AC	U.S.A	2	3	240	80	19.2	Slow	Workplace
SAE J3068	AC	U.S.A	3	3	450		62.5	Fast	Public
CCS 1	DC	U.S.A	1	-	500	80	40	Fast	Public
CCS 1	DC	U.S.A	2	-	450	200	90	Fast	Public
CCS 1	DC	U.S.A	3	-	600	400	240	Fast	Public
IEC 62196 – 2	AC	China	1	1	220		3.7	Slow	Home
IEC 62196 – 2	AC	China	2	1	220		22	Slow	Workplace
IEC 62196 – 2	AC	China	3	1	380		62.5	Fast	Home, Workplace
GB/T - 20234	DC	China	1	-	1000	200	200	Fast	Public
SAE J1772	AC	Japan	2	1	200	12-16	3.7	Slow	Home, Workplace
SAE J1772	AC	Japan	3	3	415	16	6.6	Slow	Workplace
CHAdeMO	DC	Japan		-	50 - 500	125	62.5	Fast	Public
IEC 62196 – 2	AC	Europe	2	1	230	16	3.7	Slow	Home
IEC 62196 – 2	AC	Europe	3	3	690	63	43.5	Fast	Public
IEC 62196 – 3	DC	Europe		3	1000	250	250	Fast	Public
IEC 60309	AC	India	1	1	230	15	2.5	Slow	Home
IEC 60309	AC	India	1	3	230	15	3.3	Slow	Public
IEC 62196 – 2	AC	India	2	3	380-415		22 to 130	Fast	Public
GB/T 20234.3	DC	India	1	-	48 / 72	200	10/15	Slow	Public
CHAdeMO	DC	India	3	-	200 - 500		Min 50	Slow	Public
CCS1	DC	India	3	-	200-750		Min 50	Slow	Public

passive thermal control technologies the cell temperature is kept under control [217].

To address the vehicle's driving range, charging time, and acceleration, a significant increase in battery capacity will result in the need to upgrade the battery thermal management system at an additional cost and volume. According to Richard K. Lattanzio and Corrie E. Clark [218] due to battery production and charging, the emission estimate reports the release of 15% more fine PM and 273% more Sulphur oxides are from a Li-Ion based battery EV. Even though total energy resource consumption and fossil fuel resource consumption are both down by 29% and 37%, respectively, water resource use is up by 56%. The price of Li-Ion battery for a kW-hr has decreased by 88.5% since 2010 (\$137 /kW-hr) meanwhile the demand has increased to 526 GW-hr in 2020. By 2030, this is predicted to increase to 9300 GW-hr [219]. Under the sustainable development scenario, there will be 3.2TWh demand concerning batteries in the next decade because barely half of the existing Li-Ion battery manufacturing capacity of 300 GWh/year is being used. In China, Europe, and the United States, there is a high demand for batteries, which is slowing EV production. When the battery capacity drops by 30% from its initial capacity, it needs to be replaced [220]. Other electrical applications, such as a Home Uninterrupted Power Supply (Home-UPS), can benefit from

these batteries (Home-UPS) [214]. Around 1500-200 cycles is when the degradation process begins. Melanie Loveridge and Martinn had discussed about the key degradation modes that lead to capacity fade elaborately [221]. Federal regulations demand manufacturers provide a guarantee for 8 years or up to 1,00,000 miles of usage [222]. The battery replacement cost will be around \$6000 for an EV with 40kWhr battery capacity. This is about 15 – 19% of the vehicle cost.

#### D. FINDINGS

- Countries' charging standards differ, limiting native brands to within their boundaries. It adds to the confusion among OEMs, EV buyers, and Charging Station Operators. Japan and China are working together to develop a new high-power DC fast charging standard "ChaoJi" which is compatible with CHAdeMO, GB/T, US-CCS1, Euro – CCS2, and Tesla fast charging.
- For EV in the US, the OBC rating is greater, whereas it is low in India. This has a greater impact on the charging duration and the EV uptake. Although fast charging up to 150kW is possible, it is advised that the battery be charged at lower power levels to ensure a longer battery life.

