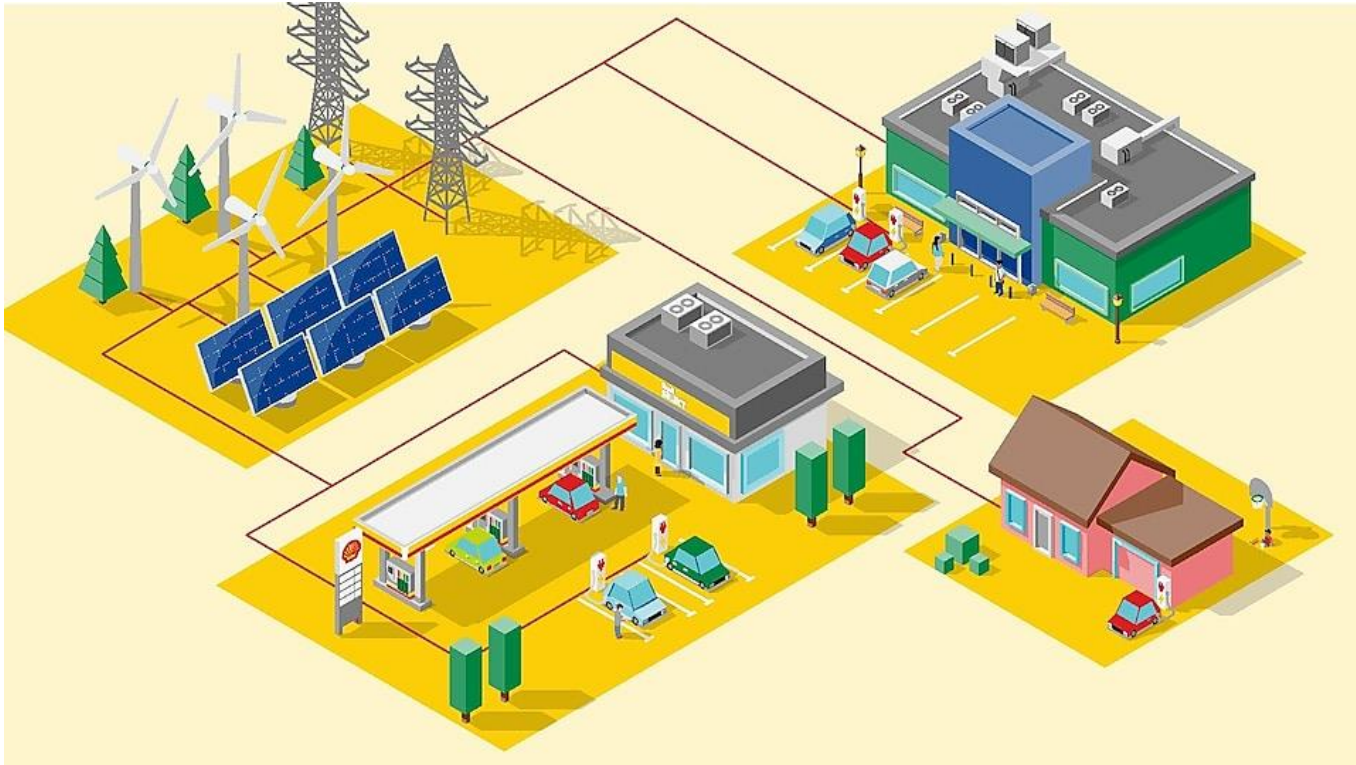


# Chapter 5:

## Investigation on EV Development Dimensions: Impacts on Our World, Barriers on Development and Their Solutions, and Market



## 5.1. EV Impacts on our world

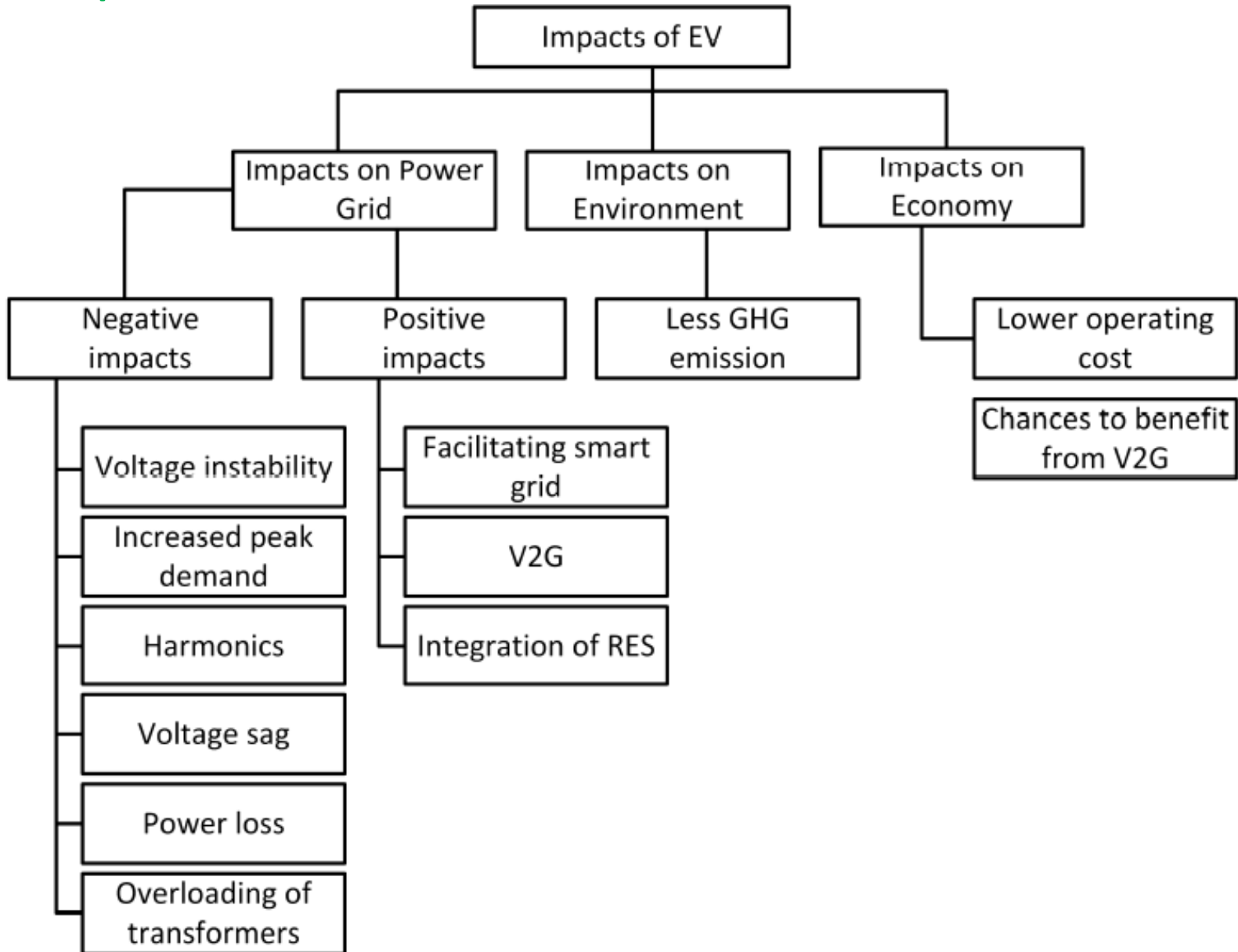
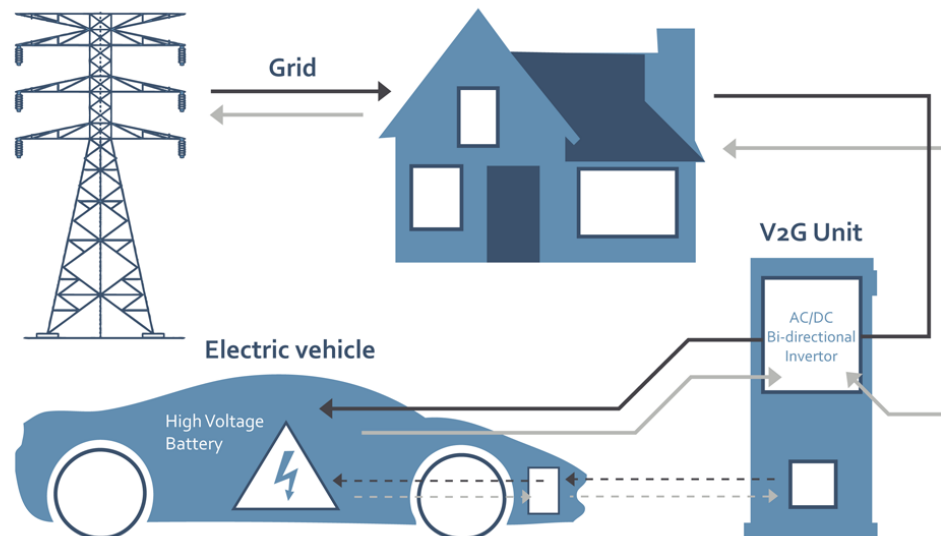


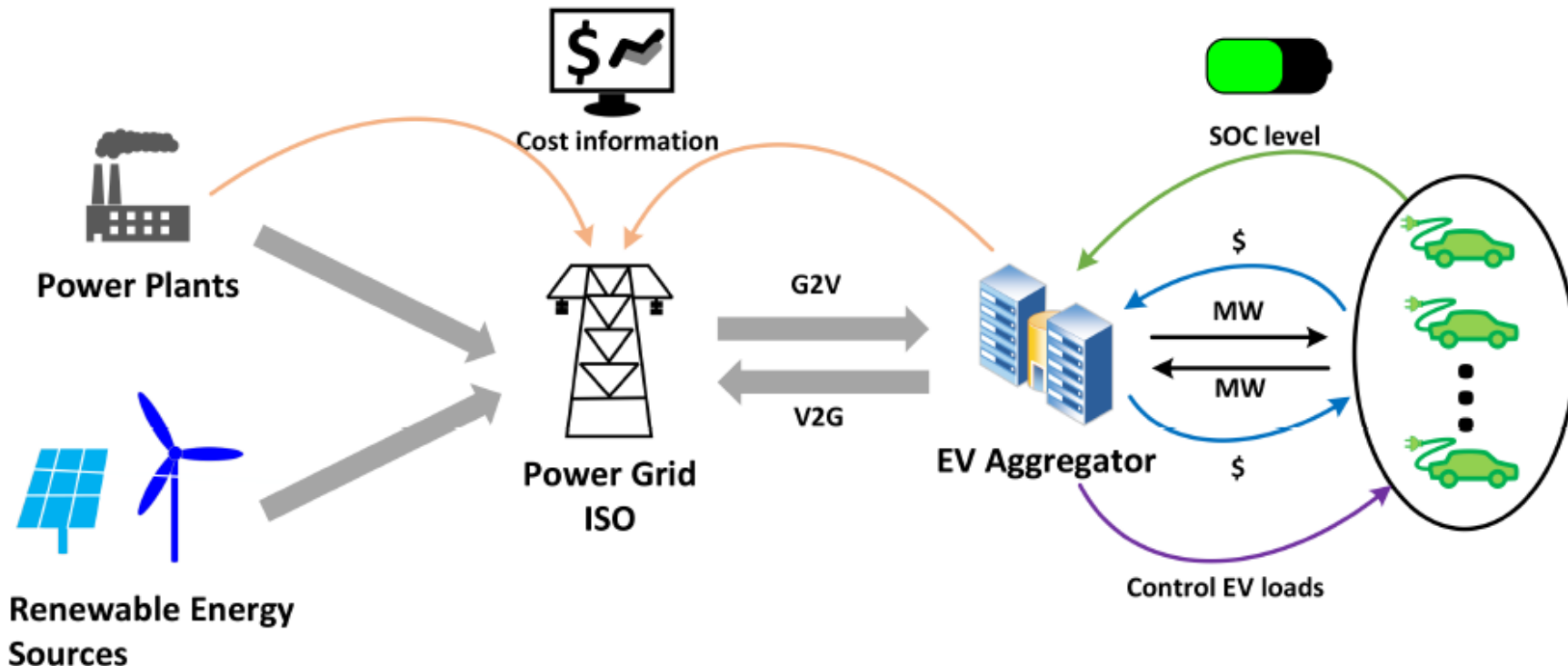
Fig. 1. A short list of the impacts of EVs on the power grid, environment and economy.

### 5.1.1. Impacts on power grid

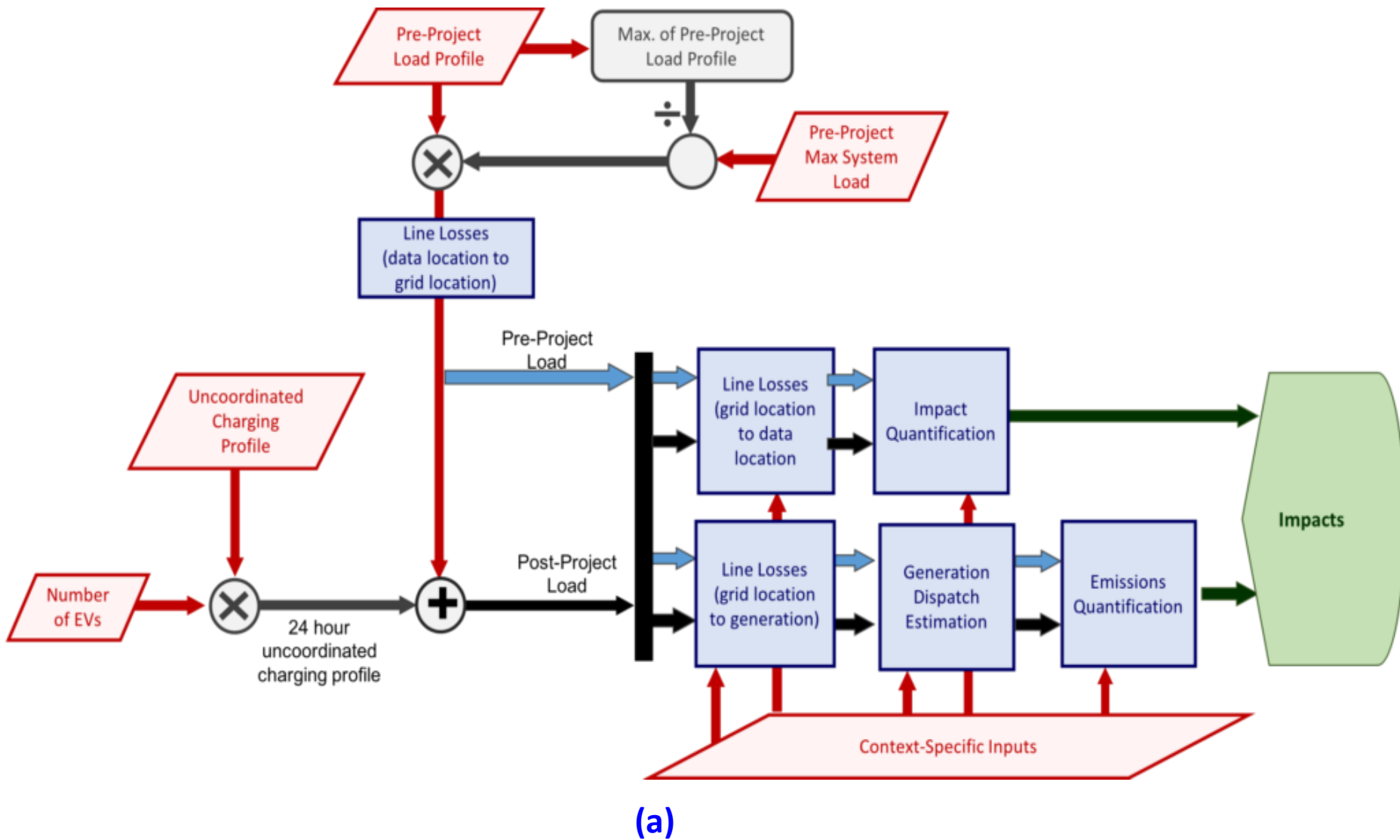
- ❑ EVs are relatively **high power loads** and they affect the power distribution system directly (distribution transformers, cables and fuses are affected by it the most).
- ✓ A **Nissan Leaf** with a 24 kWh battery pack consume power **similar to a single European household**.
- ✓ A **3.3 kW charger**, in a 220 V and 15 A system, can **raise the current demand by 17% to 25%**.
- ❑ Addition of EV load in **peak hours** can cause **load unbalance, shortage of energy, instability, and decrease in reliability and degradation of power quality** (specially more than level 1). It causes to increase the **infrastructure costs**.
- ✓ Charging without any concern to the time of drawing power from the grid is denoted as **uncoordinated charging, uncontrolled charging or dumb charging**.
- ✓ **Reducing the charging time** to distinguish vehicles in the EV market, **requires higher voltages**. Therefore, mitigating the adverse effects is not likely by employing low charging voltages.



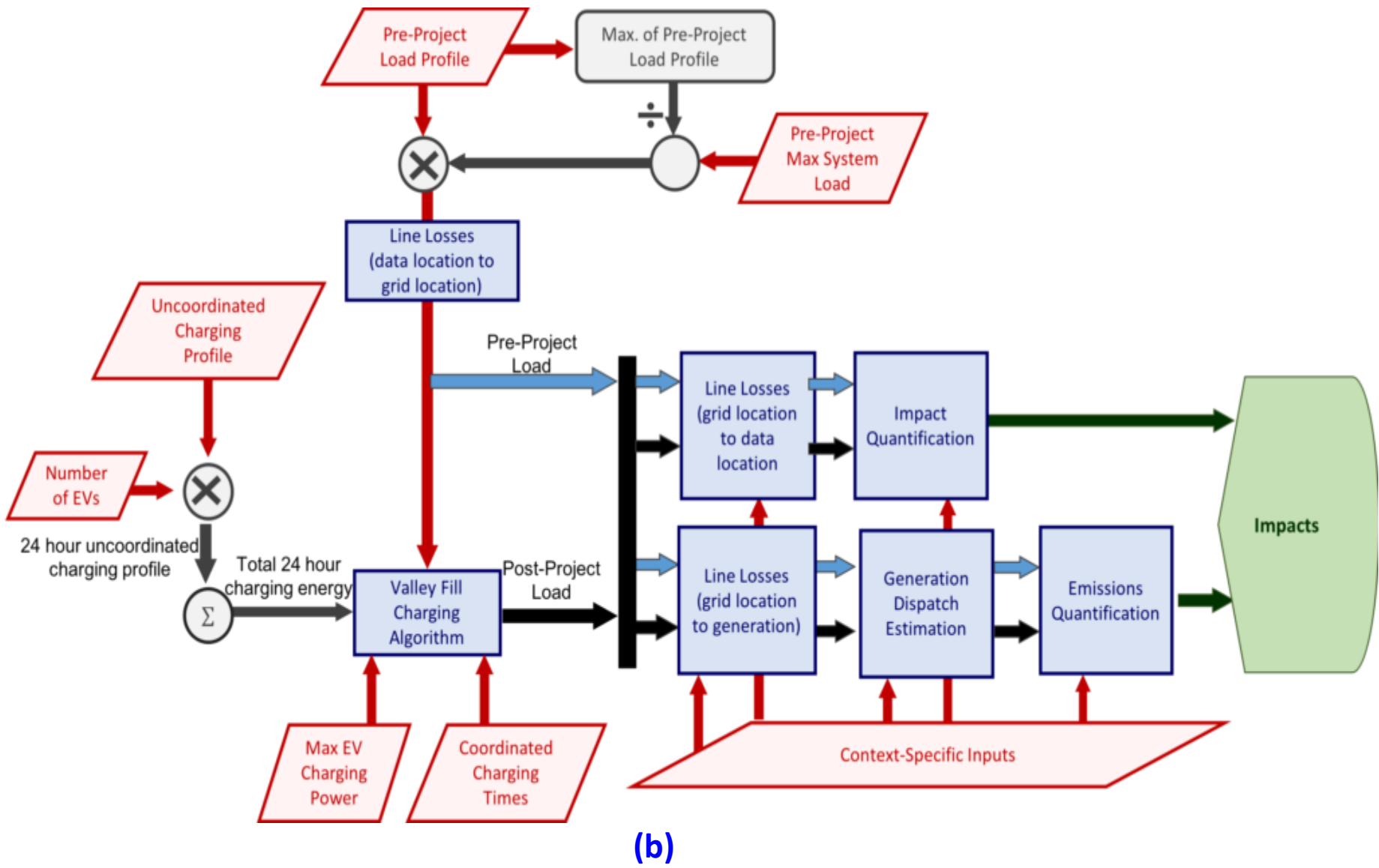
- ❑ To avoid the negative effects, and to provide efficient charging with the available infrastructure, **coordinated charging** (also called **controlled or smart charging**) has to be adopted (EVs are charged during the time periods **when the demand is low**, for example, after midnight). It needs only a few upgrades in the infrastructure.
- ✓ It not only prevents addition of extra load during peak hours, but also **increases the load in valley areas of the load curve**, facilitating proper use of power plants with better efficiency.
- ✓ **On the consumer side**, the electricity bill can be reduced as the electricity is consumed by the EVs during off peak hours, which generally have a cheaper rate than peak hours.
- ✓ smart charging systems can reduce the **increased investment cost** in distribution system by **60–70%**.



