A Review of the Electric Vehicle Charging Techniques, Standards, Progression and Evolution of EV Technologies in Germany

Aqueel Ahmad\textsuperscript{a}, Zeeshan Ahmad Khan\textsuperscript{b}, Mohammad Saad Alam\textsuperscript{a} and Siddique Khateeb\textsuperscript{c}

\textsuperscript{a}Department of Electrical Engineering, Aligarh Muslim University, Aligarh, India; \textsuperscript{b}Department of Electrical and Computer Engineering, Technical University Munich, München, Germany; \textsuperscript{c}AllCell Technologies, Chicago, IL, USA

ABSTRACT
Electric Vehicle development has been adopted as one of the national policies by the German Government as the country desires to reduce carbon emissions and address energy problem. Germany has invested a lot in the EV development. Since the launch of National Platform Electromobility in 2010 there has been continuous development in EV industry of Germany. In this paper, first the EV charging technologies are discussed, which is then followed by the elaboration of the EV charging standards by the major standardization organizations. The study then mentions the status quo and projected development of EV technology in Germany focusing on the development of charging infrastructure and battery technology. This is followed by highlighting the efforts made by German auto manufactures in the field of Electromobility and comparison with their American and Chinese counterparts. The paper then identifies the hurdles that are present in the path of achieving the goal of 1 million EVs by 2020. Then, overview of the EV developing strategy in Germany to address the challenges is presented which is followed by conclusions and references.

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CONTACT
Aqueel Ahmad  aqueelahmad@zhcet.ac.in, aqueel.100@gmail.com

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1. Introduction

The automobile industry is experiencing a technological revolution with the rise of electric vehicles (EVs) [1,2], which are challenging their internal combustion counterparts. Growing environmental awareness, innovations, market acceptance, government support, investments by original equipment manufacturers, and financial viability are together paving the road for electric vehicles. The development of EVs will not only help reduce carbon emissions from transportation sector but will also be beneficial by providing support to existing power grids [3–6]. The efforts by the governments, industries and other associated organizations have resulted in advancement of EV technology and increment in EV sales, still progress is not that rapid as was anticipated [7–9]. With large-scale investments and highly coordinated R&D, the future of EV industry looks promising, though it would be a very long journey to become an alternate and eventually replace the existing gasoline vehicles which have dominated the transportation sector for more than a century [5].

The paper first elaborates the charging techniques applicable to the EVs. First, the conductive charging method is explained followed by inductive charging [6,10] and lastly the battery swapping technology is also presented. This is followed by stating EV charging standards issued by major standardization organizations. In this section, the major charging standards have been discussed at length while a tabular presentation of the existing charging standards by the major organization is also presented [11,12]. The paper then shifts the focus to the EV progress in Germany. Germany has set the goal of achieving leadership in market and in provision of electric mobility by 2020 which is a part of its long-term zero emission mobility vision. One million electric vehicles on the road by 2020 – is the objective of Germany’s ‘National Electromobility Development Plan’ [13,14]. This paradigm shift in the transportation sector needs synchronized operation from government, industry, academia, R&D, suppliers and other linked industries. The paper first analyses the current situation and the projections of the EV sectors in Germany. Two major areas Charging Infrastructure [15–19] and Battery Technology [20,21] have been focused here. The study then moves further stating the contributions made by the German automakers so far. The vehicles launched by these manufacturers and their details in terms of their type, battery capacity and price are presented in tabular form. This will help the reader analyze the progress so far and the reasons as to why the EV industry has not been very effective in influencing the transportation sector. This is followed by highlighting the major challenges that need to be faced by Germany in order to achieve their goal of Electromobility. The paper then provides the overview of the EV development strategy which is being implemented in Germany [22–25]. This section highlights the domains which are being concentrated upon and the territories covered by them. This is followed by conclusions and references. This paper will be of utility to the industry and academia who intent to look for information regarding charging technologies, progress and predictions for the EV industry in Germany.

2. EV Charging Techniques and Standards

Major challenge for the adoption of electric vehicle is its charging. Charging involves the electrical power from the grid at an appropriate power level is injected to the battery. Charging times depends on battery and power level of charger. The major challenge is charging time and limited life of battery. Some of the technologies of charging of electric vehicle are discussed in the following sections. Figure 1 shows different EV charging techniques.