**TABLE 10. Charging terminals and specifications.**

Connector & Inlet	Name	Standards				Year	Communication Protocol	Power (kW)	
		EU (IEC)	USA (SAE, IEEE)	JAPAN (JIS)	China (GB/T)			Plug	Market
	CHAdeMO	Y	IEEE	Y		2009	CAN	400	150
	GB/T 20234.3	Y			Y	2013	CAN	185	125
	CCS1	Y	SAE	Y		2014	PLC	200	150
	CCS2	Y		Y		2013	PLC	350	350
	Tesla					2012	CAN		120
	ChaoJi			Y	Y	2020	CAN	900	

- Despite the fact that CCT standards are well-established, WCT is attracting research attention because it can cut the overall cost of an electric vehicle by reducing battery sizing.
- To have faster EV adoption, the EVSE to EV ratio should be enhanced. Despite the fact that Norway has the lowest ratio, the majority of EVs are charged at home.

**IV. GOVERNMENT POLICIES TO BOLSTER EV**

Although improvements in terms of driving range, cost, battery technology, standards, charging infrastructure establishment, and so on are needed, countries that are concerned about vehicle-related pollution released aggressive policies that underpin EV sales by providing subsidies, incentives, and credit schemes to customers and manufacturers [46]. These policies are structured to phase out CPV shortly. More than 120 countries have vowed to achieve net-zero emissions over the next few decades, accounting for 85% of the global vehicle fleet (excluding two and three-wheelers). Eleven member countries such as Canada, China, Finland, France, India, Japan, Mexico, Netherlands, Norway, United Kingdom, and Sweden along with 29 supporting companies and organizations have agreed to achieve the benchmark target of 30% EV sales share by 2030 under Clean Energy Ministerial campaign which is also known as EV30@30 [223]. The campaign is coordinated by IEA and Shanghai International Automobile City (SIAC) group. Following the first pandemic wave in 2020, government

initiatives are more oriented towards EVs and Hybrid Electric Vehicles (HEVs). The key EV policies in the countries considered will be analyzed under the following aspects:

- 1) EV Promotion Programs
- 2) Targets: EV Sales / Stock, Fuel Economy, and Emission
- 3) Purchase Incentives: Purchase Subsidy tax exemption and the eligibility criteria
- 4) Credit Scheme and its target
- 5) Charging infrastructure: Funding and Target.

The comparison on these key aspects followed in the countries considered is presented in Table 11.

**A. CHINA**

EV promotion programs are rolled out for stimulating high-quality sustained EV development and fastening EV adaptation by the governments. Chinese EV programs were put forth by the 863 EV project in 2001 and by the subsequent programs like New Energy Vehicles (NEV) in 2009, Dual Credit Policy in 2017, Carbon Neutrality Ambitions 2060, and New Energy Vehicle Industry Plan (2021-2035) (NEV-IDP). China hopes to make a 20% market share of Zero-Emission Vehicles (ZEV) which include Battery Electric Vehicle (BEV), Plug-in Hybrid Electric Vehicle (PHEV), and Fuel Cell Electric Vehicle (FCEV) by 2035, and to raise China’s ZEV to international standards. According to the NEVIDP, NEVs would account for more than 80% of newly added vehicles in public fleets from 2021 onward. By 2025, NEVs will contribute a 20% annual new vehicle sales share,