**Fig. 2. Conceptual presentation of the power supply system for EVs.**



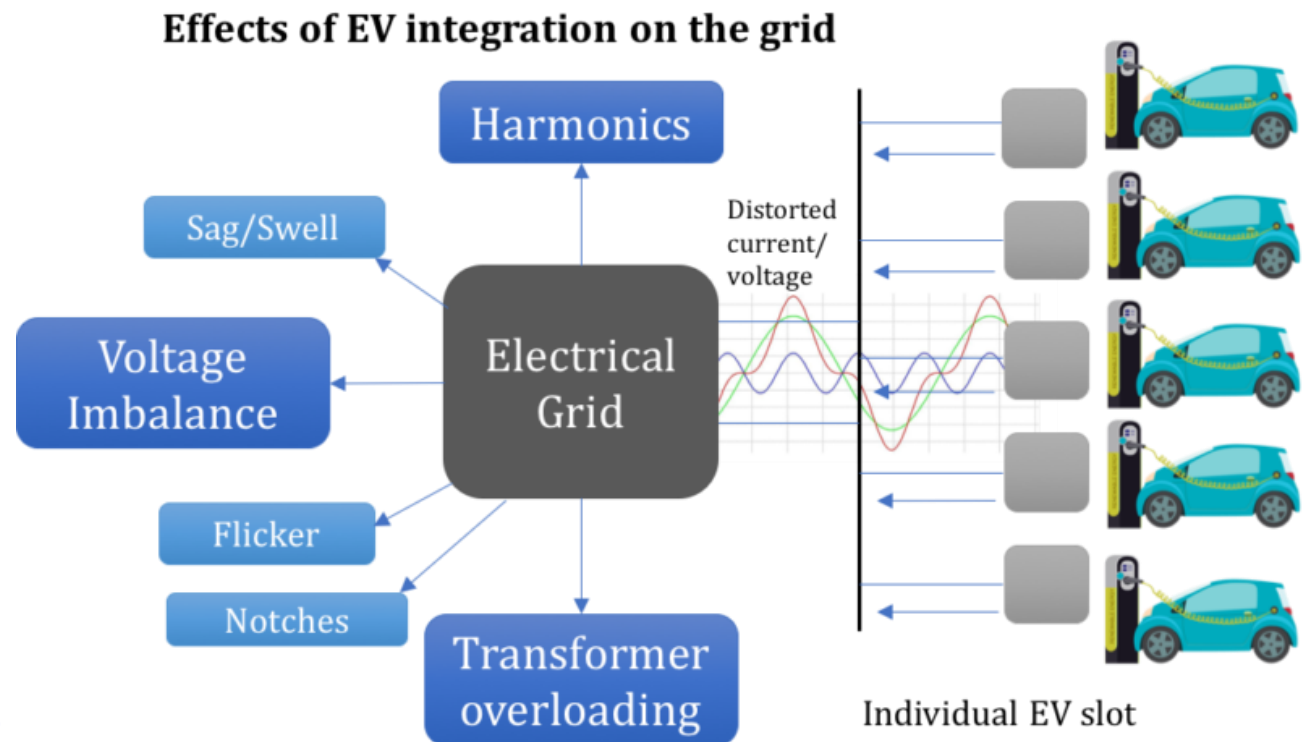
**Fig. 3. Block diagram of the uncoordinated and coordinated charging system for EVs:  
a) uncoordinated; b) coordinated.**



**Fig. 4. Block diagram of the uncoordinated and coordinated charging system for EVs: a) uncoordinated; b) coordinated.**

❑ The **major problems** that are faced in the power systems because of EVs can be charted as follows:

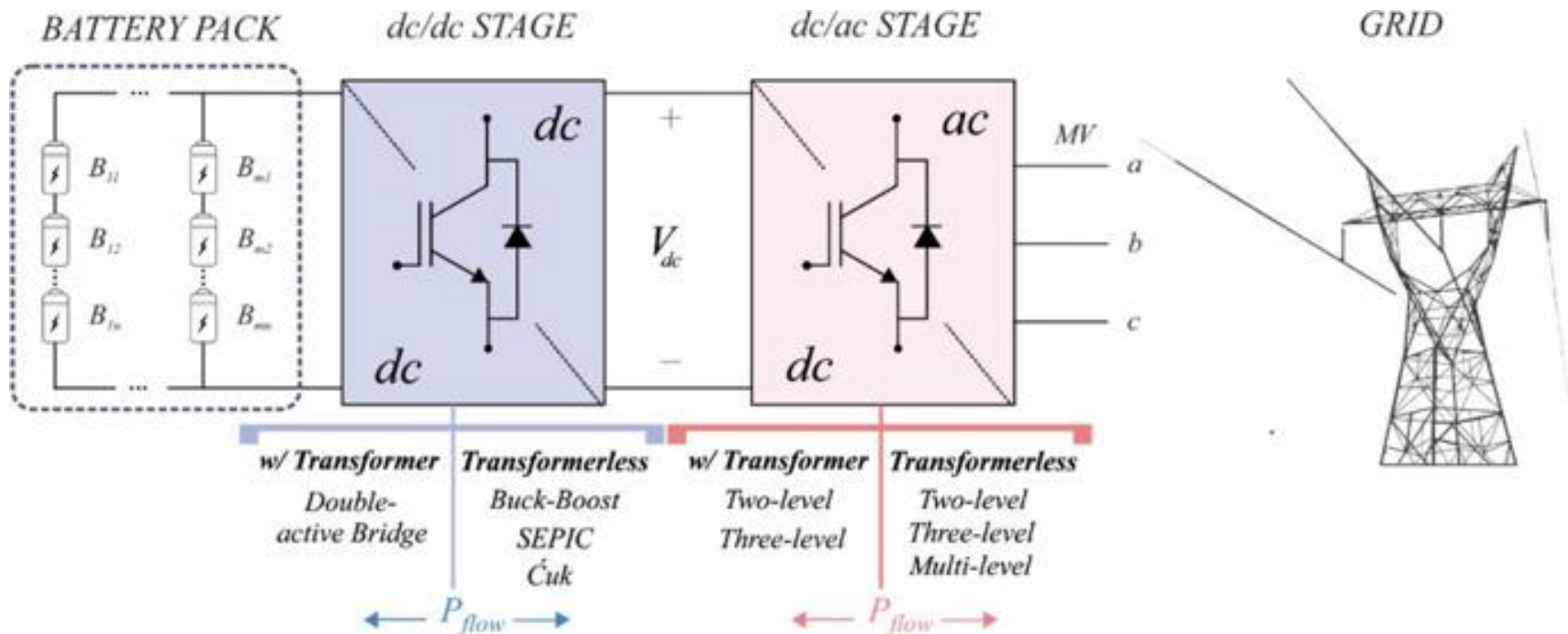
a) **Voltage instability:** can occur because of **load characteristics**, and that instability can lead to **blackouts**. EV loads have **nonlinear characteristics**, which are different than the general industrial or domestic loads, and **draw large quantities power in a short time period** (unpredictable). If the EVs have **constant impedance** load characteristics, then it is possible for the grid to support a lot of vehicles **without facing any instability**. To anticipate these loads properly, **appropriate modeling** methods and **control systems like fuzzy logic controllers** are required to calculate voltages and SOC of batteries.



**Fig. 5. EV utilizing effects on the power grid.**

**b) Harmonics:** The EV chargers are nonlinear, gives raise high frequency components of current and voltage, known as harmonics. Harmonics **reduce the power quality** and causes **stress in the power system equipment** like cables and fuses. The present cabling is capable of withstanding **25% EV penetration if slow charging is used**, in case of rapid charging, **the amount comes down to 15%**. the **modern EVs generate less  $THD_i$** , than the conventional ones, though their  **$THD_v$  are higher**. Three ways to reduce harmonics:

1. with **increased number of EVs**, there are chances of harmonics cancellation because of different load patterns (Different EV chargers can produce **different phase angles and magnitudes** which can lead to such cancellations).
2. Even eliminate harmonics is reduced by **applying PWM in the EV chargers**.
3. High  $THD_i$  can be avoided by using filtering equipment at the supply system.



**Fig. 6. Conceptual presentation of interaction between an Charging infrastructure and grid.**

- c) **Voltage sag:** A decrease in the RMS value of voltage for half a cycle or 1 min is denoted as voltage sag. It can be caused by **overload** or **during the starting of electric machines**. **20% EV penetration** can exceed the voltage sag limit. **60% EV penetration** is possible without any negative impact is possible **if controlled charging** is employed. Considerable decrease in voltage sag is achieved with application of voltage droop charging. Application of smart grid can help in great extents in mitigating the sag.
- d) **Power loss:** The extra loss of power caused by EV charging is  $PL_{EV} - PL_{original}$ .  $PL_{original}$  is the loss occurred when the EVs are not connected to the grid and  $PL_{EV}$  is the loss with EVs connected. **The power loss is increased as high as 40% in off peak hours considering 60% of the UK PEVs to be connected to distribution system. Uncoordinated charging, therefore, can increase the amount of loss furthermore.** Power generated in the **near vicinity** and also **distributed generation** can help minimizing the losses, to charge the vehicles near the local power plant.

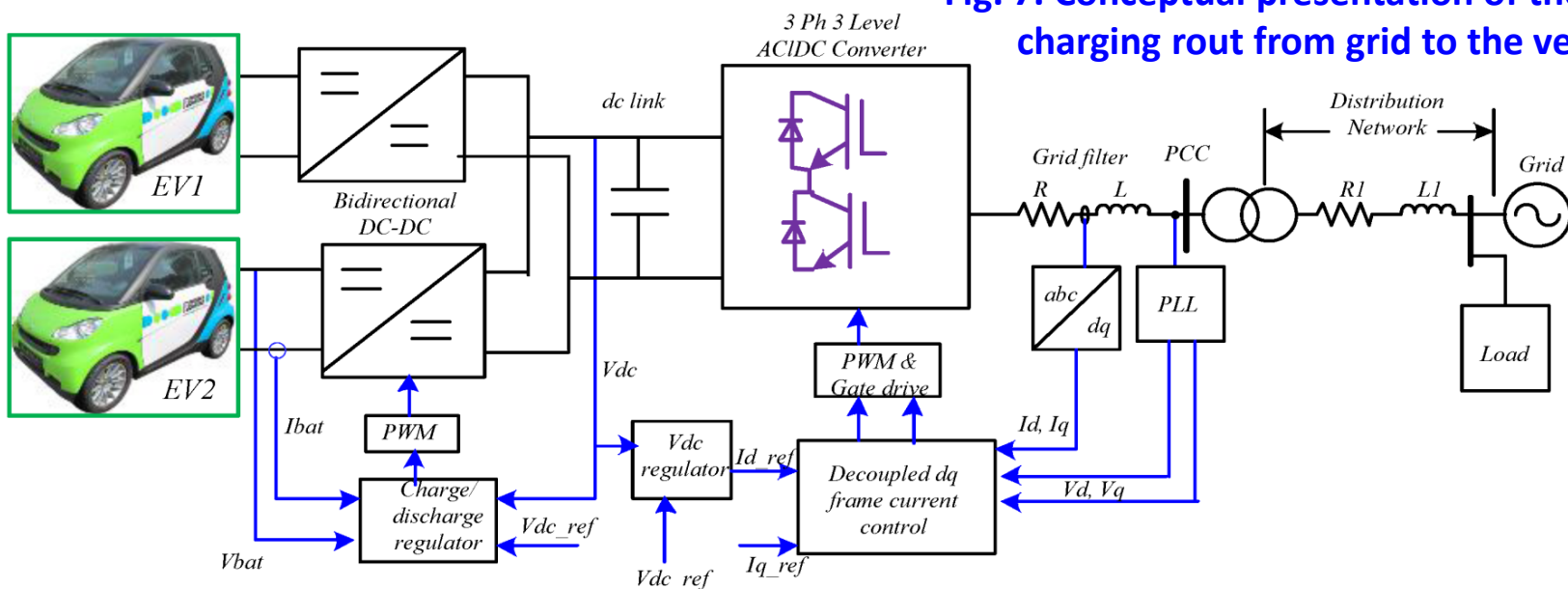


Fig. 7. Conceptual presentation of the complete charging route from grid to the vehicles.

- e) **Transformers overloading:** The extra heat generated by EV loads can lead to increased aging rate of the transformers, but it **also depends on the ambient temperature.** It is negligible in cold weather. Factors taken into account for estimation of the lifetime of a transformer are the **rate of EV penetration, starting time of charging and the ambient temperature.** It is stated that **transformers can withstand 10% EV penetration** without getting any decrease in lifetime. The effect of **level 1 charging (until 20%),** is in fact, has **negligible** effect on this lifetime, but **significant increase in level 2 charging (10% EV penetration)** can lead to the **failure of transformers.** Charging that takes place right after an EV being plugged in can be detrimental to the transformers.
- f) **Power quality degradation:** The increased amount of **harmonics and imbalance in voltage** will degrade the power quality in case of massive scale EV penetration to grid.

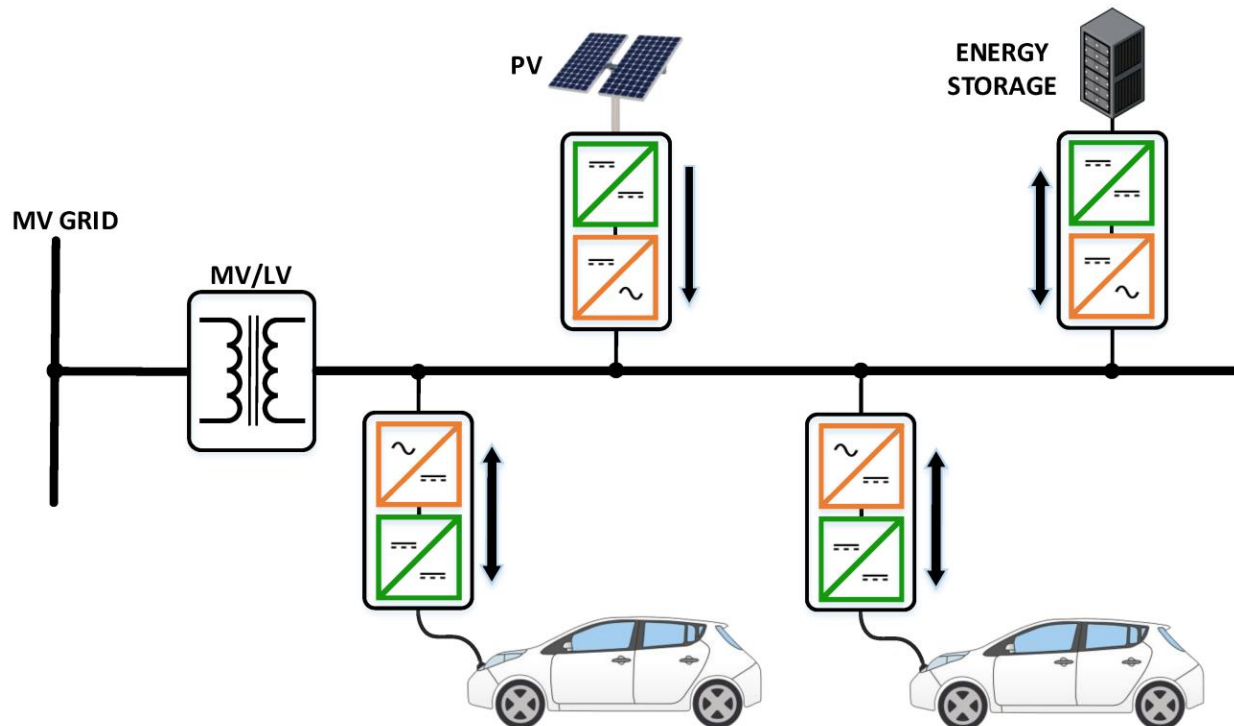


Fig. 8. Power utilizing from the grid by EVs.

□ On the plus side, EVs has the **positive impacts** on the power systems as follows:

- a) **Smart grid:** In the smart grid system, **intelligent communication and decision making** is incorporated with the grid architecture. Smart grid is highly regarded as the future of power grids and have advantages of **reliable power** supply and **advanced control**. In such a system, the **much coordinated charging** is easily achievable as interaction with the grid system becomes very much convenient even from the user end. The interaction of EVs and smart grid can facilitate opportunities like **V2G** and better integration of **renewable energy**. In fact, EV is one the eight priorities listed to create a smart grid.
- b) **V2G applications:** V2G is a method where the EV can provide power to the grid. In this system, the vehicles act as loads when they are drawing energy, and then can become dynamic energy storages by feeding back the energy to the grid. In coordinated charging, the EV loads are applied **in the valley points of the load curve**, in V2G; EVs can act as the power sources to provide during peak hours. V2G is realizable with the smart grid system and EVs can be used as **dynamic loads** or **dynamic storage systems**.

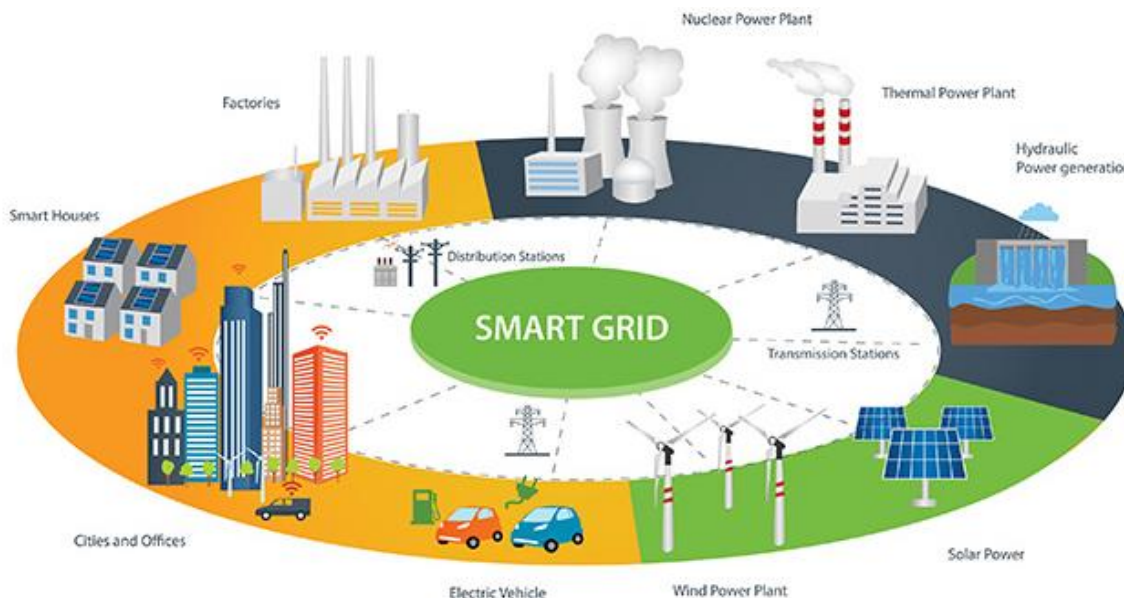
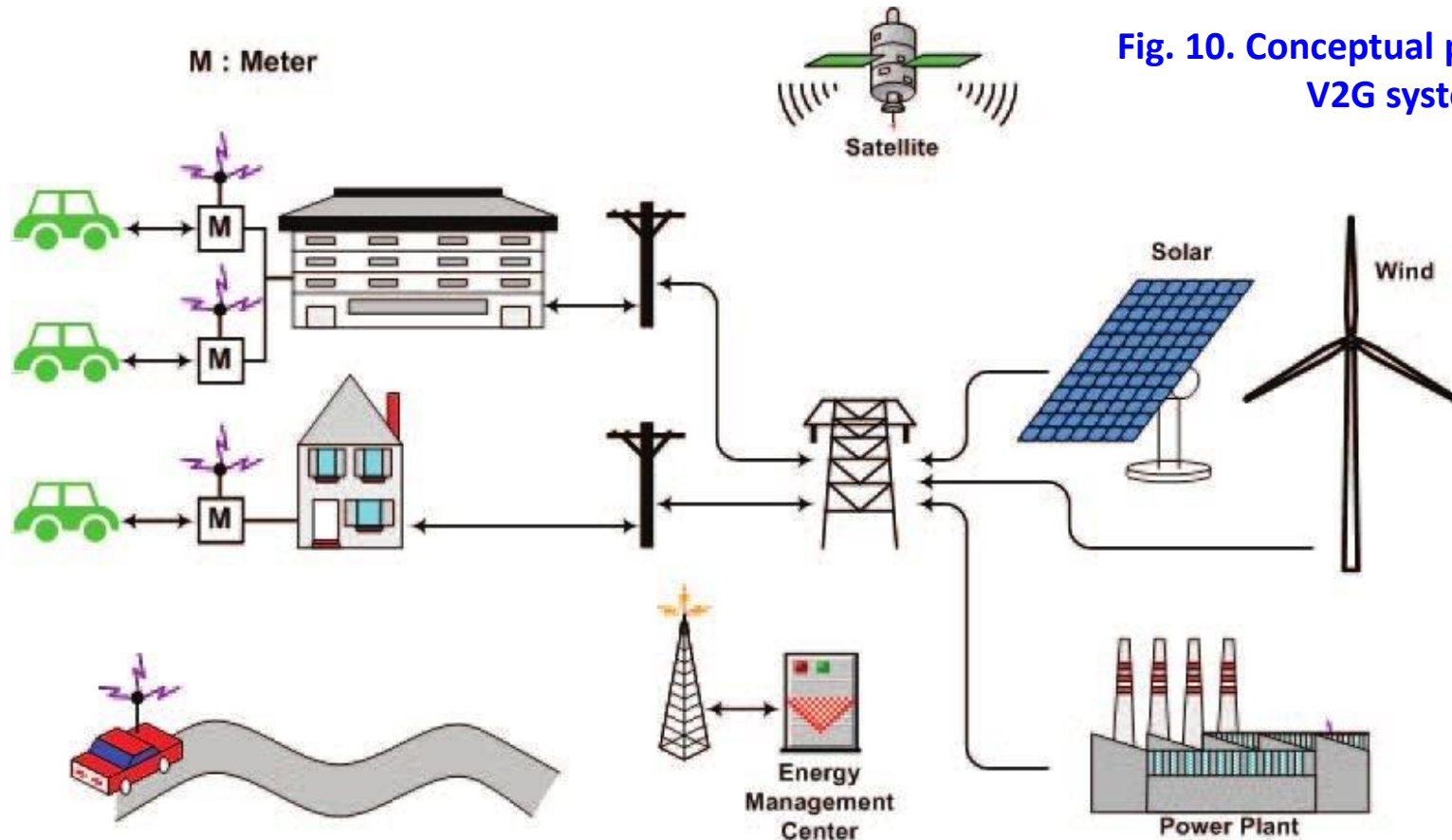


Fig. 9. Simple presentation of the smart grid beside the EVs.

❖ **The V2G power flow in the smart grid systems can be:**

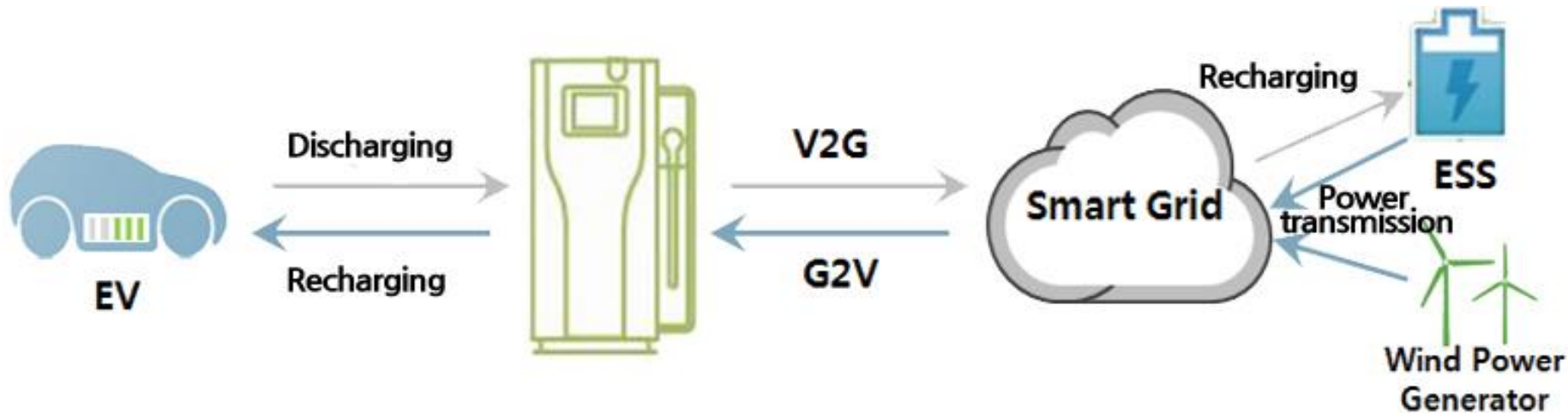
**I. Unidirectional system:** is analogous to the coordinated charging scheme; the **vehicles are charged when the load is low**, but the time to charge the vehicles is decided automatically by the system. Vehicles using this scheme can simply be plugged in anytime and put there; the system will choose a suitable time and charge it. **Smart meters are required for enabling this system.** With a driver variable charging scheme, **the peak power demand can be reduced by 56%**. This system particularly attractive as it required little upgradation of the existing infrastructure; creating a communication system in-between the grid and the EVs is all that is needed.