2.1. EV Charging Methods

Charging of the Electric Vehicle battery is accomplished majorly by three methods: Conductive charging method [6,26–29], Inductive charging method [10,29–32] and Battery swapping technique [33–35].
2.1. Conductive Charging

Conductive Charging allows direct connection of charger and vehicle, where physical contact is there between power supply and battery. It consists of rectifier and converter with some power factor correction and classified as on-board and off-board charger. On-board charger contains rectifier and battery regulation inside the vehicle, whereas off-board charger has outside. It is classified on the basis of various current voltage combinations as shown in Figure 2. The physical connection between charger and vehicle limits contact at higher potential difference. Fast charger may get damaged or sparked to produce risk at high power level of charging. Daily habit of charging using slow charger gets problematic while disremembering the charging at night.

2.1.2. Inductive Charging

Inductive power transfer allows battery charging using the varying magnetic field [36] to transfer power through the air-gap between the primary coil in the ground (transmitter) and the secondary coil in vehicle (receiver) without any galvanic connection [5,37,38]. This simplifies the charging process and reduces the risk of any potential harm to use when handling the electrical equipment [13]. Additionally, the absence of any mechanical parts for power transfer enables the concept of ‘opportunity charging’ [5] implying that the charging process can be integrated with the normal vehicle operation. This will cause frequent charging/discharging resulting in decrement of battery depth of discharge which increases the battery life and also reduces the size of on-board energy storage system [6]. Figure 3 represents the layout of a wireless power transfer system.

**Working:** The process of wireless power transfer is divided into three different steps. Conversion of power supply, resonance between the coils to transfer power and finally again conversion to charge the battery [9]. First, input AC supply is converted to high-frequency AC [39–44]. This is used to drive the transmitting (primary) coil by means of a compensating network. This high-frequency current in the transmitter side coil generates an alternating magnetic field which induces AC voltages in the receiver (secondary) coil [45–49]. By resonating with the compensation network on receiver side, the transferred power and efficiency are significantly improved. Finally, the AC power obtained is rectified to charge the battery, and in order to improve the efficiency of the system magnetic resonant coupling and DC-DC converter must be employed on receiving side [37,50–55]. The frequency for this system varies in the range from 20 to 100 kHz. Over this range, the converters in the system can operate with as high as 90% efficiency. There exist two methods for inductive charging: Static Inductive Charging and Dynamic Inductive Charging. On the other hand, there are some technical challenges of inductive charger is the efficiency of transmission and safety. Efficiency if power transfer depends on alignment between transmitter and receiver [36,56–63], power pad design [47–49,64–67], frequency of operation [43,68–73], compensation topology [60,61,74–77], and distance between the transmitter and receiver.

2.1.3. Static Inductive Charging

As the name suggests, the vehicle remains stationary or static during charging. The owner could simply park the car at a spot and leave it for charging with a certain range for acceptable misalignment. This is convenient as it eliminates the necessity for a physical connection between the vehicle’s battery and the utility supply [13]. This kind of an arrangement is suited at places like shopping malls, office garage, etc. where the vehicle is being parked for a particular time interval [78]. The long-term goal is to extend this concept to allow power transfer between vehicle and utility while the vehicle is in motion, which is known as dynamic charging [79]. Figure 4 shows the concept of Static Wireless charging. Static Inductive charging

![Conductive Charging Power Levels](image-url)

**Figure 2.** Different categories of conductive chargers.
technology requires large battery pack to increase the range as in case of conductive charging. To overcome the problem dynamic wireless charging is the potential solution.

2.1.4. Dynamic Inductive Charging (DIC)
This inductive charging enables the power transfer while the vehicle is in motion [3,80]. This method is evolutionary and is gaining significant attention from the research fraternity due to its numerous advantages. Using this method, it is possible to charge public transport (buses and taxis) at the stops when people board and off board. This notion can be extended to highways or roadways where certain lanes can be powered continuously to provide charging to vehicles in events of slow movements due charge depletion or high traffic [37]. This would enable the manufacturers to reduce the size of on-board storage unit thereby, reducing weight, complexity, initial costs and will proved the user freedom from range anxiety [23,81]. Figure 5 demonstrates the concept of dynamic inductive charging.

Dynamic charging implementation can incorporate two kinds of magnetic couplers. First, is the one in which a single coupler is laid on the track longitudinally while the second is the one in which the coupler is segmented into different coils. This type of approach is significantly advantageous because it enables the system to energize only the segment above which the vehicle’s receiver system is present thereby, reducing the energy loss [56]. Some of the challenges of DIC system: very high installation cost, installation possible only on the highways, universities, except public places; complex management for scheduling, payment, and management [82] of DIC system.