and by 2035, it seeks to achieve 100% electrification of public fleets with BEVs accounting for 50% of NEV sales. Electric car sales rose from 4.8% in 2019 to 5.7% in the second half of 2020 as a result of the regulatory change. This regulation change also raises the level of competition between low-cost domestic brands and foreign brands available on the local market [224]. For the new passenger light-duty vehicles with under 3500kg, the Ministry of Industry and Information Technology (MIIT) has issued a mandate to achieve 117gCO<sub>2</sub>/km or 25km/liter [225]. According to the NEVIDP, one of the objectives is to reduce average electricity consumption from 150 to 120Wh/km [224]. In April 2020, the Ministry of Finance reduced the direct NEV subsidy by 10%, and earlier this year by another 20%. Because New EV subsidies support the Chinese EV market, and as a result of the pandemics after effects, the subsidy period has been extended until 2022, after which it will be gradually phased out. The purchase subsidy is applicable for NEVs with a maximum retail price below CNY 300,000 (USD 42,400). The amount of the subsidy varies depending on the Electric Driving Range (EDR). A subsidy of CNY 16,200 (USD 2,300) is available for BEVs with an EDR between 300 and 400km, while a subsidy of CNY 22,500 (USD 3,200) is available for BEVs with an EDR greater than 400km. A subsidy of CNY 8,500 (1,200) is applicable for PHEV having EDR greater than 50 km. Subsidies will be limited to 2 million NEVs per year from 2020 to 2022 having a speed of 100km/hr and battery density of 125 Wh/kg. 10 % on purchase tax exemption is also provided to underpin EV uptake. Rather than a one-time purchase subsidy, the new policy recommends an incentive program during vehicle ownership and usage [226]. According to the NEV credit mandate of 2017, credits are based on EDR, energy efficiency, and rated power of fuel cell systems for EVs [227]. International Council on Clean Transportation (ICCT) reports the reduced per-EV credits and stringent NEV credit target for 2021–2023 in February 2021. The update sets an 18% credit target for the passenger EV to achieve by 2023 [226], [228], [229]. Funding is provided by both central and state to establish PCS. The Ministry of Finance, the MIIT, and the National Development and Reform Commission (2019) play a major role in the setting up of PCS [230]. Chinese cities like Beijing, Tianjin, Shanghai, Sichuan, Henan, Guangdong, Shandong, Jiangxi, Hunan and Hainan declared to install 1.2 million chargers by 2025 in response to the USD 1.4 trillion Digital Infrastructure Public Spending Program [231]. Henan encourages local governments by financial rewards for meeting the household charger target [232]. Moving away from subsidizing local vehicle purchases and toward infrastructure deployment support, according to these stakeholders, could be the new focus to accelerate EV adoption. This is evident as more than 29 provinces and cities in China made the process easier for availing the license plate, waiving traffic restrictions, and reducing parking or free parking, charging rebates to new ZEV adopters rather than providing

EV promotional subsidies. The battery industry aims in developing cheaper (CNY 1.3/kWh) and high energy density batteries 300Wh/kg [233]. A ban on conventional vehicle manufacturers on noncompliance with energy performance-related norms was declared by the government [227]. R&D group, technology patents, and after-sales service are made as mandatory requirements for OEMs [234]. The recent policy revision encourages shared, intelligent and connected mobility [224].

## B. THE U.S.

The Zero Emission Vehicle Program (ZEV-P), which is a part of the California Air Resources Board's (CARB) advanced clean cars package of coordinated standards and the United States' Electrify Forward Act [235], plays an important role in stimulating and sustaining EV adoption in most of the provinces in the United States. California has been a forerunner, influencing many states like Colorado, Connecticut, Maine, Maryland, Massachusetts, New Jersey, New York, Oregon, Rhode Island, and Vermont to take up the ZEV-P and Green House Gas (GHG) emission laws to minimize vehicle-related pollution. California Climate Investments (CCI) provides financial aid for the Clean Vehicle Assistance Program (CVAP) to make environmentally-friendly vehicles accessible and affordable to all who qualify [236]. California, Connecticut, Maryland, Massachusetts, New Jersey, New York, Oregon, Rhode Island, Vermont, and Washington are among the ZEV Alliance members striving toward a 100% ZEV goal under PCs and Light-Duty Truck (LDT) categories by 2050 [19], [237], [238]. By 2025, these states seek to have 3.3 million ZEVs (BEV, PHEV, FCEV), with California aiming for 1.5 and 5 million ZEVs by 2025 and 2030, respectively. The new cars shall satisfy to have 18.5 km/liter of Corporate Average Fuel Economy (CAFE) or 114gCO<sub>2</sub>/km. In response to the Covid-19 crisis, 1.5 billion USD is allocated for purchasing electric or hydrogen vehicles. According to the fact sheet released by the United States' white house, an investment of 174 billion USD in the EV market is being promised [221]. Electric driving is also encouraged through the Driving Clean Assistance Program (DCAP). A subsidy of up to USD 5,000 is available to low-income California residents who want to buy a new or used hybrid or EV [239]. Through the vehicle buyback program, the new EV customer receives a subsidy of USD 1,200. Tax credit up to USD 7,500 was offered as rebates for the first 200,000 vehicles (PHEV and BEV) having a minimum battery capacity of 5kWh released by the manufacturers and later the subsidy was reduced by 50% and offered for 6 months [240]. About 30% of electric cars sold in the United States were benefited from the tax incentives in 2020. ZEV aims to achieve 22% EV credit by 2025. Despite the pandemic, because of stronger EV policies at the state level EV market continued stable during 2020 though CPV car sales witnessed a 23% fall. In 2021, USD 300 million has been allocated in the budget towards infrastructure support by the state. Through the U.S. infrastructure plan 2021, 500,000