**Fig. 10. Conceptual presentation of V2G system.**

**II. Bidirectional system:** allows vehicles to provide power back to the grid. In this scenario, vehicles using this scheme will supply energy to the grid from their storage when it is required. This method has several appealing aspects. EVs have energy storages, and in many cases, they are not used for a long time (the cars in the parking lots of an office block, which stay unused till office hour is over, vehicles stay parked 95% of the time). These potential storages can be used when there is excess generation or low demand and when the energy is needed, it is taken back to the grid. The vehicle owners can also get economical benefit by selling this energy to the grid. **Bidirectional charging, needs:**

- ✓ chargers capable of providing power flow in both directions;
- ✓ Smart meters to keep track of the units consumed and sold, and advanced metering Infrastructure (AMI) to learn about the unit charges in real time to get actual cost associated with the charging or discharging at the exact time of the day. **The AMI system can shift 54% of the demand to off-peak periods, and can reduce peak consumption by 36%.**



**Fig. 11. Conceptual presentation of the bidirectional V2G system and smart grid.**

- ❑ The bidirectional system, in fact, can provide 12.3% more annual revenue than the unidirectional one. But taking the metering and protections systems required in the bidirectional method, this revenue is nullified and indicates the unidirectional system is more practical. Frequent charging and discharging caused by bidirectional charging can also reduce battery life and increase energy losses from the conversion processes.
- ❖ In a V2G scenario, operators with a vehicle fleet are likely to reduce their cost of operation by 26.5%.
- ❖ Another concept that is produced using the smart grid and the EVs, called **Virtual Power Plant (VPP)**, where a cluster of vehicles is considered as a power plant and dealt like one in the system.

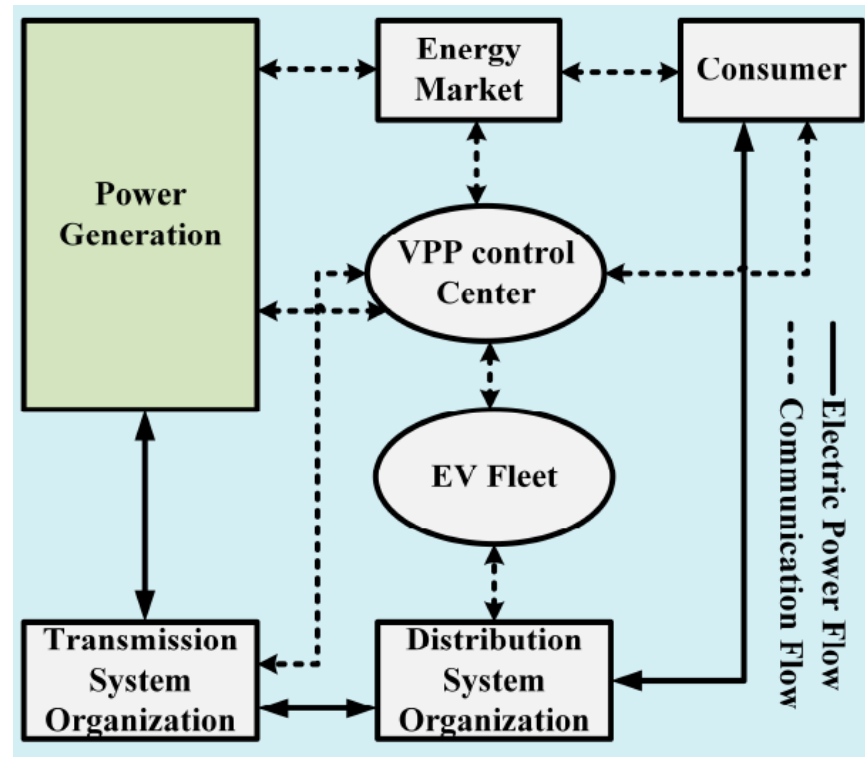


Fig. 12. VPP architecture and control.

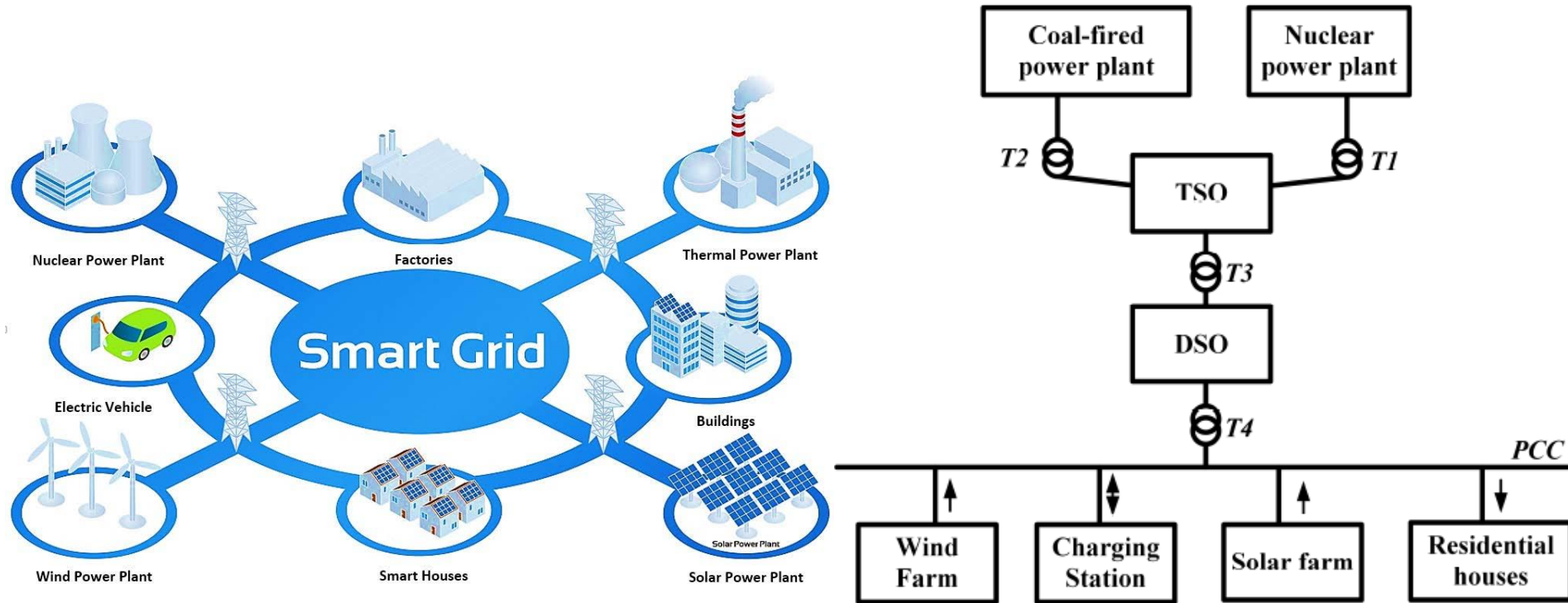
**Table 1. Unidirectional and bidirectional V2G characteristics..**

V2G System	Description	Services	Advantages	Limitations
<b>Unidirectional</b>	Controls EV charging rate with a unidirectional power flow directed from grid to EV based on incentive systems and energy scheduling	<ul style="list-style-type: none"> <li>• Ancillary service—load levelling</li> </ul>	<ul style="list-style-type: none"> <li>• Maximized profit</li> <li>• Minimized power loss</li> <li>• Minimized operation cost</li> <li>• Minimized emission</li> </ul>	<ul style="list-style-type: none"> <li>• Limited service range</li> </ul>
<b>Bidirectional</b>	Bidirectional power flow between grid and EV to attain a range of benefits	<ul style="list-style-type: none"> <li>• Ancillary service—spinning reserve</li> <li>• Load leveling</li> <li>• Peak power shaving</li> <li>• Active power support</li> <li>• Reactive power support/Power factor correction</li> <li>• Voltage regulation</li> <li>• Harmonic filtering</li> <li>• Support for integration of renewable</li> </ul>	<ul style="list-style-type: none"> <li>• Maximized profit</li> <li>• Minimized power loss</li> <li>• Minimized operation cost</li> <li>• Minimized emission</li> <li>• Prevention of grid overloading</li> <li>• Failure recovery</li> <li>• Improved load profile</li> <li>• Maximization of renewable energy generation</li> </ul>	<ul style="list-style-type: none"> <li>• Fast battery degradation</li> <li>• Complex hardware</li> <li>• High capital cost</li> <li>• Social barriers</li> </ul>

**c) Integration of Renewable Energy Sources (RES):** Renewable energy usage becomes more promising with EVs integrated into the other power sources. EV owners can use RES to generate power locally to charge their EVs. For example:

- ✓ Parking roofs have high potential for the placement of **PV panels** which can charge the vehicles parked underneath as well as supplying the grid in case of excess generation.

- ❖ The V2G structure is further helpful to integrate RES for charging of EVs, and to the grid as well, as it enables the selling of energy to the grid when there is surplus, for example, when vehicles are parked and the system knows the user will not need the vehicle before a certain time. **V2G can also enable increased penetration of wind energy (41%–59%) in the grid in an isolated system.**



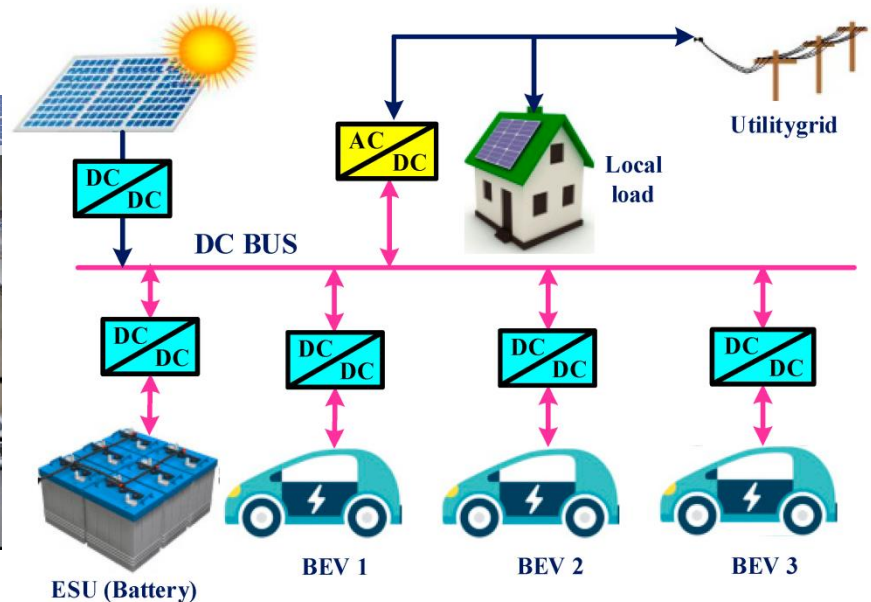
**Fig. 13. Wind and solar integration in the grid with the help of EV in V2G system. TSO: Transmission System Organization; DSO: Distribution System Organization; T1 to T4 represent the transformers coupling the generation, transmission, and distribution stages.**

**Table 2. Scopes of assisting Renewable Energy Source (RES) integration using EV. Con.**

Interaction with RES	Field of Application	Contribution
Solar PV	Smart home	<ul style="list-style-type: none"> <li>• Implementation of PV and EV in smart home to reduce emission</li> <li>• Development of stand-alone home EV charger based on solar PV system</li> <li>• Development of future home with uninterruptable power by implementing V2G with solar PV</li> </ul>
	Parking lot	<ul style="list-style-type: none"> <li>• Analysis of EV charging using solar PV at parking lots</li> <li>• Scheduling of charging and discharging for intelligent parking lot</li> </ul>
	Grid distribution network	<ul style="list-style-type: none"> <li>• Assessment of power system performance with integration of grid connected EV and solar PV</li> <li>• Development of EV charging control strategy for grid connected solar PV based charging station</li> <li>• Development of optimization algorithm to coordinate V2G services</li> </ul>
	Micro grid	<ul style="list-style-type: none"> <li>• Development of generation scheduling for micro grid consisting of EV and solar PV</li> </ul>
Wind turbine	Grid distribution network	<ul style="list-style-type: none"> <li>• Determination of EV interaction potential with wind energy generation</li> <li>• Development of V2G systems to overcome wind intermittency problems</li> </ul>
	Micro grid	<ul style="list-style-type: none"> <li>• Development of coordinating algorithm for energy dispatching of V2G and wind generation</li> </ul>


**Table 3. Scopes of assisting RES integration using EV.**

Interaction with RES	Field of Application	Contribution
Solar PV and wind turbine	Smart home	<ul style="list-style-type: none"> <li>Development of control strategy for smart homes with grid-interactive EV and renewable sources</li> </ul>
	Parking lot	<ul style="list-style-type: none"> <li>Design of intelligent optimization framework for integrating renewable sources and EVs</li> </ul>
	Grid distribution network	<ul style="list-style-type: none"> <li>Potential analysis of grid connected EVs for balancing intermittency of renewable sources</li> <li>Emission analysis of EVs associated with renewable generation</li> <li>Development of optimized algorithm to integrate EVs and renewable sources to the grid</li> </ul>
	Micro grid	<ul style="list-style-type: none"> <li>Development of V2G control for maximized renewable integration in micro grid</li> </ul>



## 5.1.2 Impacts on environment

a) **GHG emission reduction** One of the main factors that propelled the increase of EVs popularity is their contribution to **reduce the GHG emissions**. Conventional ICE vehicles burn fuels directly and thus produce harmful gases, including **CO<sub>2</sub>** and **CO**. Though HEVs and PHEVs have IC engines, their emissions are less than the conventional vehicles.















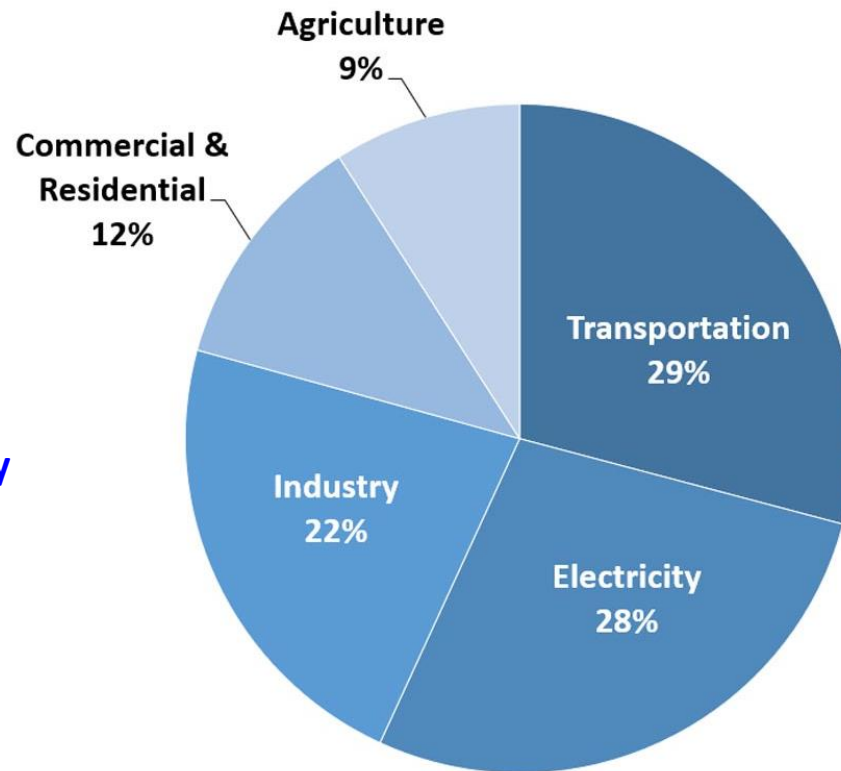
	CONVENTIONAL	HYBRID	PLUG-IN HYBRID	ALL -ELECTRIC
Sources of Energy				
Consumption				
Emissions				
Examples		Toyota Prius (C, V) Ford C-Max, Fusion Hybrid Hyundai Sonata Hybrid Volkswagen Jetta Hybrid Lexus RX 450h Infiniti Q70 Hybrid	Ford C-Max, Fusion Energi Honda Accord PHV Chevy Volt Toyota Prius PHV Cadillac ELR Porsche Panamera S E-Hybrid	Nissan Leaf Tesla Model S BMW i3 Mitsubishi MiEV Chevrolet Spark EV

Fig. 14. A General comparison among various types of vehicles in pollution mass.

- ❑ There are also theories that the electrical energy consumed by the EVs can give **rise to GHG emission from the power plants**, which have to produce more because of the extra load added in form of EVs. The power generation from coal and natural gas will produce more CO<sub>2</sub> from EV penetration than ICEs. However, all the power is not generated from such resources. There are many other power generating technologies that produce less GHG. With those considered, the GHG production from power plants because of EV penetration is less than the amount produced by equivalent power generation from ICE vehicles. The power plants also produce energy in bulk, thus minimizing the per unit emission. **With renewable sources integrated properly, which the EVs can support strongly, the emission from both power generation and transportation sector can be reduced.**



**Fig. 15. Total U.S. GHG emission by economic sector in 2017.**

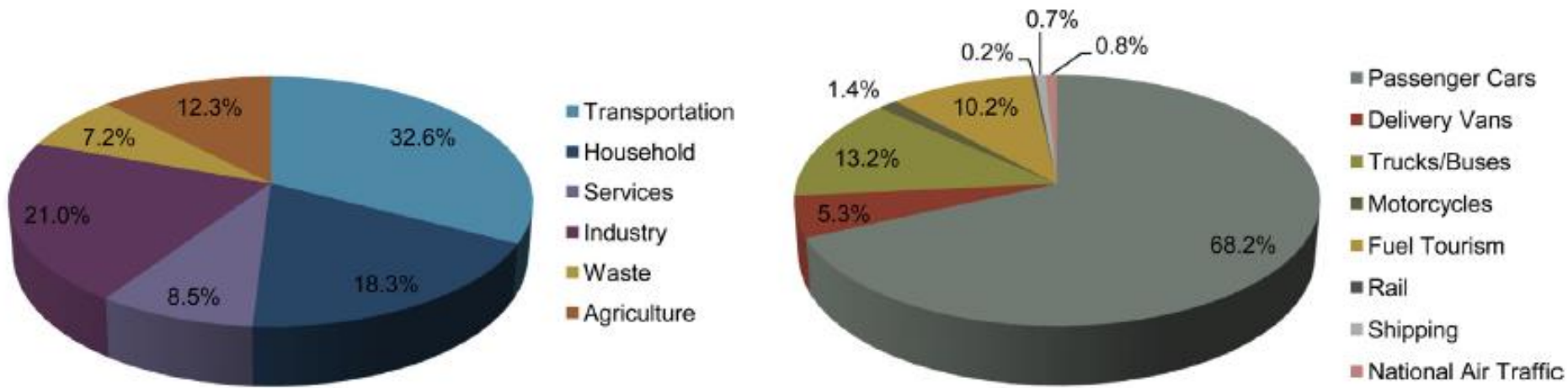
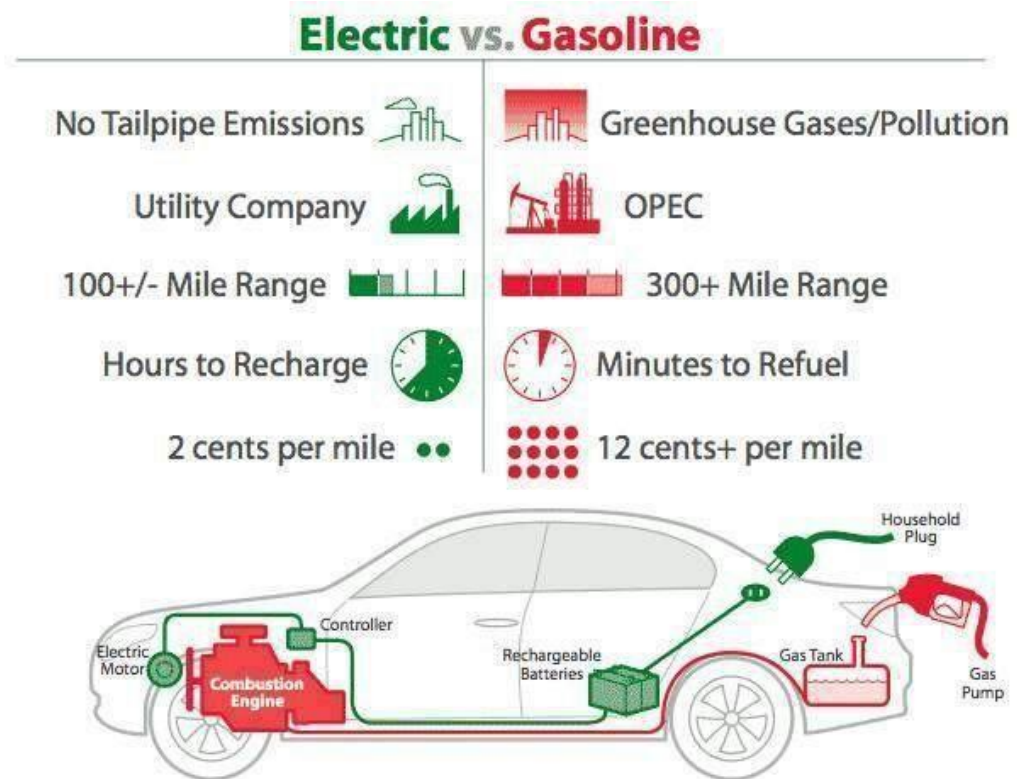
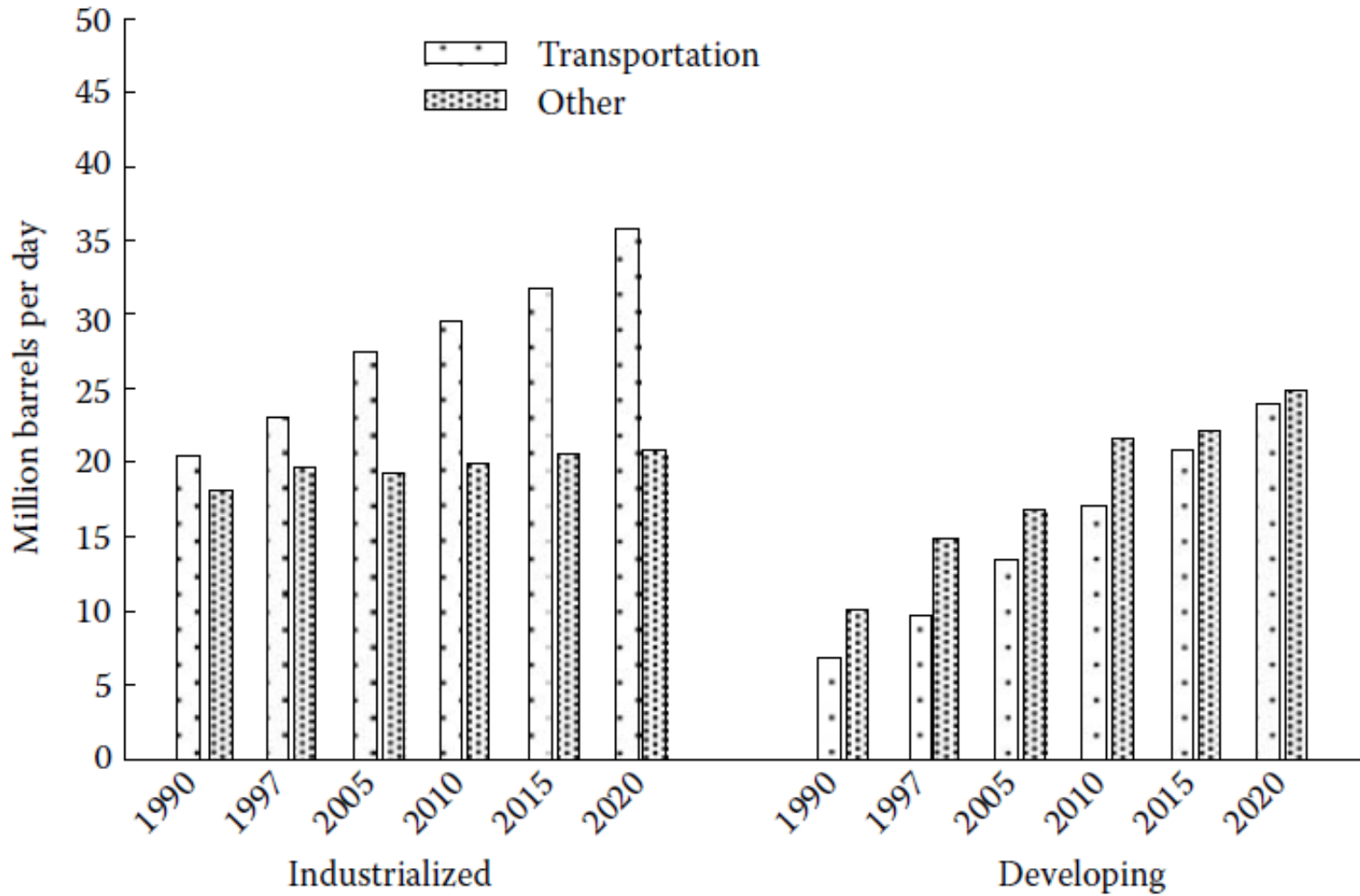


Fig. 16. Annual GHG emissions in Switzerland by sector (left) and within the transportation sector (right).