2.1.5. Battery Swapping
One of the most time efficient and hassle-free charging method is the battery swapping technique. This method involves the replacement of the depleted battery with a fresh one to support the electric drive. The battery swapping station is chiefly composed of a distribution transformer, AC–DC converters, battery chargers, vehicle batteries, robotic arms, charging racks, maintenance system, control system, and other equipment involved in the swapping and charging of the batteries [34,83,84]. One significant merit is the Battery Swapping Stations have the ability to perform bulk bi-directional power flow with the grid. During peak demand the stored batteries inject power into the grid and during the off peak hours the charging is performed, thus improving the load curve and resulting in increased efficiency of the local power systems [85–88].
This is a very big challenge for battery swapping to design the batteries in such a way that can easily be exchanged and be compatible.

- **Infrastructure**
  Infrastructure would be very complex and very expansive as compared to other charging strategies. Each charging station will demand a huge power from the grid. Each car would be using two batteries at a time, one would be at the charging station and the other inside the car.

- **Battery ownership**
  Vehicle owner have to purchase two batteries which is to be exchanged alternately or doesn’t own the battery means all burden on the charging station.

**Interchangeability**
Different manufacturer are having their own compatibility, the probability of getting battery with same condition is difficult to find. Driving behavior will effect if swapped battery is having less state of health [90].

- **Feasibility**

Additionally, providing added financial benefits to the station owners and reducing their dependence on utilities for supplying power to them if they have enough charged batteries to support their functioning. They will also optimize the scheduling of public transport. Figure 6 shows the structure of the swapping station. Following are the challenges of battery swapping systems [84,89,90].

**Figure 5.** The concept of dynamic inductive charging.

**Figure 6.** Structure of a battery swapping station.
2.2. EV Charging Standards

In this section, the different charging standards developed by different standardization organizations across the globe have been mentioned while highlighting those which are widely implemented. Table 1 shows the xEV charging standards issued by the major Standardization Organizations.

The IEC 61851-1 Ed. 2.0 (2010) [91] was designed to provide all the information significant to the construction of a charging infrastructure. These are developed by the TC 69 with the intent of being a complete guide to any professional designing a charging infrastructure. The standard defines ratings of the AC supply voltage, EV charging modes, specific requirements for the vehicle inlet, connector, plug, and socket outlet. The IEC 61851-23 Ed. 1.0 [92] which together with IEC 61851-1 (Ed. 2.0), gives the requirements for D.C. EV charging stations (conductive charging) and the general requirements for the control communication between a D.C. EV charging station and an EV. The standard was published in 2014 with the rationale to standardize the DC charging and its aspects after it was established that the DC charging system was more efficient than the AC charging system.

IEC 62196-1 Ed. 2.0 [93] published in 2014 superseding IEC 62196-1 refers to the plugs being employed for the industrial and multiphase applications like in chemical industries, heavy industries, water treatment plants, construction sites, and shipyards. Few of these plug types were also being employed for the automotive charging process and they are covered by the IEC 62196-2 Ed. 1.0.

The IEC 62196-2 Ed. 1.0 [94] applied to plugs and connectors having a nominal rated operating voltage not exceeding 500 V A.C., 50–60 Hz, and rated current not exceeding 63A three-phase or 70A single phase, for use in conductive charging of electric vehicles. The types of plugs include single phase coupler (J1772 connector), single phase and three phase coupler (Mennekes connector), single phase and three phase coupler with shutter (SCAME connector) and DC coupler (CHAdeMO connector). For the wireless charging, IEC 61980-1 Ed. 1.0 [95] applies to the equipment for the Inductive Charging from the grid to EV for purposes of supplying to energy storage and/or other on-board electrical systems in an operational state when connected to the grid and for wireless power transfer equipment supplied from on-site storage systems (e.g. buffer batteries, Ultra Capacitors etc.).

The SAE J1772 [96] standard also cover conductive charging requirement to facilitate the charging of EV/ PHEV in North-America while the SAE J1773 [97] issued by the Hybrid EV committee establishes the minimum interface compatibility requirements for electric vehicle (EV) inductively coupled charging in the same geographical regions. This type of inductively coupled charging is anticipated to transfer power at frequencies higher than the power line frequencies. The SAE J1772 was developed in 2009 for conductive charging and applied to EVs and PHEVs including the Chevrolet Volt, Nissan Leaf, Ford Focus Electric and Toyota Prius PHEV among others.