**TABLE 11. Comparison of key aspects in government policies in the countries considered.**

Key Aspects	Countries					
	China	U.S.	Japan	Germany	India	Norway
<b>EV Promotion Programs</b>	863 EV, NEV, Dual Credit Policy, Carbon Neutrality Ambitions, NEVIDP, Digital Infrastructure Public Spending Program	ZEV-P, CARB, CCI funding to CVAP. DACP	NeGV, CEV, W2W	European Green Deal, Smart Mobility Strategy and Action Plan,	NEMMP, FAME,	
<b>Targets</b>						
EV Sales / Stock	ZEV: 20% sales share by 2035. Annual sales share target: 20% by 2025 and reach 100% by 2035	ZEV: 3.3 million by 2025. ZEV (PC and LDT): 100% sales by 2050	BEV and PHEV: 20-30% by 2035 and 100% by 2050	BEV and FCEV: 7-10 million by 2030. ZEV: 100% by 2050	EVs: 30% sales share by 2030	ZEVs: 100% sales share by 2025
Fuel Economy	25km/litre for CPV and 120Wh/km for EVs	18.5 km/liter	17.54 km/litre		20.96 km/litre	
Emission	117gCO <sub>2</sub> /km	114gCO <sub>2</sub> /km	132gCO <sub>2</sub> /km	95 g CO <sub>2</sub> /km	113 g CO <sub>2</sub> /km	85gCO <sub>2</sub> /km
<b>Purchase Initiative</b>						
Purchase Subsidy tax exemption & Eligibility Criteria	Subsidy available till 2022 and limited to first 2 million NEVs/year which has a sticker pricing below CNY 300,000, Max. Speed of 100km/hr and battery density of 125 Wh/kg. Subsidy for EVs: CNY 16,200, if 300<EDR<400kms. CNY 22,500, if EDR>400kms. Subsidy for PHEVs: CNY 8,500, if EDR>50kms.	Max. of USD 5,000 is made available through DCAP as Subsidy. Additional Subsidy of USD 1,200 is offered through vehicle buyback program. Tax credit up to USD 7,500 was offered as rebates for the first 200,000 vehicles with a minimum battery capacity of 5kWh. ZEV aims to achieve 22% EV credit by 2025.	Subsidy for EVs: JPY 400,000 offered by the government apart from the municipal subsidies, if EVs have EDR>400kms. No purchase and weight taxes. Tax rebates, road tax, and toll fare subsidies subsidized or free parking space, access to special lanes, and charging stations	BEVs and PHEVs with a retail price capped at EUR 40,000 are eligible for a EUR 6,000 purchase subsidy, while BEVs and PHEVs with a retail price between EUR 40,000 and EUR 5,000 are eligible for a EUR 5,000 purchase subsidy. VAT reduced to 16% until 2030. Free subsidized parking, designated parking spaces, and access to bus lanes.	BEVs and PHEVs with a maximum retail price of less than INR 1,500,000 receives a subsidy of INR 10,000 per kWh. A maximum of INR 300,000 is offered as a subsidy. A tax deduction of INR 150,000 on interest paid on electric car loans are permitted. Taxes on EV parts manufacture have been reduced to 17.16% from 21.55 to minimize the overall EV cost.	Until 2022, a purchase tax on CPV is levied based on their weight, CO <sub>2</sub> emissions, and NOX emissions. Purchase of new or used EV receives complete exemption of purchase tax and VAT, the yearly road insurance and a rebate on corporate car fleet tax is allowed. 50% off on parking fees and toll rates since 2018. Access to bus. On scrapping the CPVs for the purchase of ZEVs, fiscal compensation is provided.
<b>Credit Scheme &amp; target</b>	Credits are based on EDR, energy efficiency, Power rating of fuel cell systems for EVs					
<b>Charging Infrastructure</b>	By 2025: Install 1.2 million chargers	500,000 chargers shall be installed. Installing Home Chargers: reimbursement of up to USD 2,000 and federal tax credit of 30% on the equipment and installation cost, up to USD 1,000	Reimbursement on charging infrastructure costs as a subsidy policy: 50 to 67%.	By 2030: Install 1 million charging stations Subsidy for Renewable energy-based PCS provide 80% subsidy on the overall cost. Tax exemption for employers on setting up free EV charging station.	FAME II has set aside INR 10 billion for the deployment of network charging stations, with incentives ranging from 50% to 100% of the charger cost, depending on location and accessibility. One slow PCS every km and one fast PCS every 100km.	Build multi-standard fast-charging stations every 50 km on all major highways in Norway.