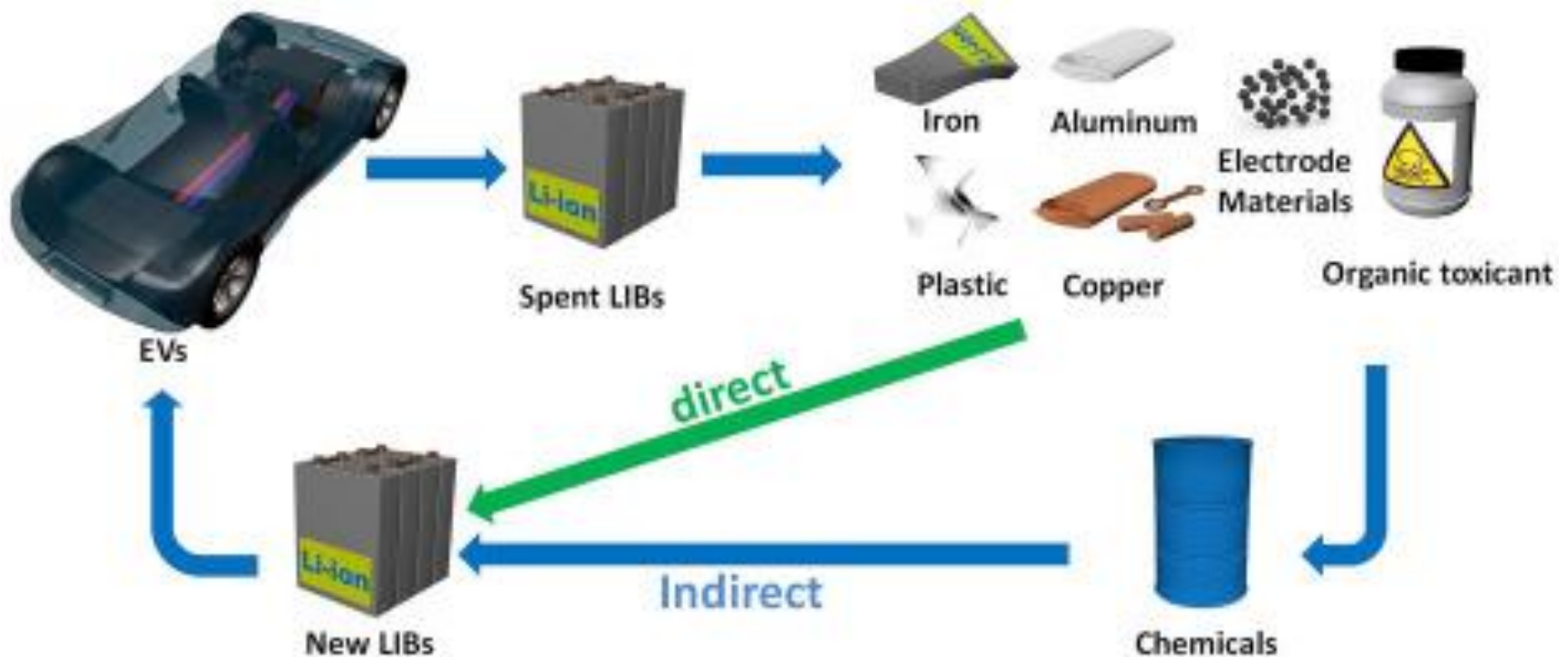
Fig. 17. A general comparison between the EVs and ICE vehicles in some of usual aspects.





**Fig. 18. World oil consumption in transportation and others for industrialized and developing countries.**

- b) Lower noise Production:** which can reduce sound pollution, mostly in urban areas due to eliminating combustion in the propulsion system.
- c) Recycling problem of the batteries:** raises serious concerns though, as there are few organizations capable of recycling the lithium-ion batteries fully. However, like the previous nickel-metal and lead-acid ones, lithium-ion cells are not made of caustic chemicals, and their reuse can reduce 'peak lithium' or 'peak oil' demands.



**Fig. 19. Cycle of Li-Ion battery reproduction.**

### 5.1.3. Impacts on economy

- a) **Low operating cost:** From the **perspective of the EV owners**, EVs provide **less operating cost** because of their superior efficiency (Tank to Wheels); it can be **up to 70%** where ICE vehicles have efficiencies in the range of **15% to 25%**. The **current high cost of EVs** is likely to come down from **mass production** and **better energy policies**, which will further increase the economic gains of the owners.
- b) **Chances to benefit from V2G:** **V2G** also allows the owners to obtain a financial benefit from their vehicles by providing service to the grid. The power service providers benefit from EV integration mainly by **implementing coordinated charging** and **V2G**. It allows them to adopt better peak shaving strategies as well as to integrate renewable sources. EV fleets can lead to \$200 to \$300 savings in cost per vehicle per year.

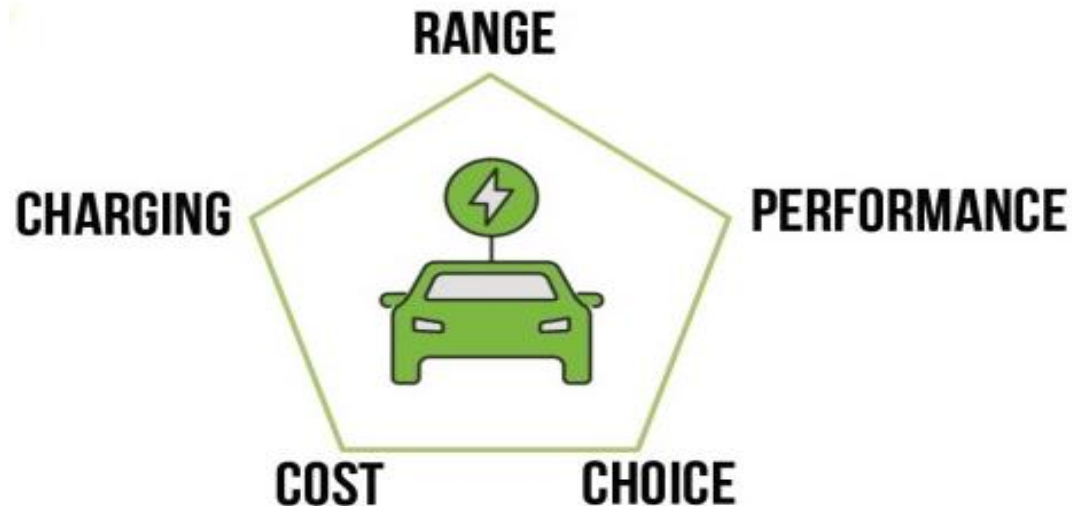
### 5.1.4. Impacts on sport

- Hybrid technologies** are **not used extensively** in **motor sports** to enhance the performance of the vehicles. EVs now have their own formula racing series named **'Formula E'**, which started in Beijing in September 2014.
- Autonomous EVs** are also being planned to take part in a segment of this series called **'Roborace'**.



# Chapter 6:

## EV Public Adoption: Barriers, Optimization Techniques, and Future Developments



## 5.2. EV public adoption: barriers, optimization techniques, future developments;

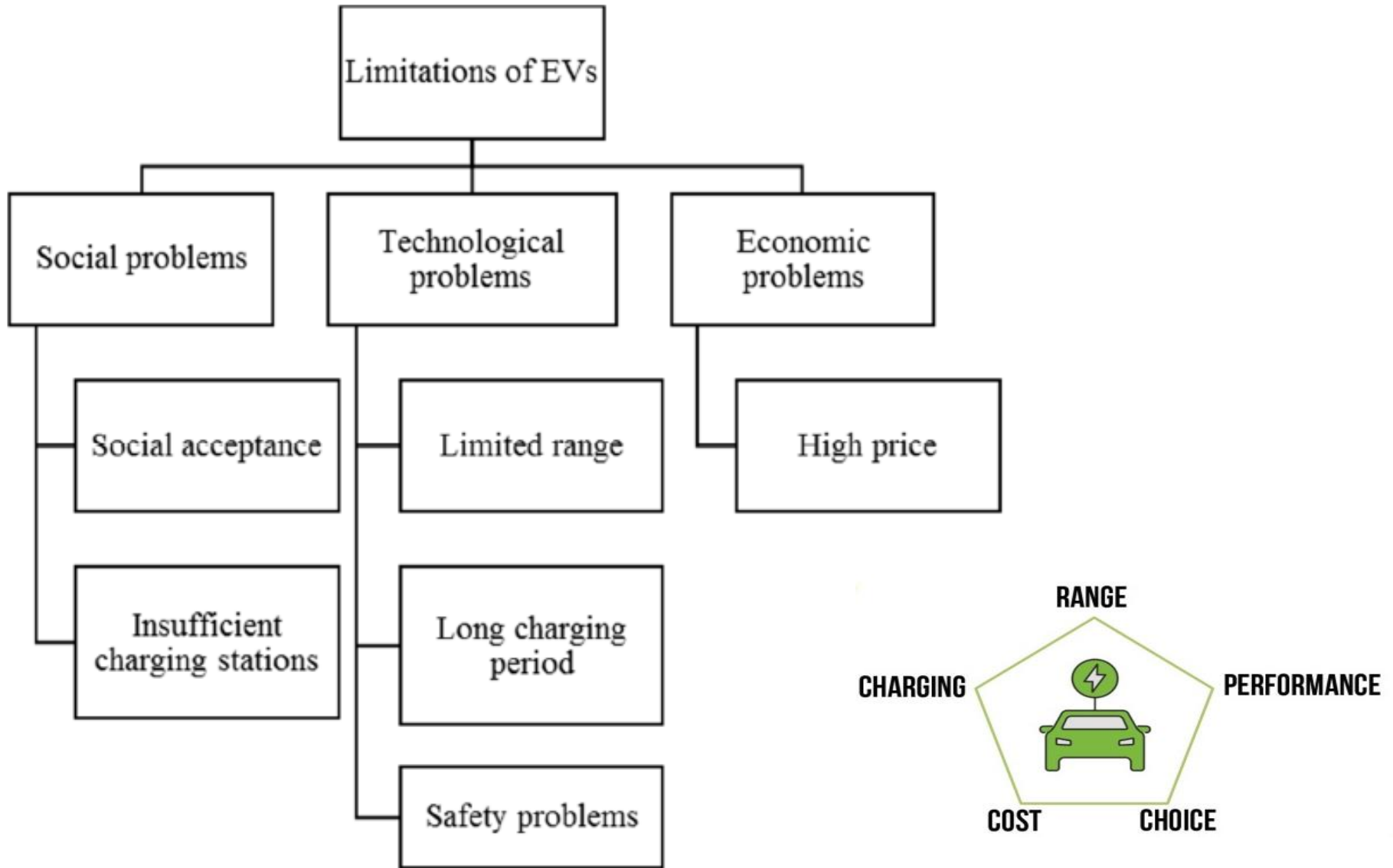


Fig. 20. Social, technological, and economic problems faced by EVs.

## 5.2.1. Social problems

- a) **Social acceptance:** The acceptance of a **new** and **immature** technology, along with its consequences, takes some time in the society as it means change of certain habits. Using an EV instead of a conventional vehicle means some changes that are not easy to adopt:
- change of driving patterns;
  - refueling habits;
  - preparedness to use an alternative transport in case of low battery.
- b) **Insufficient charging stations:** Though public charging stations have increased a lot in number, still they are not enough. **Coupled with the lengthy charging time**, this acts as a major deterrent against EV penetration. **Not all the public charging stations** are compatible with every car as well; therefore it also becomes a challenge **to find a proper charging point** when it is required to replete the battery. There is also the risk of getting a **fully occupied charging station** with no room for another car.
- ❖ **Tesla and Nissan have been expanding their own charging networks**, as it, in turn means they can sell more of their EVs. Hydrogen refueling stations are not abundant yet as well. It is necessary as well to increase the adoption of FCEVs.
  - ❖ To get the better out of the remaining stations, there are different trip planning applications, both web based and manufacturer provided, which helps to **obtain a route so that there are enough charging facilities to reach the destination.**

## 5.2.2. Technological problems

❑ The main obstacles that have frustrated EVs' domination are the drawbacks of the related technology. **Batteries** are the main area of concern as their **contribution to the weight** of the car is significant. **Range and charging period** also depend on the battery. These factors, along with a few others, are demonstrated below:

a) **Limited range:** EVs are held back by the capacity of their batteries. The range indicates the concern about finding a charging station before the battery drains out. The range also depends on:

- speed of the vehicle;
- driving style;
- cargo the vehicle is carrying;
- terrain it is being driven on;
- energy consuming services (air conditioning, ...).



❖ **range anxiety** remains a **major obstacle** for EVs to overcome. This does not affect the use of EVs for urban areas though, as in most cases this range is enough for daily travelling inside city limits.

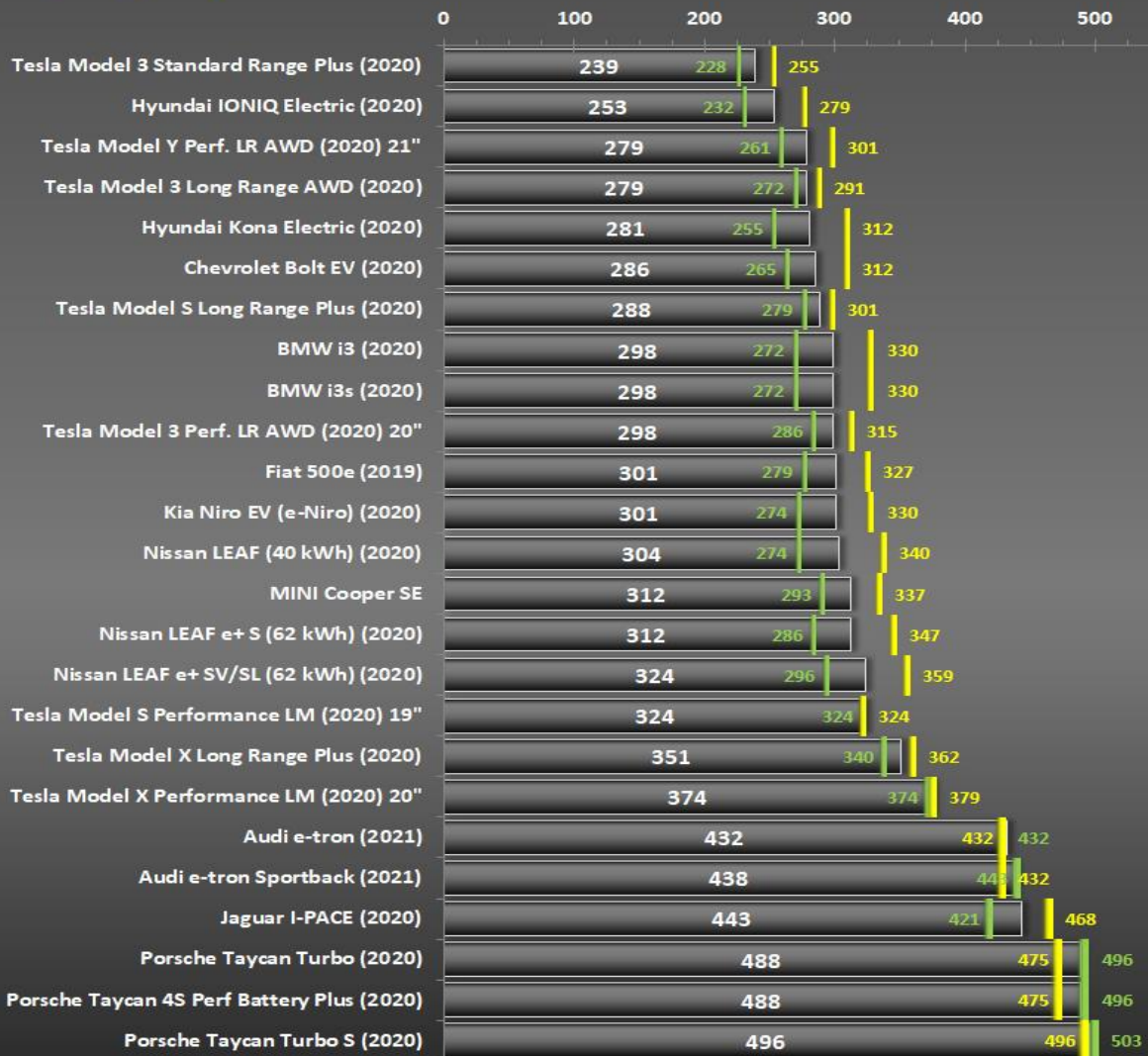
❖ **Range extenders, which produce electricity from fuel**, are also available with models like **BMW i3** as an option. Vehicles with such facilities are currently being called as **Extended Range Electric Vehicles (EREV)**.

## All-Electric Vehicle Comparison - U.S.

EPA Energy Consumption - Combined (Wh/mile)



City / Highway

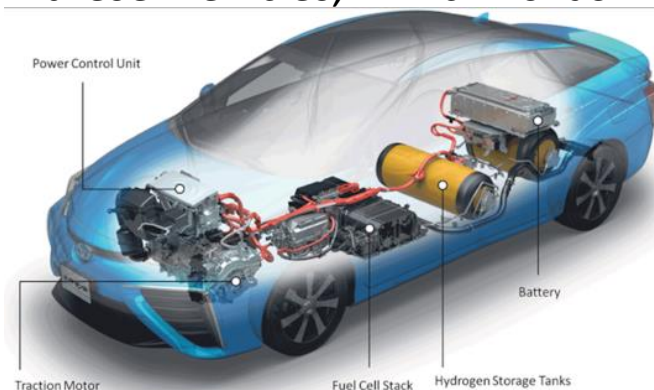


**Fig. 21. All-electric range of some of the EVs in city and highway condition driving.**

**b) Long charging period:** Depending on the **type of a charger** and a **battery pack size**, charging can take from a **few minutes to hours**; this truly makes EVs incompetent against the ICE vehicles which only take a few minutes to get refueled (**to have an hour decreased from the charging time, people are willing to pay \$425–\$3250**). A way to make the charging time faster is to **increase the voltage level** and employment of better chargers.

✓ There are also the FCEV that do not require charging like other EVs. Filling up the **hydrogen tank** is all that has to be done in case of these vehicles, which is **as convenient as filling up a fuel tank**, but FCEVs need:

- sufficient Hydrogen refueling stations ;
- feasible way to produce the Hydrogen in order to thrive.



**c) Safety concerns:** The concerns about safety are rising mainly about the **FCEVs** nowadays. There are concerns that, if hydrogen escapes the tanks it is kept into, can cause serious harm, as it is highly flammable. It has no color either, **making a leak hard to notice**. There is also the chance of the **tanks to explode** in case of a collision.

❖ To counter these problems, the automakers have taken measures to ensure the integrity of the tanks; **they are wrapped with carbon fibers in case of the Toyota Mirai**. In this EV, the hydrogen handling parts are placed outside the cabin, allowing the gas to disperse easily in case of any leak. there are also arrangements to **seal the tank outlet** in case of high-speed collision.

### 5.2.3. Economical problems

- a) **High price:** The price of the EVs is quite **high compared to their ICE counterparts**. This is because of the **high cost of batteries and fuel cells**. To make people overlook this factor, governments in different countries including the **UK and Germany**, have provided **incentives and tax breaks** which provide the buyers of EVs with **subsidies**. **Mass production and technological advancements** will lead to a decrease in the prices of batteries as well as fuel cells.
- ❖ Affordable EVs with a long range like **Chevrolet Bolt** has already appeared in the market, while another vehicle with the same promises (**Tesla Model 3**) is anticipated to arrive soon.



**Table 4. Tentative solutions for current limitations of EVs.**

Limitation	Probable Solution
Limited range	Better energy source and energy management technology
Long charging period	Better charging technology
Safety problems	Advanced manufacturing scheme and build quality
Insufficient charging stations	Placement of sufficient stations capable of providing services to all kinds of vehicles
High price	Mass production, advanced technology, government incentives



**Table 5. Hurdles in key EV factors.**

Factor	Hurdles
Recharging	Weight of charger, durability, cost, recycling, size, charging time
Hybrid EV	Battery, durability, weight, cost
Hydrogen fuel cell	Cost, hydrogen production, infrastructure, storage, durability, reliability
Auxiliary power unit	Size, cost, weight, durability, safety, reliability, cooling, efficiency

## 5.2.4. Optimization techniques of EVs

### a) The energy consuming accessories on a car include:

- ✓ power steering,
- ✓ air conditioning,
- ✓ lights,
- ✓ infotainment systems etc.
- ❖ Operating these in an energy efficient way or turning some of these off can increase the range of a vehicle.
- ❖ LEDs can be used for lighting because of their high efficiency.

- ☐ To make the best out of the available energy, EVs apply various **aerodynamics** and **mass reduction** techniques, and **lightweight materials** are used to decrease the body weight as well.