The Underwriters Laboratory has circulated the UL2202 [98], UL2251 [99], UL2594 [100], UL2734 [101], UL2871 [102] and UL9741 [103] standards to address the charging issues with Electric Vehicles. The UL2202 establishes the requirements for the Conductive Charging System equipment required for recharging the storage batteries in EV. The UL2202 safety standard is being implemented by a number of industries like Delphi (120 V/15A, Level 1 Charger) among others in their charging equipment’s.

3. Status Quo and Projected Development of EV Technology in Germany

Looking at the prominence of mitigating the carbon footprint from the transportation sector and ensuring reduced reliance on the oil supply, countries over the globe have been making expedite efforts. Germany has been one of the countries which are the forefront of addressing this issue. The German Government established the National Platform Electromobility (NPE) in 2010 [104] and launched the ambitious ‘National Electromobility Development Plan’ under which it targets 1 million electric vehicles on road by 2020 and increasing manifolds this figure to 5 million by 2030 [105–107]. To accomplish this vision, the German Federal Government has so far invested in the region of 1.5 billion Euros in electric mobility development [108]. The thrust areas of research under

Table 1. xEV charging standards issued by the major standardization organizations.

| IEC | SAE | UL | ESO | NTCAS | JARI | JIS | ARAI |
|-----|-----|----|-----|-------|------|-----|------|
| IEC 61851-XX-1X Ed. X | J 1772 (RIP) | UL2202 | EN 61851-XX | GB/T 18487.X-2001 | C601: 2000 | TS D 0007: 2012 | AIS-138/D1 |
| IEC 62982 Ed. 1.0 | J 1773 | UL2251 | CLC/TS 50457-X:2008 | GB/T 20344.X-2011 | G105-1993 | JIS D 1304: 2004 |
| IEC 62982 Ed. X | J 2954 (WIP) | UL2734 | | QC/T 895-2011 | G106-2000 | JIS D 61851-23/24:2014 |
| IEC 62983 Ed. X | | UL2871 | | QC/T 841-2010 | G107-2000 | JIS D 61963: 2014 |
| IEC 62984 Ed. X | | UL9741 | | | G108-2001 | |
| IEC 62983 Ed. 1.0 | | | | | G109-2001 | |

Note: X in the table symbolizes that exists multiple standards in that particular series and are denoted by series number.
this platform include the battery and the development of charging infrastructure [19,109], safety and reliability systems, electric drive, smart grid integration [110–112] and other associated technologies. Through these concerted efforts, the government aims to address holistically the issue of Electromobility: from the vehicle battery, electric drive technology through charging network, standards, and regulations to the power supply and smart grid integration. Throughout Germany, flagship R&D projects have been launched in the areas of batteries, electric drive technologies, vehicle to grid integration, vehicle design, and communication technologies to ensure that the technology is developed at a steady pace and that no associated aspect is left uncovered [108]. In order to prioritize the purchase of EVs by consumers, German Government launched several tax incentive measures and road traffic management schemes under the Electromobility act which came into effect from 2015 and will last all the way to 2030 [113]. Some of the vital points of this act are provided as:

1. The government will provide a subsidy of 4000€ for Battery Electric Vehicles (BEVs) and 3000€ for Plug-In Hybrid Electric Vehicles (PHEVs) [114].
2. To further the benefits, the government has exempted the BEVs from motor vehicle tax.
3. For corporate consumers, the government provided freedom from income tax disadvantages upon the purchase of electric and hybrid vehicles due to the high initial costs of these vehicles.
4. When on the road these vehicles are entitled to special parking places that will be allocated by local authorities as enacted by the government.
5. There also exists a proposal to allow access of public transport lanes for these vehicles to provide them an escape from the routine traffic, which makes a very lucrative reason to drive these vehicles on the road.

Many more of these points exist within this act, but the essence of manuscript does not allow to delve further in this issue. To conclude, it can be effectively said that these steps if implemented successfully over the defined time scale will definitely aid the government in achieving their goal.

### 3.1. Present Status and Future Projections

In Germany, Plug-In electric vehicles have managed cumulative sales of 66,764 from January 2010 through September 2016 [115]. This makes Germany fifth largest in Europe and eighth largest in the world in terms of number of registered Plug-In electrics. Figure 7 gives the statistical representation of the registered plug-in cars by Germany from 2010 to 2015.