new EV chargers shall be installed [241]. XVII Innovative Clean Energy Loan Program [242] supports the deployment of EV charging stations. Charger incentives include direct investment and purchase incentives for installing public and private charging. Participants in the DCAP will get a reimbursement of up to USD 2,000 for acquiring and installing a home charger, as well as a federal tax credit of 30% on the equipment and installation cost, up to USD 1,000.

### C. JAPAN

The Next Generation Vehicle Promotion Center (NeGV) promotes EV through Clean Energy Vehicle (CEV) subsidy program initiated in 2018 and the Well-to-Wheel (W2W) Zero Emission in the subsequent year. Japan has fixed a clear sales target to be achieved between 2030 and 2035 concerning BEV and PHEV (20 – 30 %) and attain 100% sales share by 2050. The Ministry of Economy Trade and Industry (METI) and the Ministry of Land Infrastructure Transport and Tourism (MLITT) declared a CAFE target of 17.54 km/liter (32% better higher than 2016 values) for Passenger Light-Duty Vehicles (PLDV) by 2030. It also plans to reduce fuel consumption by 23.8% compared to the present level, [243], [244] as well as CO<sub>2</sub> emissions (132gCO<sub>2</sub>/km) by 25% compared to the 2015 figure [245]. Agency for Natural Resources and Energy (NRE) aims to improve the economy by 13.4% for heavy trucks and 14.3% for buses compared to 2015 levels by 2025 [217]. Automaker's GHG emission per car to be brought down by 80% at the end of 2050 [246]. Japan has been active in offering subsidies to EV buyers since 2017 with no purchase and weight taxes. In addition to the 13 billion JPY (USD 120 million) set up for fuel-efficient cars in 2017, 1 billion JPY (1 million USD) was set aside to speed up the introduction of HEV, PHEV, and BEV trucks and buses in 2018. To support FCEV, 2.6 billion JPY (24 million USD) was also allotted. For EVs with a range of more than 400 km, a JPY 400,000 (USD 3,700) subsidy has been offered by the government apart from the municipal subsidies. Though this might be significantly less than European subsidies of up to JPY 1 million, it still brings down the price gap further. The government has considered doubling the subsidy for new EVs charged using renewable energy [247] as well as handling the EV sales decline due to Covid-19. The upper limit of the subsidies remains unchanged for PHEV and FCEVs [247]. The period of incentives extended for 2 more years. Tax rebates, road tax, and toll fare subsidies subsidized or free parking space, access to special lanes, and charging stations are the primary reason for EV purchase in Japan. The initiative resulted in a 35 % increase in EV sales in January 2021 when compared to January 2020. The policy provides 50 to 67% charging infrastructure costs as a subsidy.