### b) Regenerative braking is used to restore energy lost in braking. The restored energy can be stored in different ways:

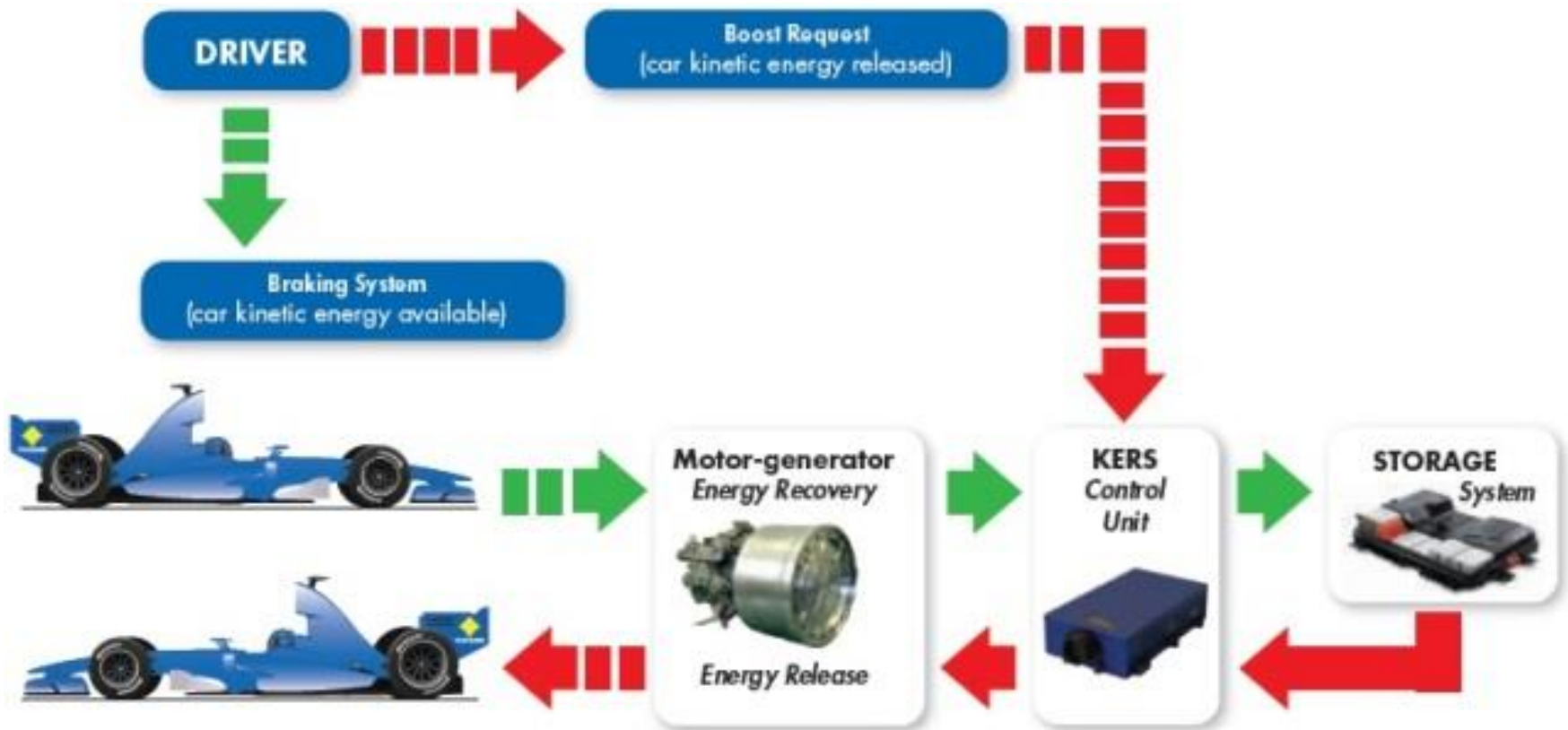
- ✓ can be stored **directly in the ESS**;
- ✓ can be stored by **compressing air** by means of hydraulic motor;
- ✓ can be store by springs, in form of gravitational energy.
- ❖ **Formula One** vehicles employ **kinetic energy recovery systems (KERSs)** to use the energy gathered during braking to provide extra power during accelerating. The **Porsche 911 GT3R hybrid** uses a **flywheel energy storage system** to store this energy.



1. Power electronics  
2. Portal shaft with two electric motors  
3. High-voltage cable  
4. Electrical flywheel battery  
5. Power electronics

**Table 6. Different methods of recovering energy during braking.**

Storage System	Energy Converter	Recovered Energy	Application
Electric storage	Electric motor /generator	~50%	BEV, HEV
Compressed gas storage	Hydraulic motor	>70%	Heavy-duty vehicles
Flywheel	Rotational kinetic energy	>70%	Formula One (F1) racing
Gravitational energy storage	Spring storage system	-	Train



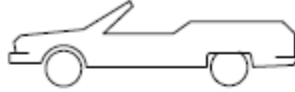
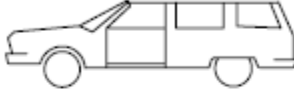
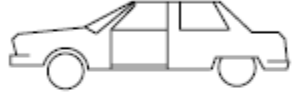
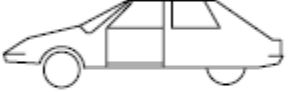



**Fig. 22. Regenerative braking cycle for EVs.**

c) **Aerodynamic techniques** are used in vehicles **to reduce the drag coefficient**, which reduces the required power. Power needed to overcome the drag force is:

$$P_d = \frac{1}{2} \rho v^3 A C_d$$

❖  $C_d$  is the drag coefficient. The **Toyota Prius** claims a drag coefficient of **0.24** for the 2017 model, the same as the **Tesla Model S**. The **2012 Nissan Leaf** had this value set at **0.28**.

**Fig. 23. Indicative drag coefficients for different body shapes.**

Vehicle type	Coefficient of aerodynamic resistance
 Open convertible	0.5...0.7
 Van body	0.5...0.7
 Ponton body	0.4...0.55
 Wedged-shaped body; headlamps and bumpers are integrated into the body, covered underbody, optimized cooling air flow	0.3...0.4
 Headlamp and all wheels in body, covered underbody	0.2...0.25
 K-shaped (small breakaway section)	0.23
 Optimum streamlined design	0.15...0.20
Trucks, road trains	0.8...1.5
Buses	0.6...0.7
Streamlined buses	0.3...0.4
Motorcycles	0.6...0.7

d) **Different energy management schemes can be employed to ensure efficient use of the available energy, .** Presented control strategies for energy management included systems using **fuzzy logic, deterministic rule** and **optimization based** schemes:

✓ Geng et al., worked on a plug-in series hybrid FCV. The objective of their control system was to **consume the minimum amount of hydrogen** while preserving the health of the proton exchange membrane fuel cell (PEMFC). The control system was **comprised of two stages**; the first stage **determined the SOC and control references**, whereas the second stage **determined the PEMFC health parameters**. This method proved to be capable of **reducing the hydrogen consumption while increasing the life-time** to the fuel cell.

✓ Murphey et al., examined another intelligent management system, which used **machine learning combined with dynamic programming** to determine **energy optimization strategies** for roadway and traffic-congestion scenarios **for real-time energy flow control of a hybrid EV**. Their system is simulated using a Ford Escape Hybrid model; it revealed the system was effective in finding out congestion level, optimal battery power and optimal speed.

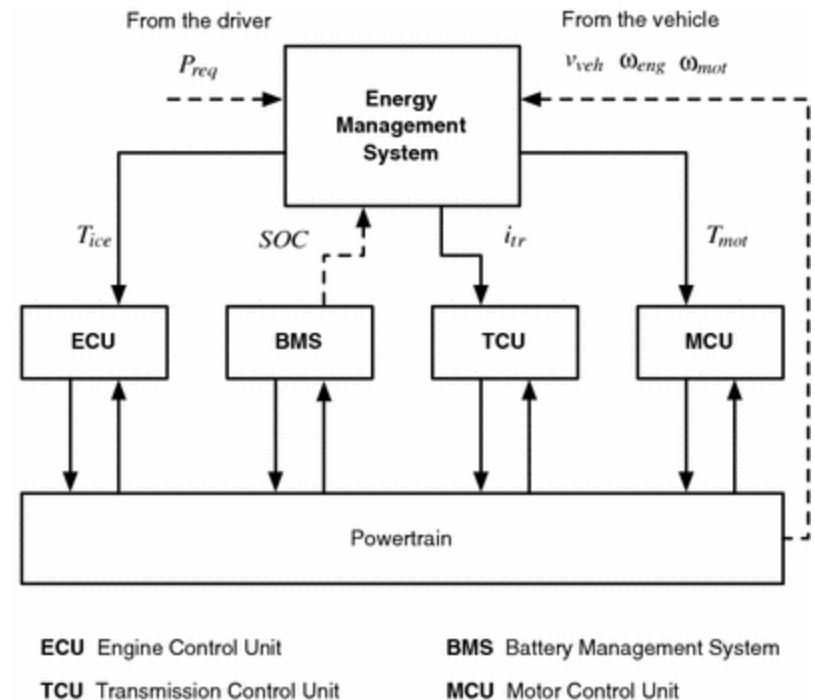
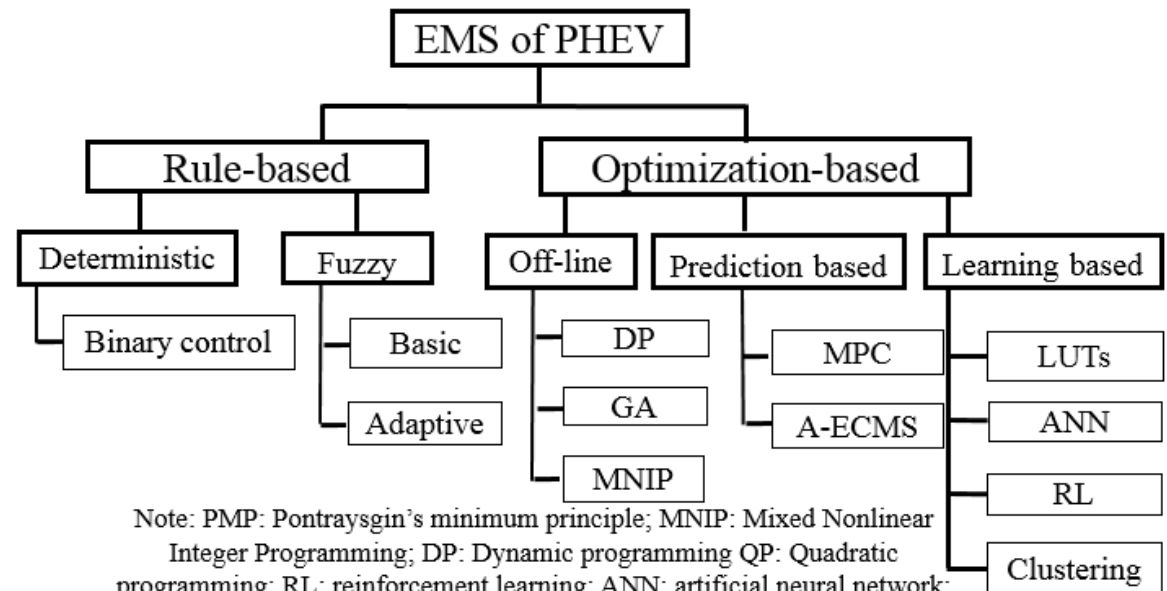


Fig. 24. EMS of a HEV and its communication with other parts. 36

- ✓ Geng et al., proposed a control mechanism for energy management for a PHEV **employing batteries and a micro turbine**. They introduced a new parameter, named the “energy ratio”, to produce the equivalent factor, which was used in the popular **Equivalent Consumption Minimization Strategy (ECMS)** to deduce the minimum driving cost by applying Pontryagin’s minimum principle. This method claimed to reduce the cost by 7.7–21.6%.
- ✓ Moura et al., explored efficient ways to **split power demand among different power sources** of mid-sized sedan PHEVs. They used a number of drive cycles, rather than a single one, assessed the potential of depleting charge in a controlled manner, and considered relative pricing of fuel and electricity for **optimal power management** of the vehicle.

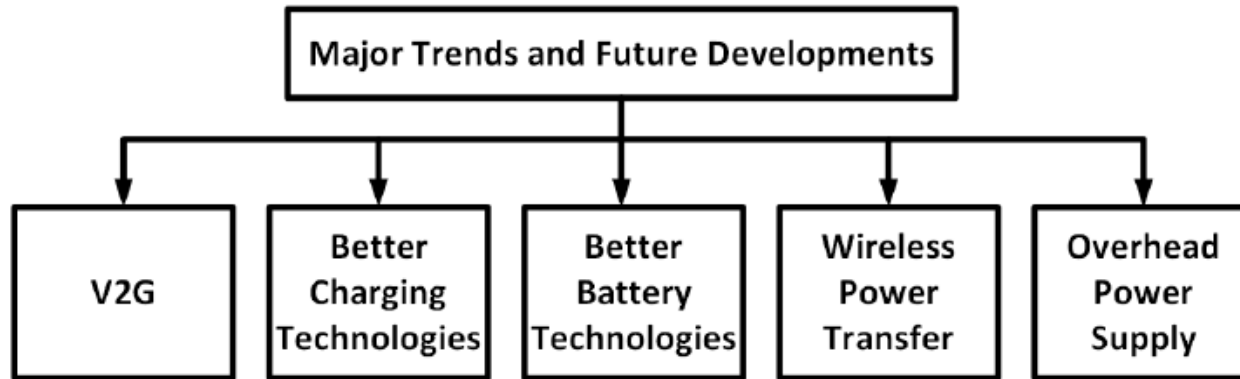


Note: PMP: Pontryagin’s minimum principle; MNIP: Mixed Nonlinear Integer Programming; DP: Dynamic programming; QP: Quadratic programming; RL: reinforcement learning; ANN: artificial neural network; LUTs: look-up-tables; MPC: model predictive control; AECMS: Adaptive equivalent consumption minimization strategy

**Fig. 25. Various EMS schemes for PHEVs.**

## 5.2.5. Future developments of EVs

Fig. 26. Major trends and sectors for future developments for EVs.



- ❑ The adoption of EVs has opened doors for new possibilities and ways to improve both the vehicles and the systems associated with it, which are as:
  - a) **V2G** is the link between these **EV** and **smart grid** technologies and both get benefitted from it. With V2G comes other essential systems required for a sustainable EV scenario: **charge scheduling**, **Virtual Power Plant (VPP)**, **smart metering** etc.
  - b) **The existing charging technologies** have to improve: The **charging time** has to be decreased extensively for making EVs more flexible. At the same time, chargers and **Electric Vehicle Supply Equipment (EVSE)** have to be able to **communicate with the grid** for facilitating V2G, **smart metering**, and if needed, **bidirectional charging**.
  - c) **There is a need for batteries** that use **non-toxic materials** and have **higher power density**, **less cost and weight**, **more capacity**, and **needs less time to recharge**. Though technologies better than **Li-ion** have been discovered already, they are not being pursued industrially because of the **huge costs associated with creating a working version**. **Li-air batteries** could be a good option to increase the range of EVs.<sup>38</sup>

- d) **WPT** systems are likely to replace the current cabled charging system. Electric roads for wireless charging of vehicles may appear as well. **Vehicles that follow a designated route** along the highway, like **trucks**, can get their power from overhead lines like trains or trams. It will allow them to gather energy as long as their route resides with the power lines, then carry on with energy from on-board sources. Such a system has been tested by **Siemens** using **diesel-hybrid trucks from Scania** on a highway in Sweden.
- e) **New ways of recovering energy** from the vehicle may appear. **Goodyear** has demonstrated a tire that can **harvest energy from the heat generated** there using thermo-piezoelectric material. There are also chances of **solar-powered vehicles**. Until now, these have not appeared useful as installed solar cells only manage to convert up to **20% of the input power**.
- f) **Various power supply** for **on-board charging** with higher efficiency and better power quality are considered as the main power electronics topics for EV applications.
- g) **Much research is going on to make the electronics and sensors** in EVs **more compact, rugged and cheaper**. Some examples can be the works on **gas sensors, smart LED drivers, smart drivers for automotive alternators, advanced gearboxes, and compact and smart power switches** to weather harsh conditions.
- h) **EVs are likely to move away from using PM motors**, which **use rare-earth materials**. The motors of choice can be **induction motor, synchronous reluctance motor, and switched reluctance motor**. Motors with internal permanent magnet may stay in use.

## 5.3. EVs Global Market: Current State and Future

### 5.3.1. Current state of EVs market

- ❑ **China** has become the **largest market** for EVs (35.4% of the worldwide EV scene in 2017, an rise from the mere 6.3% in 2013).
- ❑ **China** has the greatest number of manufacturers, **led by BYD** autos, which sold 96,000 EVs in 2016. This drive in China is **fueled by government initiatives** adopted to promote EV use to mitigate the country's serious air pollution.
- ❑ China huge market has attracted **major carmakers** all over the world (**Ford, Volkswagen, Volvo, and General Motors**).

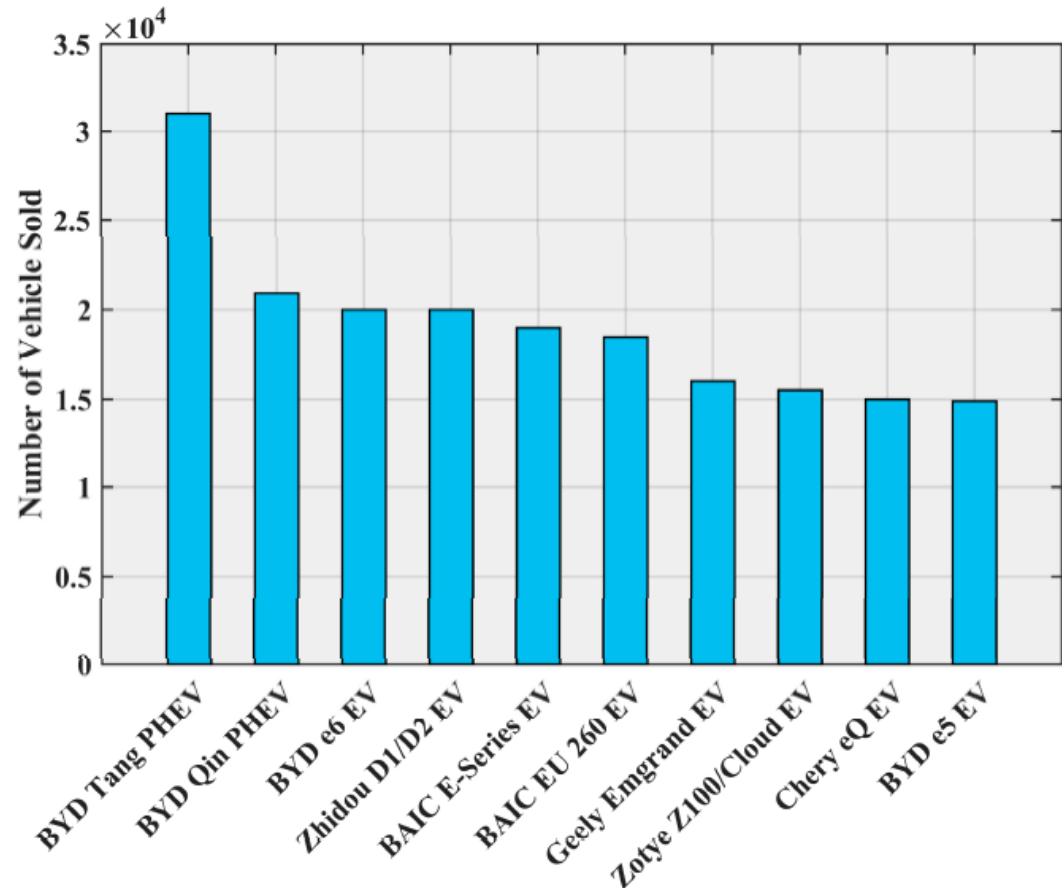
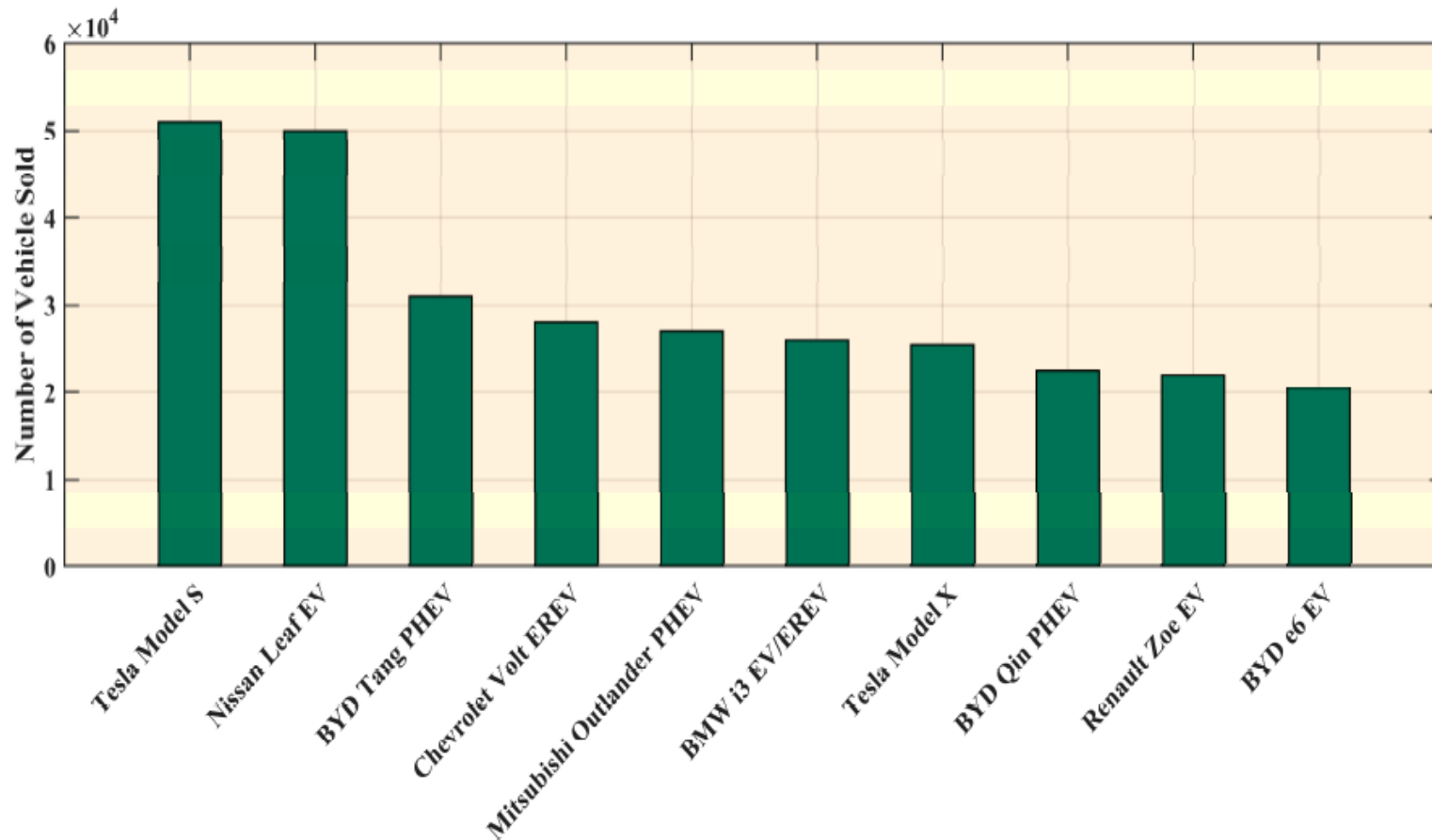


Fig. 27. Top ten EVs in China in 2016 according to the number of units sold.