From statistics it can be deduced that around 80% of the plug-in cars were registered from January 2014 to September 2016, which establishes the fact that the consumer interests in electric cars is steadily escalating. To achieve a successful market demand in Germany, it is necessary that the supporting charging infrastructure must also be developed. From the outlook of the consumer, it’s not significant if the car is charged by a.c. or d.c. supply, points in consideration are how long the car takes to charge completely and what’s the range of the car. To address these issues, there needs to be steady progress in charging infrastructure and battery technology.

### 3.2. Charging Infrastructure

By end of 2016, a total of 6517 publicly accessible charging points (2859 charging stations) [116] utilizing mostly Type 2 a.c. units (compatible with single phase and three phase a.c. and d.c. charging) were available throughout Germany. This is a considerable increase beyond a total of 5836 which was the number of charging points by the end of 2015. This shows that there has been an increment of more than 600 charging points since the end of 2015. The German Government has launched R&D projects across different states and cities to guarantee the development of technology throughout. Figure 8 shows the total number of publicly accessible charging points for electric vehicles per state.

The Statistic representing the number of publicly accessible charging points in top 10 German cities is given below:

From Figure 8 it is evident that the state Nordrhein-Westfalen (NRW) has 1335 charging points (as on 30/6/16, Source: BDEW) which is greatest among the other German states followed by Baden-Württemberg (1182) and Bavaria (937). These charging station statistics comprise standard charging as well as fast charging stations. From Figure 9, it
can be deduced that Berlin (529) tops the list in terms of cities with maximum number of charging points. Extensive research is being carried out to develop fast charging infrastructure due to big money investments and it is expected that by the end of 2017, Germany will have around 1400 fast charging points. This number is expected to increase by 5 times up to 2020, taking the total number of available fast charging points to 7100 each with a capacity of 150 kW as predicted by NPE [14]. The government plans to increase this capacity to 350 kW by 2025 to match the increase in the battery capacity of the cars. This will be complemented by increments in the grid capacity and increasing the share of renewable energy supply to charge these vehicles. Recently, the European automakers,
utilities and other associated companies, have announced
the project ‘Ultra-E’ which will enable the deployment of
25 new charging stations each with a capacity of 350 kW
for electric vehicles along the Trans-European transport
network (connecting the Netherlands, Belgium, Germany
and Austria) [117]. These measures will likely guarantee
that the charging infrastructure is available when the high
performance vehicles come up in the market and that the
consumers have to no longer worry regarding the charging
times of their vehicles [118].

**Battery Technology**: Reliable, efficient, robust, and
cheap batteries are the crux of EV development concept.
A battery constitutes around half the cost of an electric car,
so it becomes principal to reduce the cost of the batter-
ies for consumer viability and market success. At present
Li-ion is the most prevalent chemistry among the batter-
ies for BEVs and PHEVs and is likely to be leading the
research among battery technologies in the foreseeable
future. This is because these batteries possess comparatively
higher power and energy for a specific weight or
size, and can aptly reduce costs compared with other bat-
tery concepts. Additionally, they have longer life cycles
and lower self-discharging. One drawback is the risk of
overcharging which can be handled by means of a battery
management system.

The battery costs for BEVs were around €250 per kWh
for industry leaders in 2015 [119]. Therefore, for a 50 kWh
battery pack, the costs will go around €12,500. These costs
are expected to go down with the advancements in the
battery design and production technology. Further tech-
nological advancements could see the cost going to as low
as €130–€180 per kWh as anticipated for the 2020–2025
timeframe.

### 4. Progress on EVs by German Automakers

The German automakers are playing a pivotal role in
helping the country achieve its goal of 1 million EVs by
2020. The major automobile manufacturers like BMW,
Volkswagen (Audi and Porsche included), Daimler and
Mercedes-Benz among others have launched many hybrid
vehicles and are in the process of manufacturing many
more. The vehicles launched comprise hatchbacks, sedans,
SUVs, sports cars among others. A comprehensive list of
all the EVs, PHEVs, HEVs which have been launched and/
or are under development is provided in the Figure 10.