### D. GERMANY

Despite the Pandemic, the European Union (EU) has increased the roll-out of electric mobility as part of its commitment to the European Green Deal goals (2019) in achieving carbon neutrality by 2050 and the successive

New Generation EU and recovery plan [248]. The EU Sustainable and Smart Mobility Strategy and Action Plan have established ZEV adaptation targets, which adds a strong tone to this commitment [249] and cut down the transport-related emission by 40-42 % according to Germany's Climate Action Program [250]. Policymakers hope to reach 7-10 million BEV and FCEV stocked by 2030 [250] and by 2050, all PCs shall be ZEVs [251]. From 2021 onwards, the corporate fleet average tailpipe emissions should be 95 g CO<sub>2</sub>/km for new vehicles and 147 g CO<sub>2</sub>/km for new vans. Emissions are planned to be reduced by 15% and 37.5% from present levels in 2025 and 2030, respectively, while fuel economy is expected to improve by 15% and 30% in the very same years. BEVs and PHEVs with a retail price capped at EUR 40,000 (USD 45,200) are eligible for a EUR 6,000 (USD 6,800) purchase subsidy, while BEVs and PHEVs with a retail price between EUR 40,000 (USD 45,200) and EUR 5,000 (USD 5,600) are eligible for a EUR 5,000 (USD 5,600) purchase subsidy (USD 73,400). During the second half of 2020, the VAT rate was reduced from 19 to 16 %, and the annual vehicle tax exemption will be extended till 2030 for BEVs registered between 2011 and 2030 [250], [252]. EV sales were bolstered by cash for disposing of CPV, as well as subsidies and incentive programs, while a few EU countries advocate for a speedier phase-out of gasoline and diesel vehicles. Employers who offer free EV charging are exempt from paying taxes until 2030. Until 2030, Germany provides free subsidized parking, designated parking spaces, and access to bus lanes. According to the National Public EV Charging Incentives, 1 million charging stations will be established by 2030 [253], with 52,096 commercial EV charging points in Germany been successfully installed since 2017 [254]. An additional 500 million Euros added earlier this year to build new charging stations before December 2022 [254], [255]. EV infrastructure development with battery cell production, PCS, etc., would receive 2.5 billion euros (USD 2.8 billion) as per Economic Recovery Plan. The Recovery and Resilience Facility [256] comprises funding for charging stations. An EV charging point at all filling stations is made mandatory. If the PCS uses renewable energy sources, subsidies will cover 80% of the overall cost. Purchase and installation of wall box charger attract an incentive between 10-30%. Based on the charger rating subsidies are offered for PCS as mentioned in Table 12. Subsidies of up to €10,000 for low voltage PCS and up to €100,000 for medium voltage PCS are provided.

### E. INDIA

National Electric Mobility Mission Plan (NEMMP) and Faster Adoption and Manufacturing of (Hybrid &) Electric Vehicles (FAME) are the programs that promote ZEV in India [257]. In phase II of FAME, a total of INR 100 billion (1.3 billion USD) was set aside to provide subsidies for the purchase of EVs with improved batteries.

Because Indian roadways are dominated by two and three-wheelers, and the vast majority of the population relies on

**TABLE 12. Subsidy for installing PCS in Germany.**

Source	Power Rating (kW)	EURO
AC	3.7 – 22	Up to €4,000
DC	22 – 20	Up to €16,000

shared/public transportation, 41% of the financing is allotted for electric buses, 29% for two-wheelers, and 23% for three-wheelers. Emphasize public and shared e-mobility solutions shall reduce oil reliance import by 10% by 2022 [258]. India plans to have a 30% share of total EV sales by 2030. India intensifies its vehicle-related emission policy by moving from Bharat IV to Bharat VI, with a standard of 113 g CO<sub>2</sub>/km by 2022 [259], [260]. The bar for the fuel economy standard was raised to 20.96 km/liter [258]. A purchase subsidy of INR 10,000 (USD 130) per kWh is available for BEVs and PHEVs with a maximum retail price of less than INR 1,500,000 (USD 19,900). A maximum of INR 300,000 is offered as a subsidy.

A tax deduction of INR 150,000 (USD 2,000) on interest paid on electric car loans are permitted. Taxes on EV parts manufacture have been reduced to 17.16% from 21.55 to minimize the overall EV cost [261]. FAME II has set aside INR 10 billion (US\$ 130 million) for the deployment of network charging stations, with incentives ranging from 50% to 100% of the charger cost, depending on location and accessibility. According to the Society of Manufacturers of Electric Vehicles, India had 1,800 charging stations for about 16,200 electric cars, including the fleet segment, as of March 2021. India intends to have one slow PCS every km and one fast PCS every 100km.