- ❑ From a global perspective, **sales of EV grew by 36% in the USA; Europe saw a growth of 13%, while Japan observed a decrease of 11%** in the same period.
- ❑ **BYD** dominated the global market with a **13.2%** share, followed by **Tesla** in second place (**9.9%**); the other major contributors can be listed as **Volkswagen Group, BMW Group, Nissan, BAIC, and Zoyte**.
- ❑ **Tesla Model S** remained the **best-selling EV** in 2016 with 50,935 units sold, followed by the **Nissan Leaf EV** with **49,818** units.



**Fig. 28. Top ten best-selling EVs globally in 2016.**

□ The **American market** was dominated predictably by the **Tesla Model S** in 2016, **28,821** of these were sold; **Chevrolet Volt EREV** sold **24,739** units, thus securing the second place. The third place was achieved by another **Tesla Model X**; **18,192** of these Sport Utility Vehicles (SUVs) were sold in 2016.

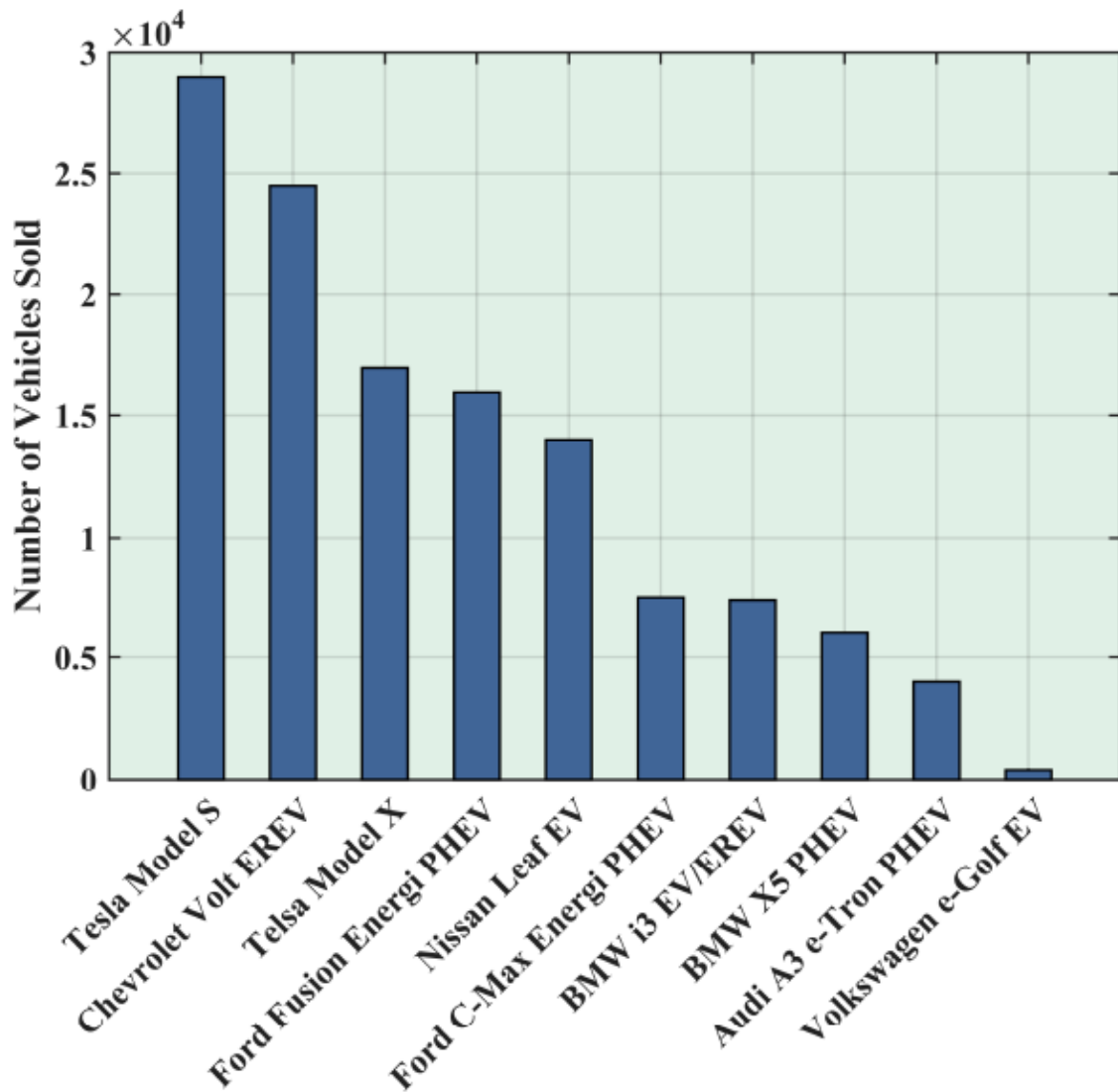
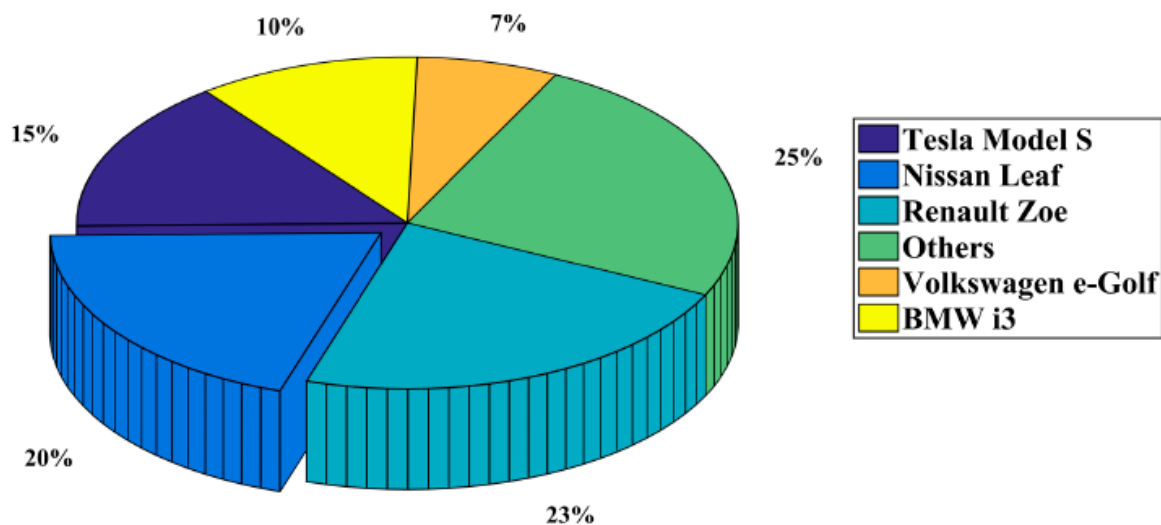


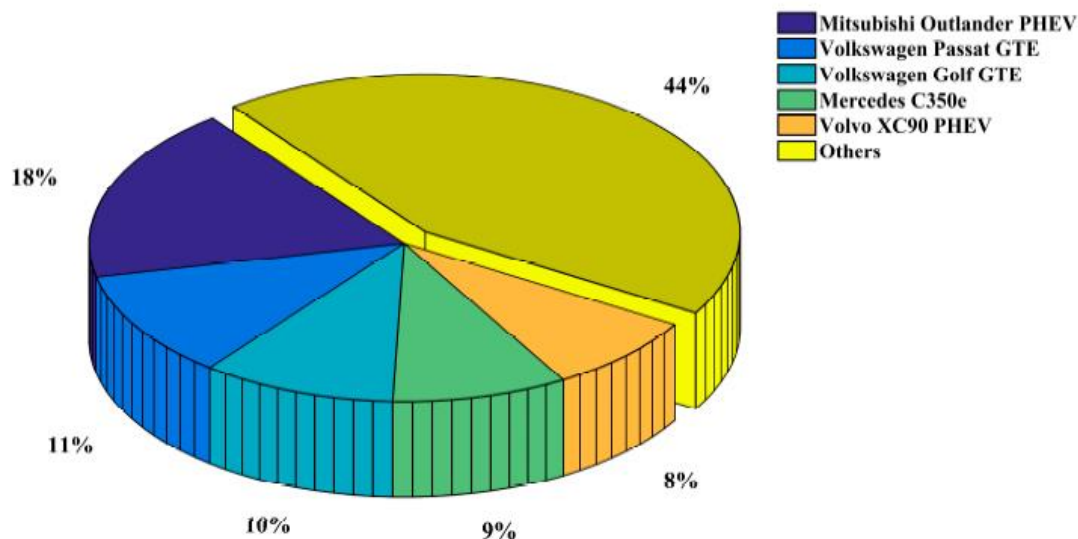
Fig. 29. Top ten best-selling EVs in the USA in 2016.

- ❑ The **Renault Zoe** was the **best-selling BEV in Europe** in 2016, with **21,338** units sold, followed by the **Nissan Leaf** with **18,614** units.
- ❑ In the **PHEV segment**, the **Mitsubishi Outlander PHEV** was the market leader in **Europe** in 2016, with **21,333** units sold; the **Volkswagen Passat GTE** held the second position with **13,330** units].

**Fig. 30. BEV market shares in Europe in 2016.**



**Fig. 31. PHEV market shares in Europe in 2016.**



## All-Electric Vehicle Comparison - U.S.

Acceleration 0-60 mph in seconds

Price (MSRP + DST and after Tax Credit)

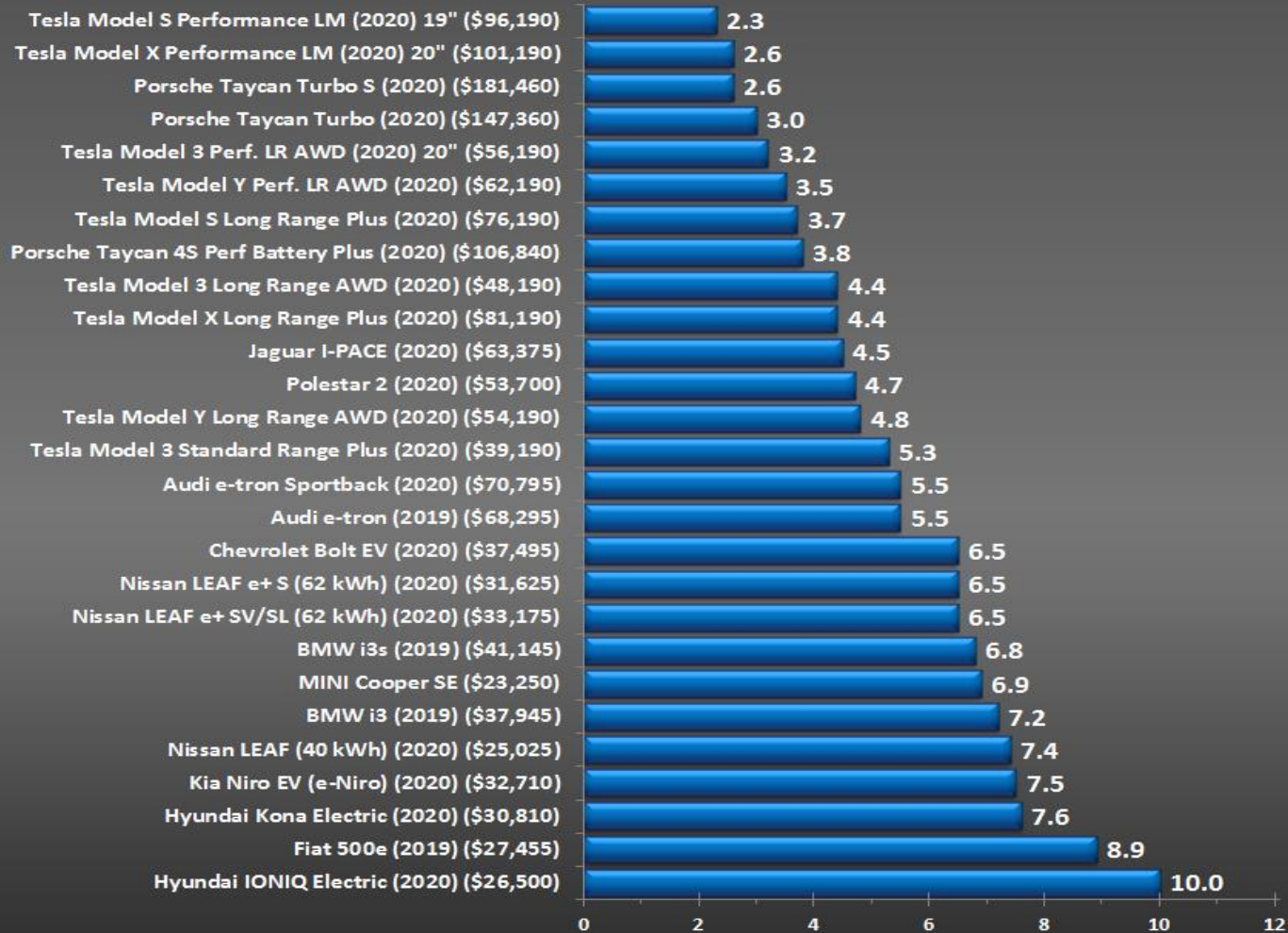


Fig. 32. Some of sold famous EVs in U.S. with price and acceleration.

## All-Electric Car Comparison - U.S.



### All-electric range (EPA)

Base price (MSRP + DST and after Tax Credit)

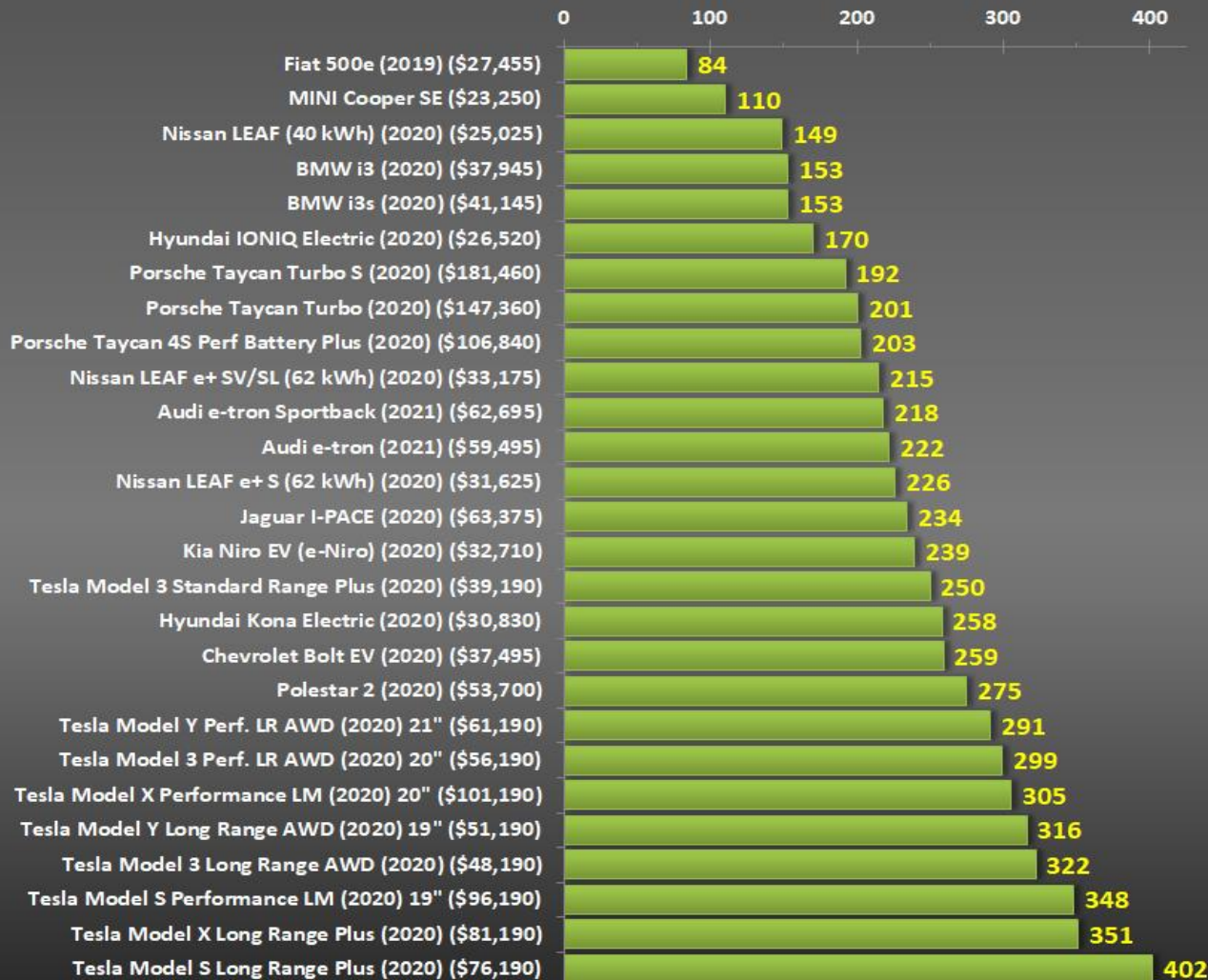


Fig. 33. Some of sold famous EVs in U.S. with price and all electric range according to EPA report.

## Tesla Car Comparison - U.S.

All-electric range (EPA) in miles

Price (MSRP + DST)



Acceleration 0-60 mph in seconds

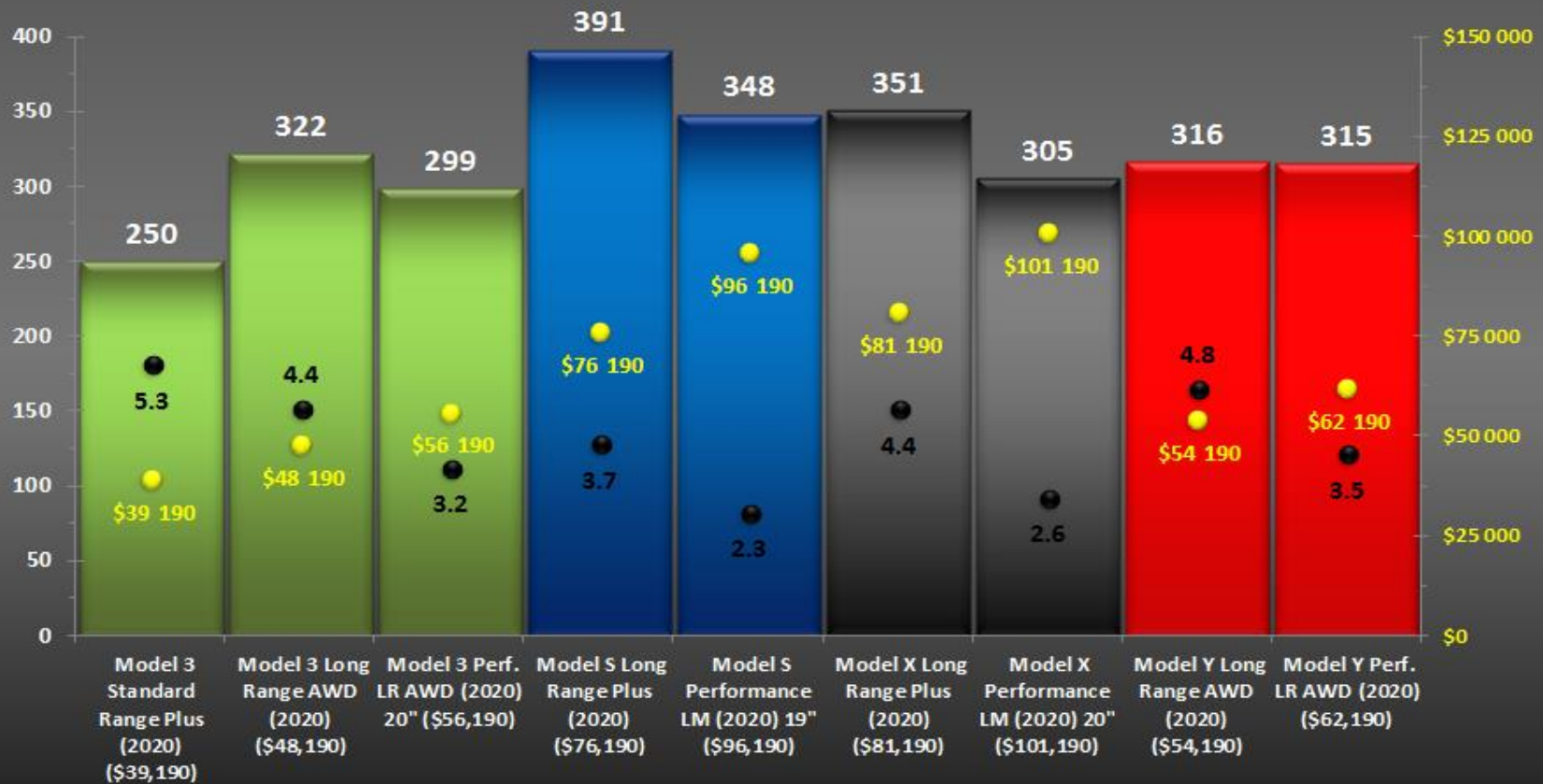


Fig. 34. Various Tesla EVs comparison in range, acceleration, and price.