| Manufacturer | Type | Model | Battery Capacity | Price (in €) |
|--------------|------|-------|------------------|-------------|
| Volkswagen (VW) | PHEV | Passat GTE | 9.9 kWh | 44,250 |
|               | PHEV | Golf GTE | 8.7 kWh | 36,900 |
|               | PHEV | XL 1    | 5.5 kWh | 111,000 |
|               | EV   | e-Golf   | 35.8 kWh | 34,900 |
|               | EV   | e-Up     | 18.7 kWh | 26,900 |
| Audi          | HEV  | A8 Hybrid Quattro | 1.3 kWh | 81,000 |
|               | PHEV | Q7 e-Tron Quattro | 17.3 kWh | 80,500 |
|               | PHEV | A3 Sportback e-Tron | 8.8 kWh | 37,900 |
|               | EV   | R8 e-Tron | 92 kWh | 37,900 |
| Daimler / Mercedes-Benz | HV | C300h | 0.9 kWh | 40,000 |
|               | PHEV | S400h | 8.7 kWh | 91,095 |
|               | PHEV | GLC 350e 4MATIC | 8.7 kWh | 52,717 |
|               | PHEV | C 350 e/e | 6.38 kWh | 52,673.75 |
|               | PHEV | GLE 500/550e 4MATIC | 8.7 kWh | 62,100 |
|               | PHEV | S 500/500e | 8.7 kWh | 92,250 |
|               | EV   | B250e | 28 kWh | 39,151 |
|               | EV   | SLS AMG Electric Drive | 48 kWh | 416,500 |
|               | FCV  | B Class F-Cell | 1.4 kWh | 22,700 |
|               | EV   | Fortwo Electric Drive | 17.6 kWh | 22,700 |
| BMW           | PHEV | 330i ePerformance | 7.7 kWh | 45,050 |
|               | PHEV | 740i/eLe ePerformance | 9.2 kWh | 91,900 |
|               | PHEV | 225xe Active Tourer iPerformance | 7.6 kWh | 38,800 |
|               | PHEV | X5 xDrive 40e | 9.2 kWh | 68,400 |
|               | PHEV | i8     | 5.2 kWh | 130,000 |
|               | EV   | i3     | 22 kWh | 34,950 |
|               | EV   | Mini E | 35 kWh | 34,950 |
| Opel / Vauxhall | PHEV | Ampera | 16 kWh | 38,300 |
| Porsche       | PHEV | Cayenne S E-Hybrid | 10.9 kWh | 76,400 |
|               | PHEV | 918 Spyder | 6.8 kWh | 684,800 |
|               | PHEV | Panamera S E-Hybrid | 9.4 kWh | 110,400 |
| Borgward      | PHEV | BX7 TS | 13.2 kWh | 23,156.18 |

**Figure 10.** EVs, PHEVs, HEVs launched by German manufacturers. Source: Mark Lines-Automotive Industry Portal.
From the below table, it is evident that the automakers have launched electric drive vehicles in almost all categories of vehicles. But battery capacity, drive anxiety and cost still remain a detrimental factor, making it difficult to compete with conventional ICE based vehicles. The following section gives an idea about the position of German Automakers relative to American and Chinese EV manufacturers.

5. Status of EV Market in Other Major Countries

5.1. China

Similar to Germany, China has set up an ambitious target of having 5 million Electric Vehicles on road by 2020 [120]. At the moment, the number of Electric and Plug-In vehicles in China have crossed the mark of 1 million and will continue to increase due to technological advancements and lucrative policies from the government. Chinese venture capital investors have poured more than $1.4 billion into electric vehicle and battery start-ups in the past three years, according to Pitch Book, compared to $2.1 billion in total global venture capital funding for the sector. The growth of EV industry in China can be attributed to these big money investments in R&D’s as well as in established industries, start-ups in the area of EVs and battery development. The Chinese EV market is at boom because of availability of large number of EV brands, not only foreign manufacturers like Tesla, Nissan but also because of the presence of numerous indigenous vehicle manufacturers, BYD, BAIC (Beijing Auto), BMW Brilliance, Changan, SAIC (Shanghai Auto) among many others. Figure 11 shows the annual EV sales in China.

These wide ranges of available manufacturers have capitalized on the demand and are offering electrically propelled vehicles in all segments ranging from two-seaters, light weight trucks all the way to buses and heavy duty vehicles. Another contributing factor to the growth of EV and battery market in China is the availability of raw material at low costs. The fact that Chinese companies have been making inroads over the past year into the lithium-ion supply chain, buying up mining assets from cobalt to lithium has allowed them to increase the production thereby decreasing the battery costs. Stringent governmental policies on provision of subsidies for EVs from foreign manufacturers have also been a driving force towards encouraging the masses to buying the EVs from indigenous manufacturers. Figure 12 shows the status of EV industry in China.