#### F. NORWAY

The EV campaign has been going on since the early 1990s, to accelerate road vehicle transition. The government intends to achieve 100% ZEV sales by 2025, although it now has the highest EV sales percentage of 75 (Fig. 6). The emission standards for new cars shall be below 85gCO<sub>2</sub>/km. According to the “Polluter pay principle” policy adopted, the vehicle with higher emission levels shall receive higher tax. Until 2022, a purchase tax on CPV is levied based on their weight, CO<sub>2</sub> emissions, and NOX emissions [240], [262]. Both at the national and local levels, the country has an appealing incentive strategy in place. On the national basis, the purchase of a new or used EV is free from purchase tax and VAT, the yearly road insurance fee is waived in full and a rebate on corporate car fleet tax is allowed. On a local basis, parking fees and toll rates have been reduced by half since 2018, and ZEVs are given access to bus lanes [263]. On scrapping the CPVs for the purchase of ZEVs, fiscal compensation is provided [264]. The incentives shall continue till the end of 2021 and thereafter the same shall be reviewed for revision as per market growth. Since, 2017 financial support has been offered to build multi-standard fast-charging stations every 50 km on all major highways in Norway. With a wide PCS network, simultaneous DC fast charging of 33000 EVs is possible as of January 2021.

#### G. FINDINGS

- In the countries studied, long-term goals with well-defined road maps resulted in faster EV adoption.
- Stringent policies in terms of fuel economy, emission levels are pushing EV to the front.
- Subsidies are provided based on the EDR, battery capacity, etc., which allows the EV manufacturers to have high quality design.
- The government’s policy also includes the establishment of more public EV charging stations. Additional subsidies are also provided to PCS operating with renewable energy sources.
- Tax breaks, subsidized or free parking, toll exemptions, and car scrapping all aided EV adoption.

#### V. CONCLUSION

The study examined the three key elements for accelerating EV adoption are analyzed statistically and highlighted the limitations that are impeding a smoother transition in the road transportation industry. EV has a cheaper cost per km than a CPV, although the propulsion power, torque, maximum vehicle speed, and acceleration are similar. When compared to CPV, there has been a significant difference in EVs’ cost and class. In the market, a compromise on vehicle class is found. The shorter EDR offered by EV adds to the hurdle. From the perspective of the consumer, they are the most solid factors for adopting EV. A significant breakthrough in battery chemistry that results in better specific power and energy density at a lower cost per kWh is required to increase driving range as well as minimize curb weight. Only a few countries are striving to improve battery technology. Most of the leading countries like China, the USA, etc., are involved in developing standards for charging. Wireless charging standards are currently being explored at a faster pace to address the concerns of EV cost and range anxiety. The technology shortfall in the same is also reviewed. Collaboratory standard development leading to a single connector and inlet shall address the bedlam between EV manufacturers, policymakers, customers, and the charging infrastructure business that prevails due to multiple standards. This allows EVs to charge in all PCS while also allowing the best EVs in a given country to go across borders. The corporate fleet average tailpipe emission for new generation fueled vehicles can further be tightened as it is in Norway (85gCO<sub>2</sub>/km). Shared/public mobility can be emphasized to reduce fuel consumption and vehicle-related pollution. The findings of the native vehicle usage study as in India can be pooled to create a unique strategy intensifying EV volume in the vehicle segment that contributes to vehicle-related pollution. India places a greater emphasis on public transportation than on PCs. Rather than a one-time purchase subsidy, incentives or subsidies might be offered based on the number of electric km driven. The charging facility at parking, subsidized or waived parking and toll fees, access for special lanes have stimulated the interest for purchasing EV. Green tax based upon corporate fleet average tailpipe

emissions would generate funding for providing subsidies to encourage green transportation. In terms of charging stations, the EVSE to EV ratio, or EVSE per 50 or 100 km depending on the route and location to increase the density of PCS, might aid in quicker EV adoption by allowing more EVs to charge at the same time. The public and private sectors collaborate in establishing renewable energy-based PCS shall increase the EVSE to EV ratio. The domino effect created because of the transition to EV will lead to 3.2TWh demand concerning batteries in the next decade meanwhile, the 800 TWh of energy demand has to be met only by renewable energy sources. All these shall justify the major transformation happening in road transportation.

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