### Stock of light-duty plug-in electric vehicles on the road in the Netherlands (2011 -2019)

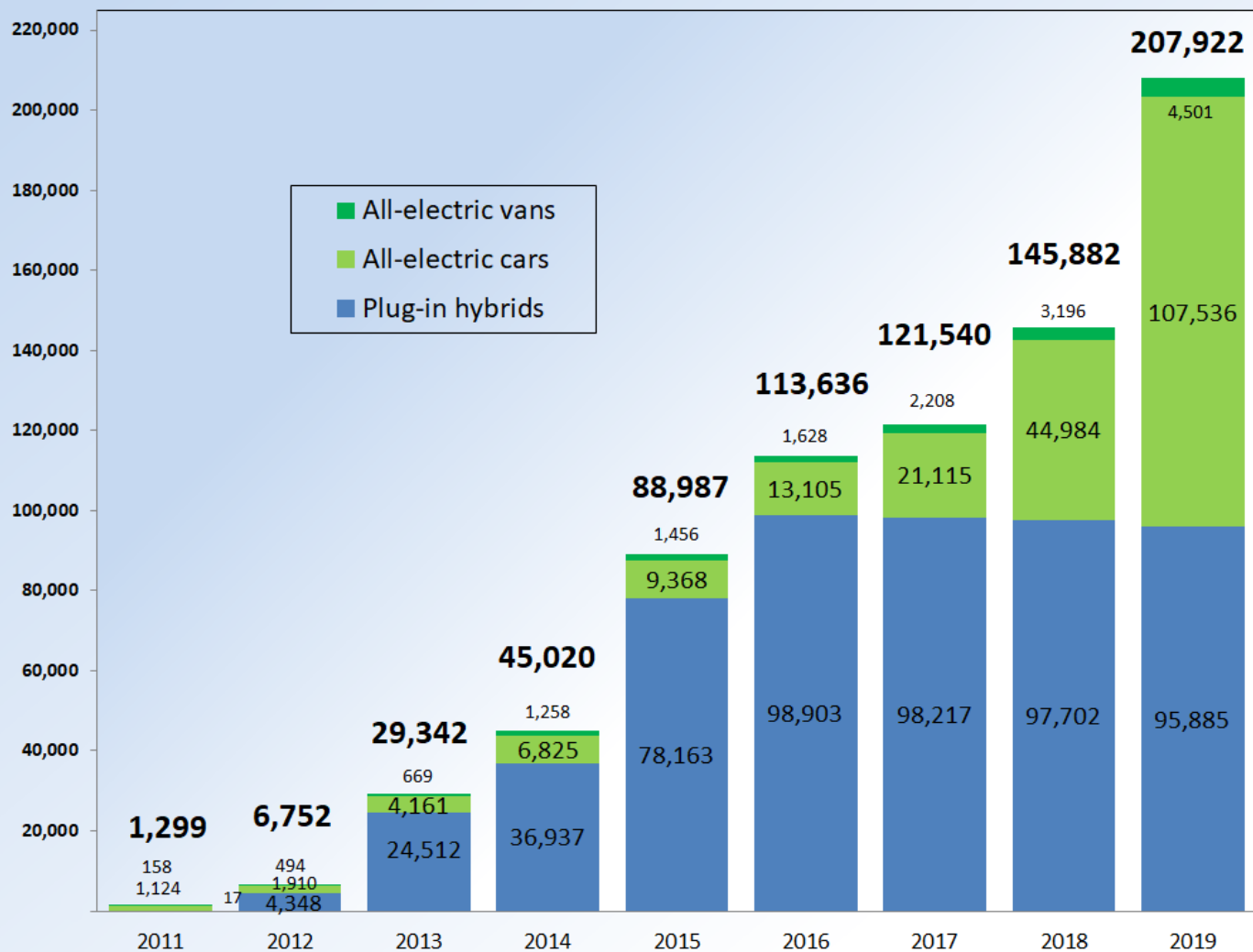
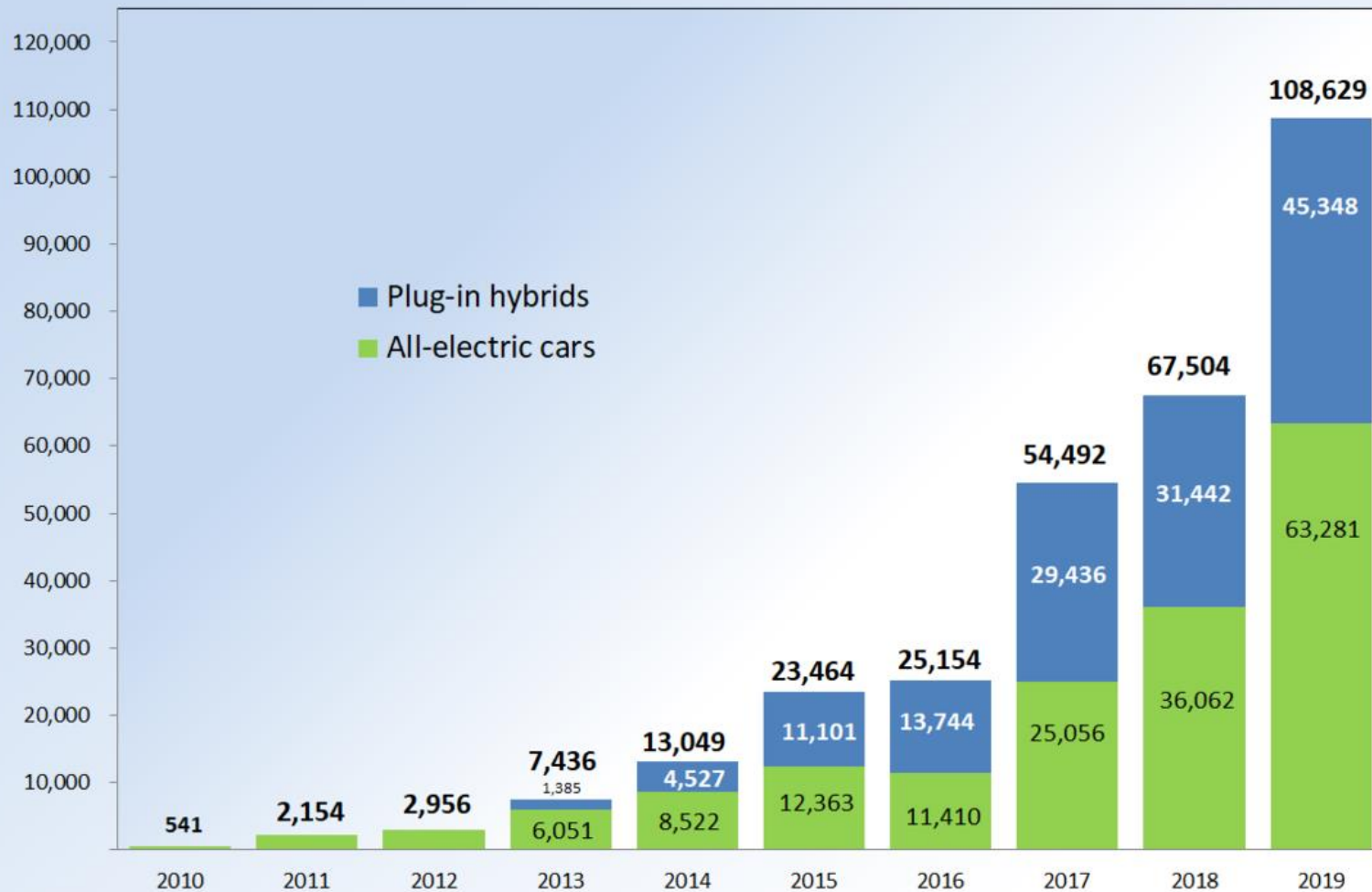


Fig. 35. Statistics of light-duty plug-in EVs on the road in Netherlands from 2011 to 2019.

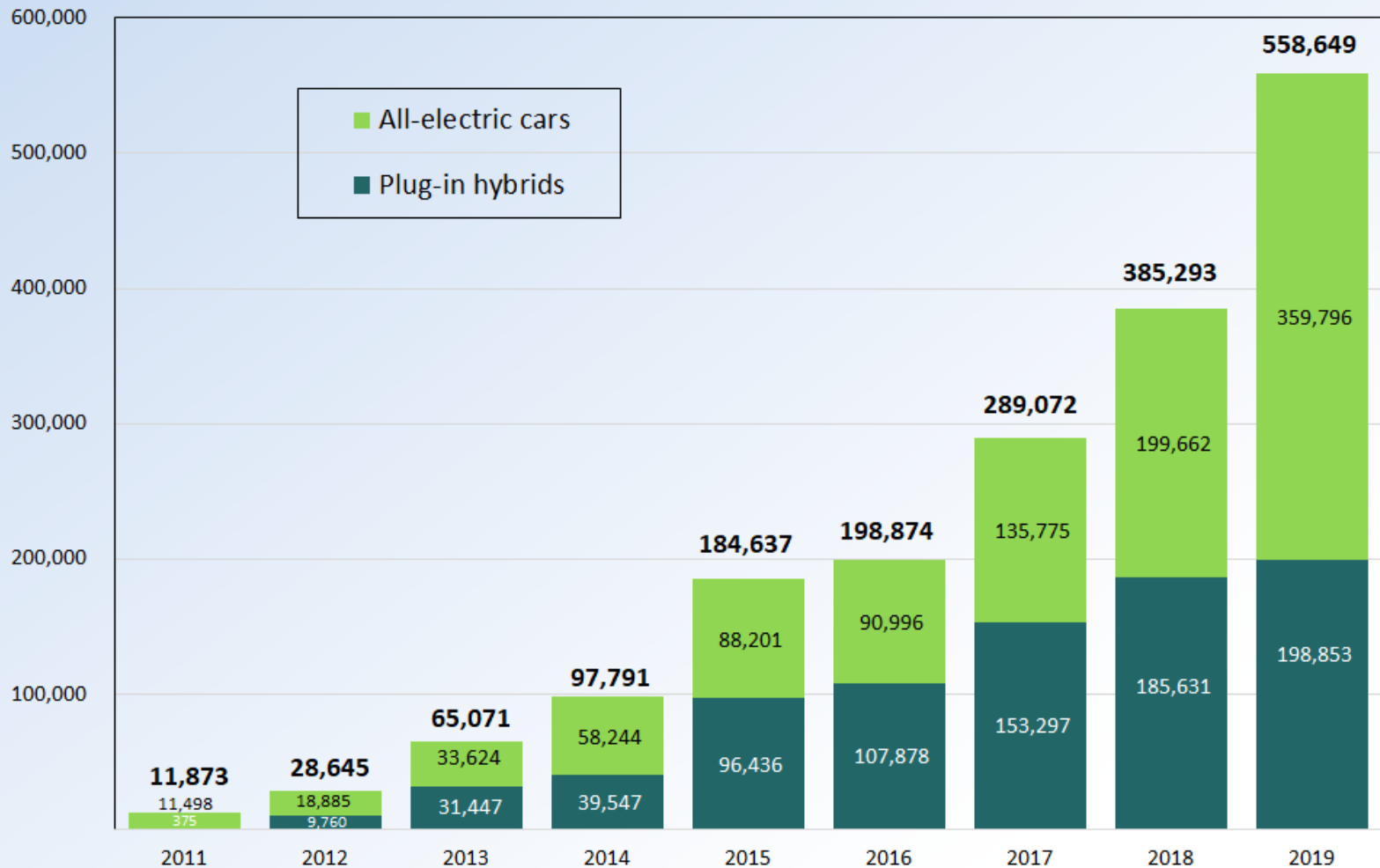
## Registrations of plug-in electric cars in Germany by year (2010 -2019)



\* **Note:** until 2012 registration figures includes range-extended electric vehicles (series plug-in hybrids)

**Fig. 36. Annual registration statistics of plug-in EVs in Germany from 2011 to 2019.**

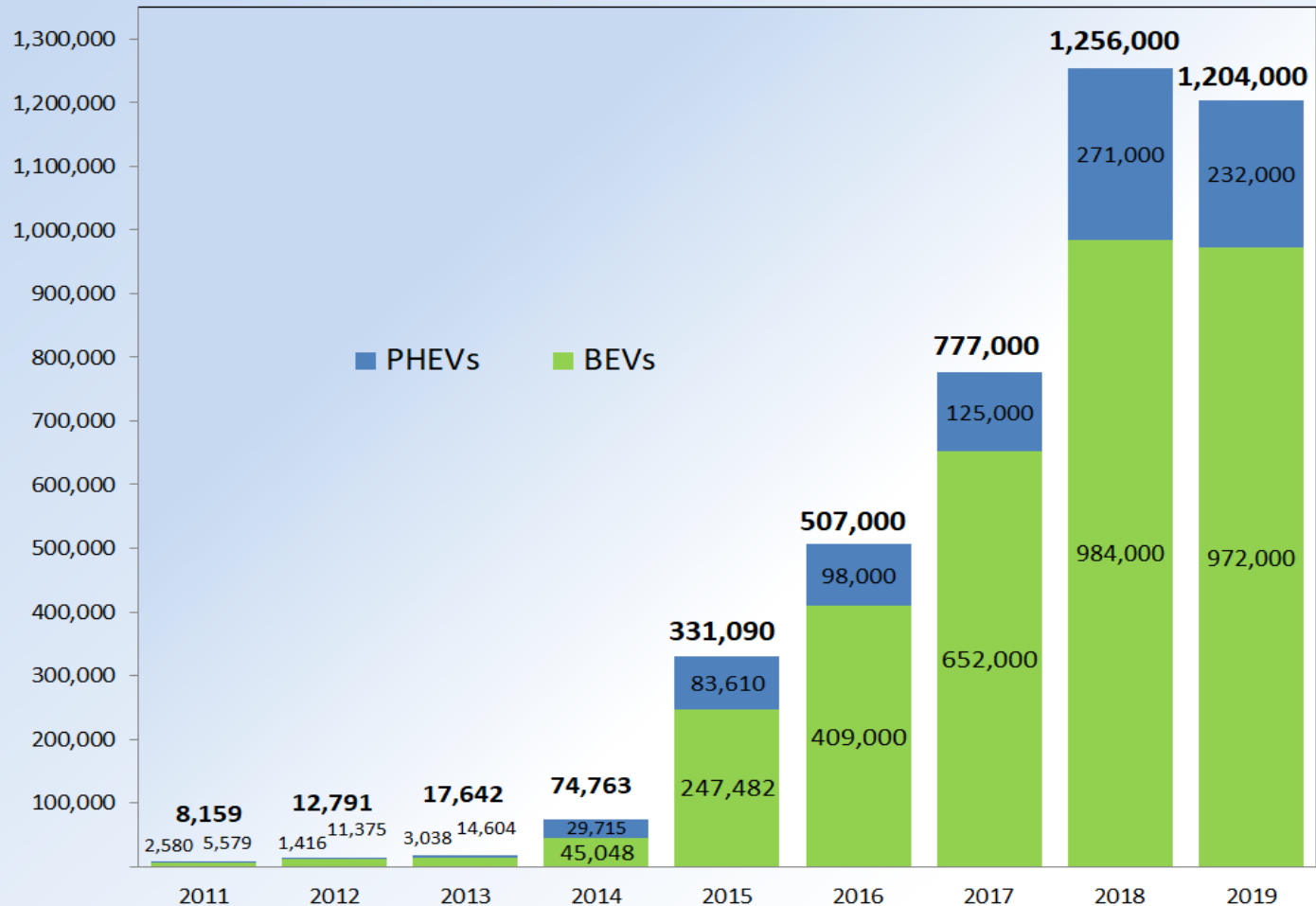
## Annual registrations of plug-in electric passenger cars in Europe\* (2011-2019)



\*Note: Combined registration figures EU + EFTA + UK. EFTA countries are Iceland, Norway, Switzerland, and Liechtenstein

**Fig. 37. Annual registration statistics of plug-in passenger EVs in Europe from 2011 to 2019.** 49

## Sales of new energy vehicles (NEVs) in China by year (2011 - 2019)



**Notes:** NEVs includes passenger cars and commercial vehicles, such as buses, sanitation trucks, and other heavy-duty vehicles  
Graph shows only plug-in electric vehicles (battery electric and plug-in hybrids). Fuel-cell vehicles are not included

**Fig. 38. Annual sales statistics of EVs in China from 2011 to 2019.**

### Annual sales of plug-in electric passenger cars in the U.S. by type of powertrain (2010 -2019)

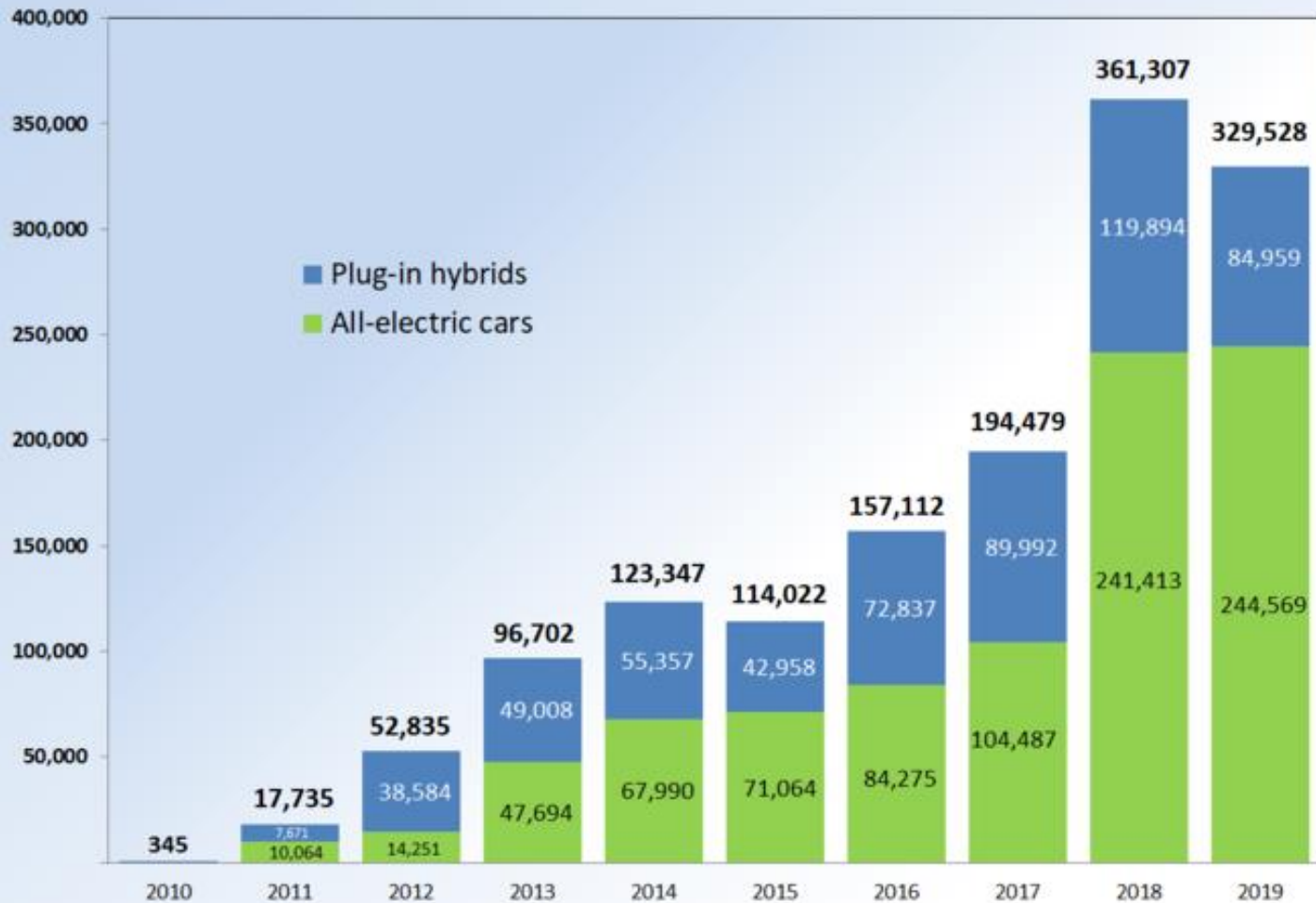
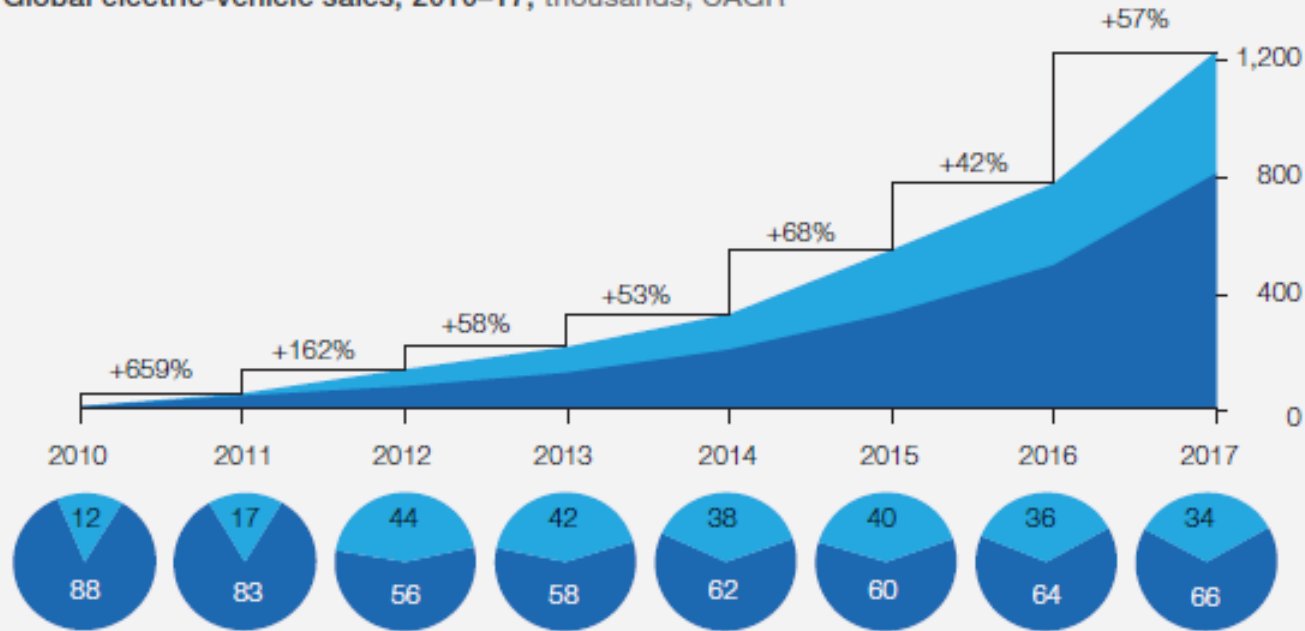


Fig. 39. Annual sales statistics of EVs in U.S. from 2011 to 2019.

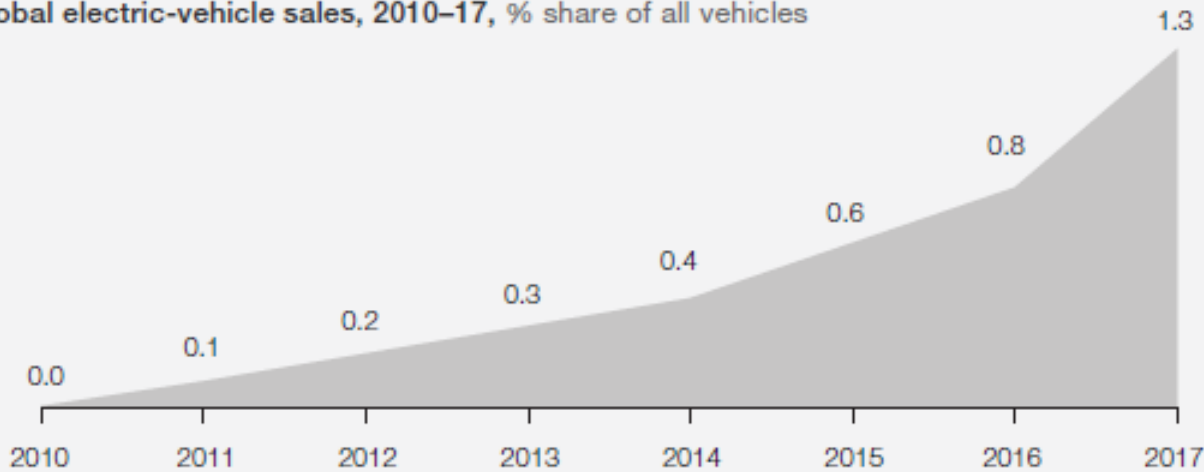
■ Plug-in hybrid-electric vehicle
 ■ Battery-electric vehicle

Global electric-vehicle sales, 2010–17, thousands, CAGR<sup>1</sup>



**Fig. 40. BEV and PHEV sales trend comparison in 2010-2017.**

Global electric-vehicle sales, 2010–17, % share of all vehicles



<sup>1</sup>Compound annual growth rate.