5.2. United States of America (USA)

USA has been at the forefront of promoting electrification and green energy in transportations sector. Presently there are 35 EV manufacturers in USA, prominent among those include Tesla Motors, Chrysler LLC, Chevrolet, Ford Motors, Nissan motors etc. These manufacturers have launched wide range of EVs in all possible segments. As of December 2016, the number of Plug-in electric vehicles in USA was more than 570,000, making it the third largest market for EVs after China and Europe. The top-selling EV in USA was Tesla Model S, which retained its spot for second time in row. The EV market in USA has seen significant expansion over the last few years after the introduction of EVs like Tesla Model S, Model X among others which involved a very high energy density battery pack capable of addressing the daily commute and highway commute requirements with a single charge. The government incentives and policies allowing incentives and tax exemptions on purchase of EVs has also been a driving force towards the growing EV market. The U.S. Government also promised US$2.4 billion in federal grants to support the development of next-generation electric cars and batteries, and US$115 million for the installation of electric vehicle charging infrastructure in 16 different metropolitan areas around the country, making the technology cheaper and at par with the conventional IC engine vehicles.
Electromobility symbolizes a mammoth task of evolving the obsolete electric drive train technology in the IEC dominated automotive industry. Germany has established the goal of becoming the leader in electric vehicle manufacturing and largest consumer market for them, which indeed adds more magnitudes to the already massive task. Successful completion of this task would require an all-inclusive approach towards development of Electromobility. This would call for cumulative effort from government, automotive manufacturers, investors, standardization authorities, utilities, suppliers, and other associated industries. The major associated challenges are be listed as:

1. Firstly, this task would require two very distinct industries to operate in tandem: Automotive industry and Power utilities. The ability to harness potential synergies in this novel arrangement will be highly reliant on how the interface is defined between electric vehicles and the power grid. Companies, universities and research institutions carrying out research in both domains will have to make major contributions to bridge the gap.

2. Secondly, this task would entail huge amount of investment from all the role players, which

From Figure 13, it can be observed that the EV sales in U.S.A. will almost double from 2015 to 2017. This boom in sales is largely because the new age EVs can address to a large extent the problem of range anxiety and with availability of charging stations (normal and supercharging stations) the time required to charge has considerably reduced.

6. Comparative Analysis of EV Progress by Chinese, German and American Automakers

This section presents an overview of the global position of the EV automakers from China, Germany, and U.S.A. From Figures 14 and 15, it is evident that China and USA are at the forefront of EV development and sales throughout.

The closest German automaker is the VW group which stands third in the global EV market share while the BMWi3 occupies the fifth position in terms of most sold EVs. It is comprehensible that Germany is at disadvantage as compared to China and USA as still there is reluctance among the leading German automakers in increasing the production scales of EVs among their vehicles. For Germany to attain its goal of global leadership it is necessary that Germany undertakes expedite efforts in the area of EV manufacturing and in provision of the supporting infrastructures.

7. Existing Challenges

From Figure 12, it can be observed that the EV sales in China have almost tripled from 2010 to 2017. This boom in sales is largely because the new age EVs can address to a large extent the problem of range anxiety and with the availability of charging stations (normal and supercharging stations) the time required to charge has considerably reduced.

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This section presents an overview of the global position of the EV automakers from China, Germany, and U.S.A. From Figures 14 and 15, it is evident that China and USA are at the forefront of EV development and sales throughout.

The closest German automaker is the VW group which stands third in the global EV market share while the BMWi3 occupies the fifth position in terms of most sold EVs. It is comprehensible that Germany is at disadvantage as compared to China and USA as still there is reluctance among the leading German automakers in increasing the production scales of EVs among their vehicles. For Germany to attain its goal of global leadership it is necessary that Germany undertakes expedite efforts in the area of EV manufacturing and in provision of the supporting infrastructures.

1. Firstly, this task would require two very distinct industries to operate in tandem: Automotive industry and Power utilities. The ability to harness potential synergies in this novel arrangement will be highly reliant on how the interface is defined between electric vehicles and the power grid. Companies, universities and research institutions carrying out research in both domains will have to make major contributions to bridge the gap.

2. Secondly, this task would entail huge amount of investment from all the role players, which

From Figure 13, it can be observed that the EV sales in U.S.A. will almost double from 2015 to 2017. This boom in sales is largely because the new age EVs can address to a large extent the problem of range anxiety and with availability of charging stations (normal and supercharging stations) the time required to charge has considerably reduced.
runaway, which exactly is a positive feedback loop during which the chemical reactions initiated in the cell leading to increase in the cell temperature, potentially resulting in fire or explosion.

(7) Consistent availability of raw materials is required to carry on the research with existing battery technologies and experiment with new combinations, any interruption in supply can curb the growth.

(8) The utilities could face problems increasing the grid capacity to integrate the electric vehicles while maintaining the grid frequency, voltage, power factor of the load, current etc. Also the share of renewable energy supply needs to increase to support the burden of charging on the grid.

Figure 14. Global EV market share by makers [122].

could present an issue as consumers are still apprehensive regarding the purchase of EVs.

(3) The coordinated operation of multiple institutions would need a proper framework of regulations, standardization, legislations to ensure stress free working in the long run.

(4) The development in the battery technologies is not very rapid which could mean impediment of the plans as it requires time to test a new battery chemistry and develop a system which would satisfy the large scale production processes.

(5) Additionally, it is huge task to make the production process cost effective while satisfying the optimal performance requirements.

(6) Safety of the drivers is another concern with the batteries of the electric cars as it is necessary to avoid the occurrence of thermal
8. Overview of EV Developing Strategy in Germany

In light of above-mentioned challenges, German Government has commenced all-encompassing EV R&D layout plans which are demonstrated in Figure 16. Figure demonstrates the scope of NPE and identifies its spectrum of its application. The NPE is mainly devoted to the BEVs and PHEVs including the Range Extended Electric Vehicle (REEV). Charging Infrastructure and Communication technology deals with the development of charging infrastructures [15,123], power grid integration [124], renewable energy integration and expansion and developing the communication interface between the grid infrastructures and vehicles. Vehicle Integration corresponds to the different types of vehicles [125] and their integration into the main grid. Drive train technology addresses the developments in drive train components like electric motor, power electronic devices, drive system, and manufacturing technology [126–128].

Battery technology covers the raw material and cell development [129], modeling and analysis, identification of innovative battery chemistries and processing technology. Recycling deals with developing proper business models need to be implemented to warranty profitable operation for mobility providers at all levels.

Another challenge is ensuring mass production of EVs by manufacturers and presenting the consumer with the diversity of choice.

It is imperative to ensure of proper recycling procedures for batteries after their life cycle and safeguarding the profitable return rates for the involved companies. Proper recycling procedure need to be developed because with the mass production of these vehicles, the number of used batteries will increase and absence of proper procedures to safely dispose them can pose environmental threats.

To become a global leader, Germany would need to develop EV technologies fast and efficiently to outrun their competitors in Americas, Asia and Europe.

These are some of the imminent challenges in the path of Electromobility and coordinated measures need to be undertaken to ensure that these hurdles are crossed in time.
9. Conclusion

For Germany, in the next 15 years it is very important to promote electric vehicle manufacturing and ownership domestically and globally for achieving their mission of being a global leader in the field of green transportation. German EV development platform has shown its potential with the fact that the manufacturing of these vehicles is now being targeted by all major automobile manufacturers, consequently market is also expanding. Big German cities are leading the way towards green transportation and even small cities and municipalities have been active in providing EV solutions. Fact that expansion of Electromobility is not only limited to personal vehicles but public transportation including buses are also being electrified suggests the extent to which Electromobility is implemented. As of September 2016, Germany stands fifth among European countries in terms of the number vehicle registrations in 2016 [25]. In terms of annual production of electric cars as percentage of total cars, Germany stands fourth in the world [25]. And looking at the ambitious plans of Germany, it is forecasted that country will lead the way in terms of electric car production by 2021 [25]. With the fact that Germany is the largest passenger car market in Europe, it is understandable that the country’s market for EVs will also expand in due time. This is largely because major German automobile manufacturers are in the process of launching EVs and HEVs in the upcoming years. The future of electric transportation system in Germany looks promising and with further advancements it is anticipated that the technology will become more accessible and user friendly.

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ORCID

Aqueel Ahmad http://orcid.org/0000-0002-7701-7236
Mohammad Saad Alam http://orcid.org/0000-0003-4008-2680

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