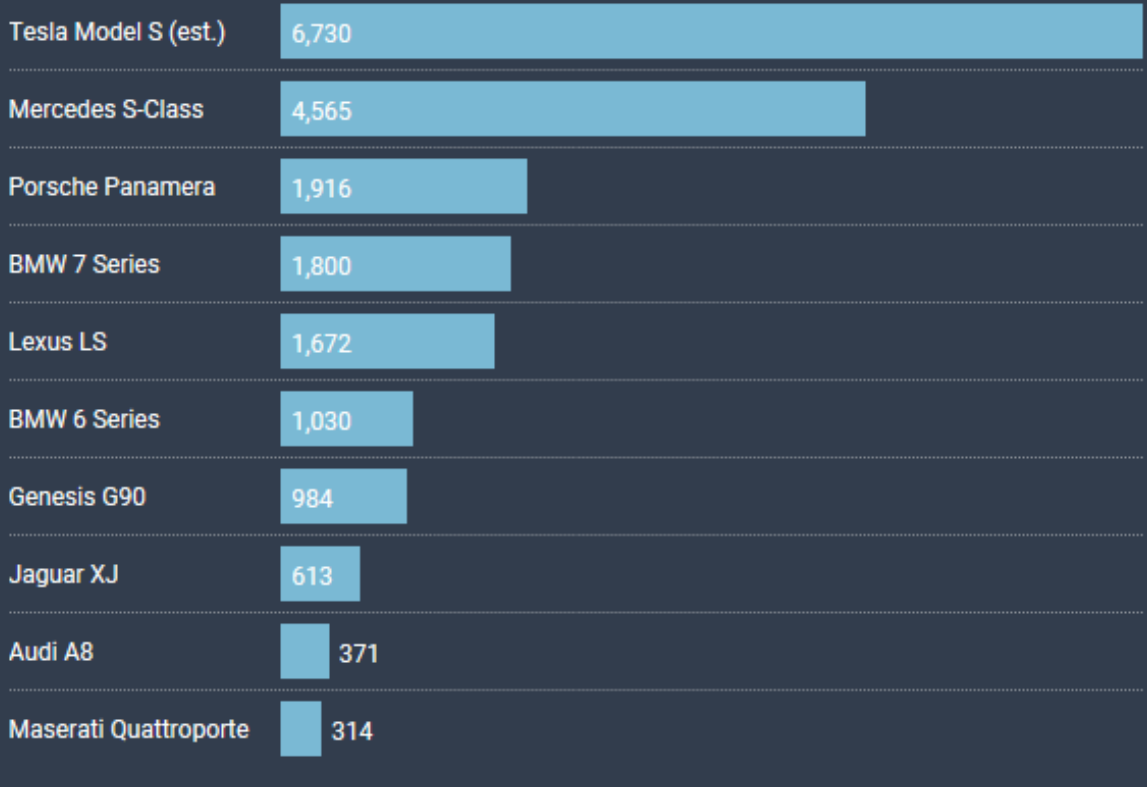
**Table 7. Automakers EV sales comparison in 2018.**

## 2018 Monthly Sales Chart

2018 U.S. EV SALES	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
<b>Tesla Model 3*</b> 	1875	2485	3820	3750	6000	5902	14250	17800	22250	17750	18650	25250	139,782
<b>Toyota Prius Prime</b>	1496	2050	2922	2626	2924	2237	1984	2071	2213	2001	2312	2759	27,595
<b>Tesla Model X*</b> 	700	975	2825	1025	1450	2550	1325	2750	3975	1225	3200	4100	26,100
<b>Tesla Model S*</b> 	800	1125	3375	1250	1520	2750	1200	2625	3750	1350	2750	3250	25,745
<b>Honda Clarity PHEV*</b>	604	911	1131	1129	1639	1495	1542	1462	1997	2025	1897	2770	18,602
<b>Chevrolet Volt*</b>	713	983	1782	1325	1675	1336	1475	1825	2129	1475	2530	1058	18,306
<b>Chevrolet Bolt EV*</b> 	1177	1424	1774	1275	1125	1083	1175	1225	1549	1975	2825	1412	18,019
<b>Nissan LEAF</b> 	150	895	1500	1171	1576	1367	1149	1315	1563	1234	1128	1667	14,715
<b>BMW 530e*</b>	224	413	689	518	729	942	536	749	756	733	1012	1363	8,664
<b>Ford Fusion Energi</b>	640	794	782	742	740	604	522	396	480	453	1131	790	8,074



## Large Luxury Car Sales (Q1 2018, USA)



**Fig. 41. Luxury car sales comparison in 2018.**

### **❑ About the EU Automotive industry:**

- ✓ 12.2 million people - or 5.6% of the EU employed population - work in the sector.
- ✓ The 3.1 million jobs in automotive manufacturing represent 10.4% of EU manufacturing employment.
- ✓ Motor vehicles account for over €400 billion in tax contributions in the EU15.
- ✓ The sector is also a key driver of knowledge and innovation, representing Europe's largest private contributor to R&D, with €44.7 billion invested annually.
- ✓ The automobile industry generates a trade surplus of €100.4 billion for the EU.

**Table 8. Specifications of some commercially available EVs.**

Vehicle Model	Motor Rating (kW)	Motor	Battery Capacity (kWh)	Electric Range (mil)
Smart FortoWo ED	55	PMSM	17.6	58
Hyundai Ioniq Elec.	88	PMSM	28	124
Mahindra Reva	35	IM	16	75
Kia Soul EV	81	PMSM	30	110
Renault Zoe	80	PMSM	41	250
Tesla Model 3	192	PMSM	75	220
Tesla Model S 70D BEV	100	IM	100	240
Chevy Bolt	150	PMSM	60	238
Chevy Volt PHEV	87	PMSM	18.4	420
Ford Focus Electric	107	PMSM	33.5	115
Nissan LEAF BEV	110	PMSM	40	151
BMW i3 BEV	125	PMSM	33	114
Audi A3 e-Tron PHEV	75	PM-SynRM	8.8	31
Toyota Prius PHEV	50	PMSM	8.8	640
Cadillac CT6 PHEV	250	PMSM	18.4	31
VW e-Golf	100	IM	35.8	125
Chery eQ	41	PMSM	23.6	157
NIO EP9	1000	PMSM	90	265
Tesla Model X	193	IM	100	325

### 5.3.2. Future perspective for EV market

- The historic learning rate for EV Li-ion battery prices from 2010-2017 was around 18%. This means that for every doubling of cumulative volume, we observe an 18% reduction in cost. Based on this, we expect battery prices to continue to decline, reaching \$96/kWh in 2025 and \$70/kWh in 2030.

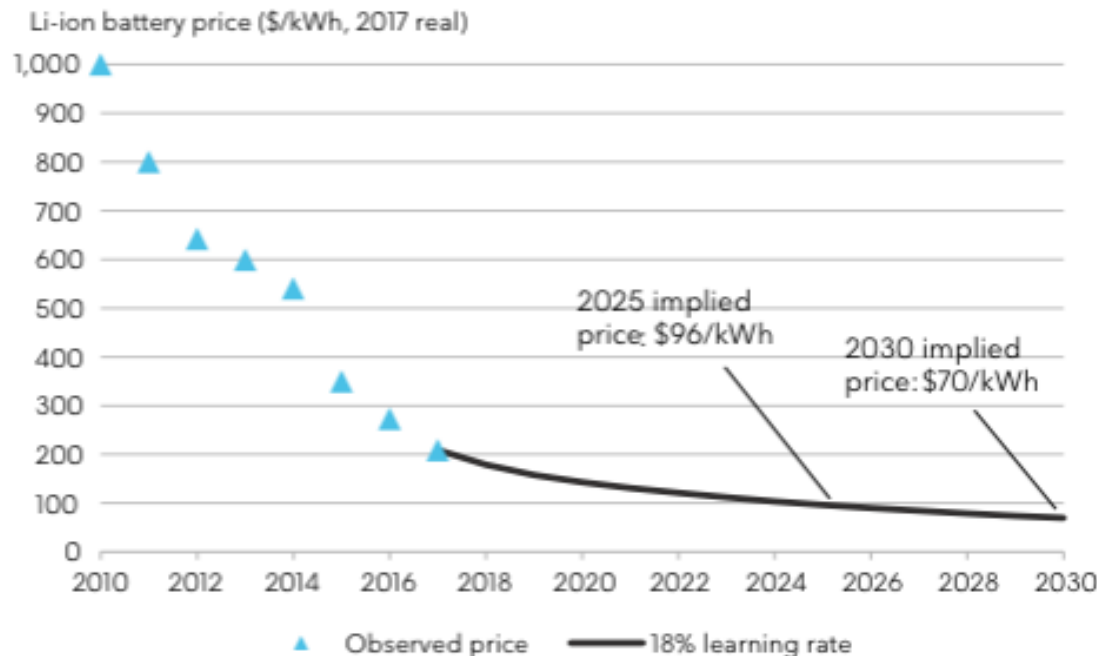
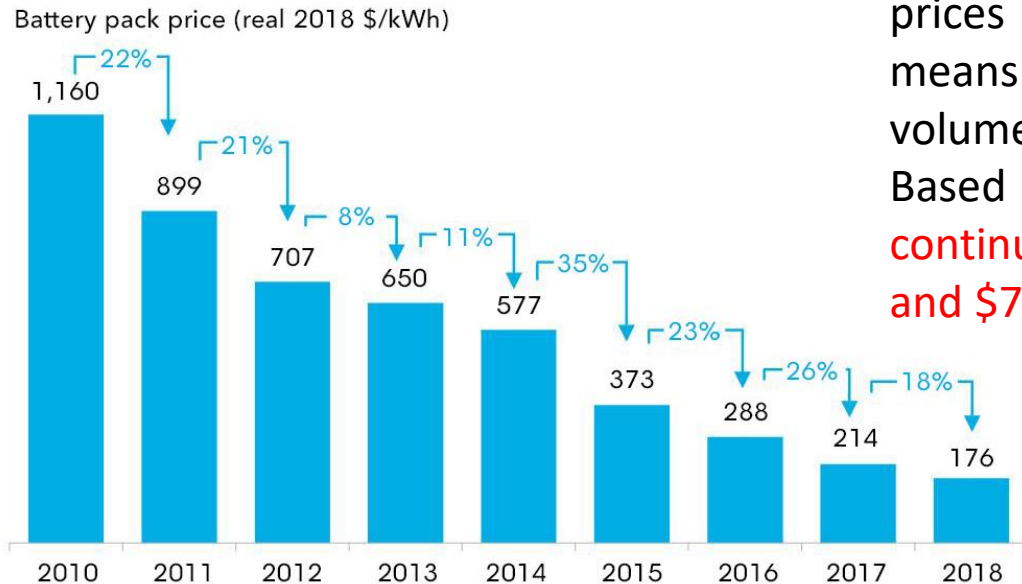
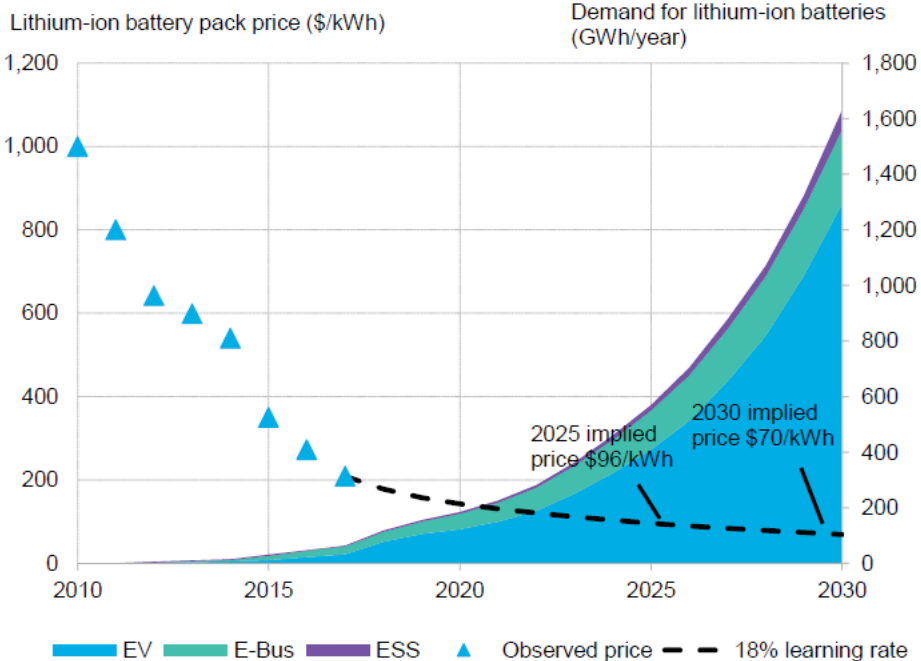
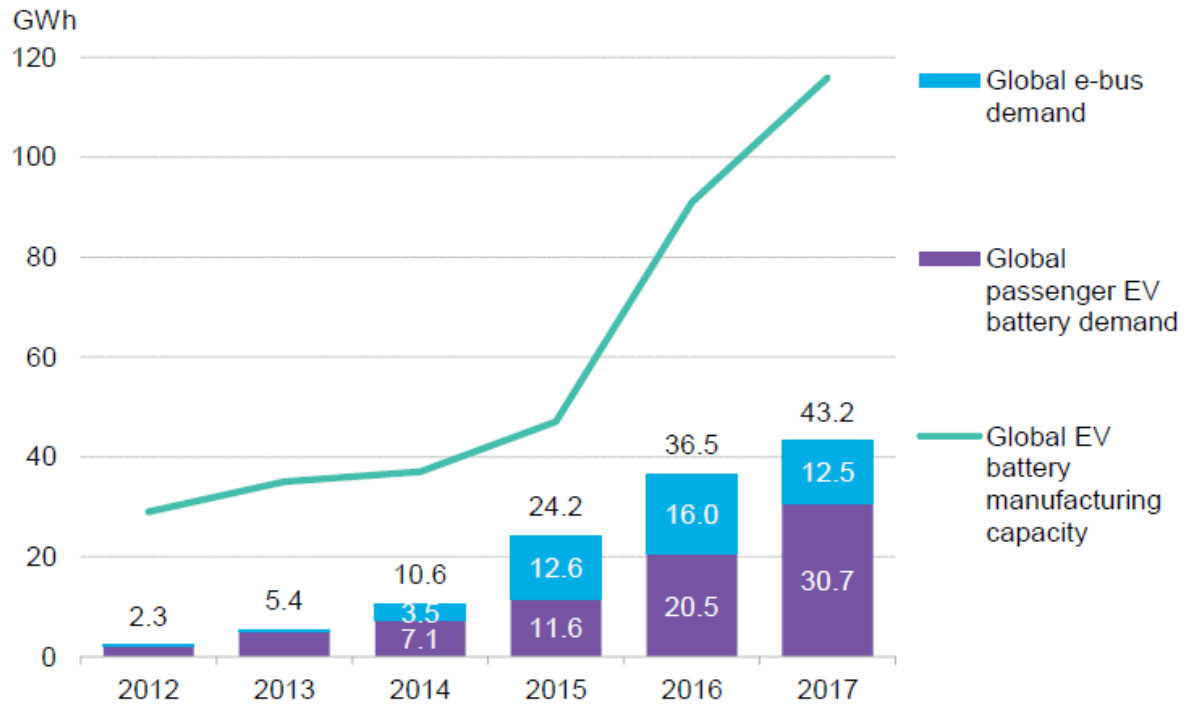


Fig. 42. Li-ion battery price trend till now (upper) and in the future (lower).

- The price for lithium-ion battery packs has fallen by 24% since 2016 and 79% since 2010.

**Fig. 43. Global e-bus Li-ion battery demand and global EV lithium-ion battery manufacturing capacity.**

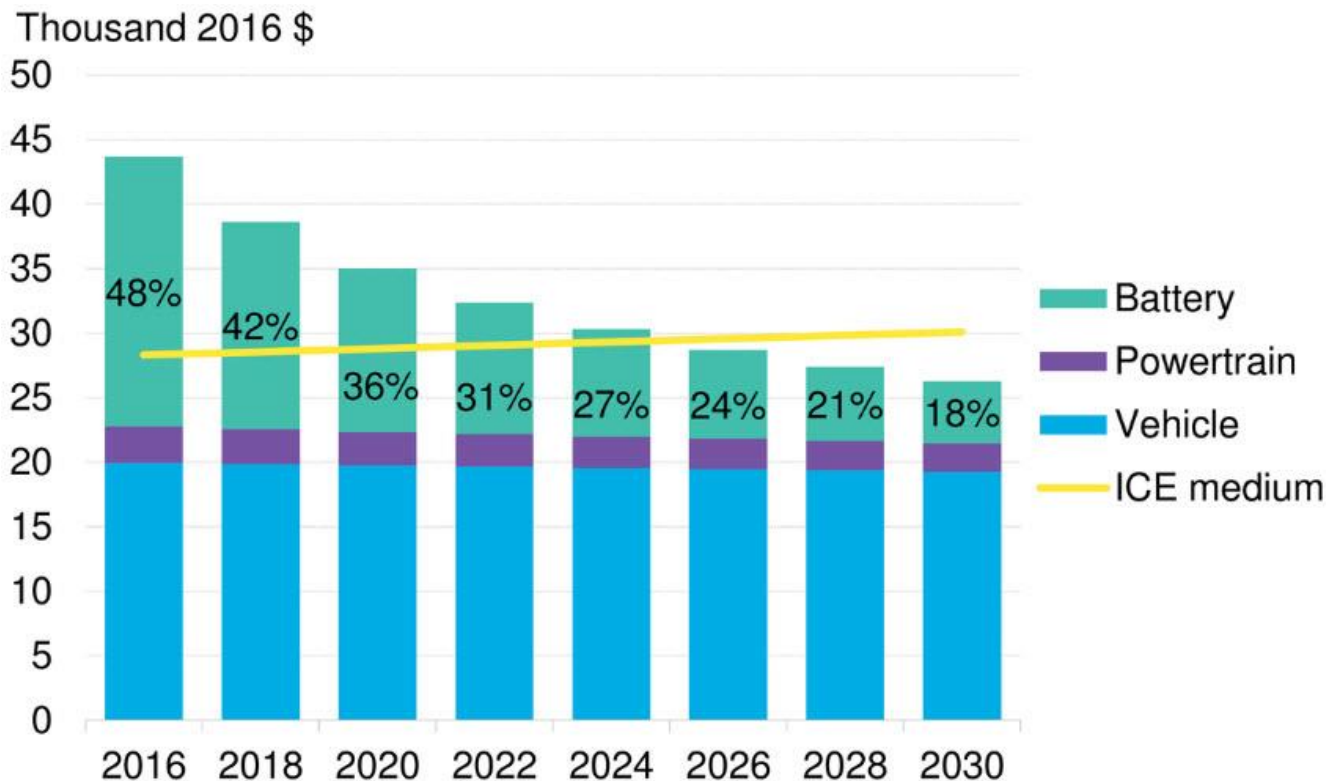
□ In 2017 battery demand from e-buses was slightly lower than in 2016, as a result of the drop in e-bus sales in China. The majority of Li-ion battery manufacturing capacity is located in China.

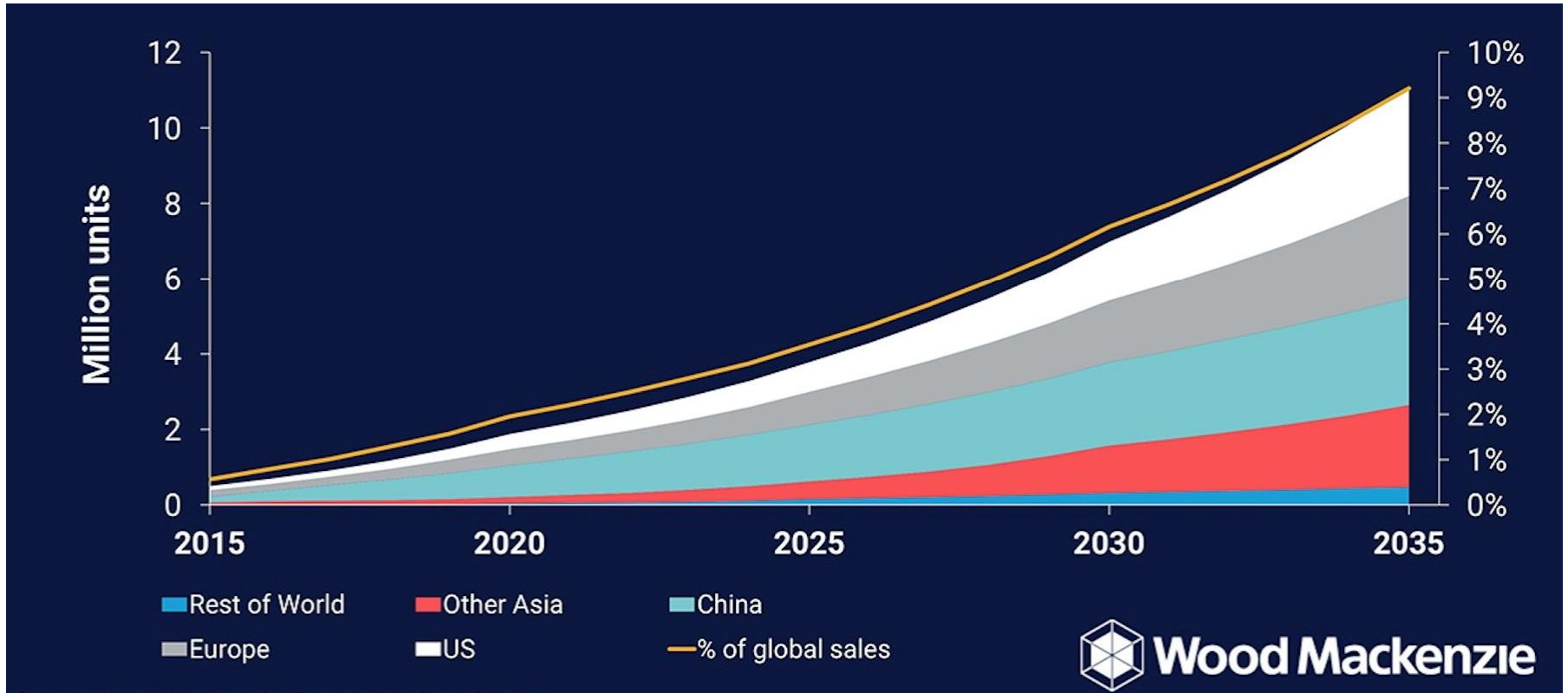


**Fig. 44. Li-ion battery pack price forecast.**

□ The **location of battery manufacturing** also plays an important role in determining costs. **Factors such as local electricity costs, labor and financing will also affect the cost of manufacturing.** Battery prices in China are currently the lowest at **both pack and cell level**, due to a **combination of scale of manufacturing, labor costs, electricity prices and favorable local conditions.** This in turn allows e-buses made in China to be considerably cheaper than in the rest of the world. We estimated the manufacturer's price for the electric BYD K9 at around 1.75 million Yuan (\$264,000) – significantly less than e-buses on offer in Europe or the U.S.

**Fig. 45. EV parts price trend in the future.**





**Fig. 46. EV sales trend in the future in various countries of the world.**

### 5.3.3. Job opportunities based on EVs

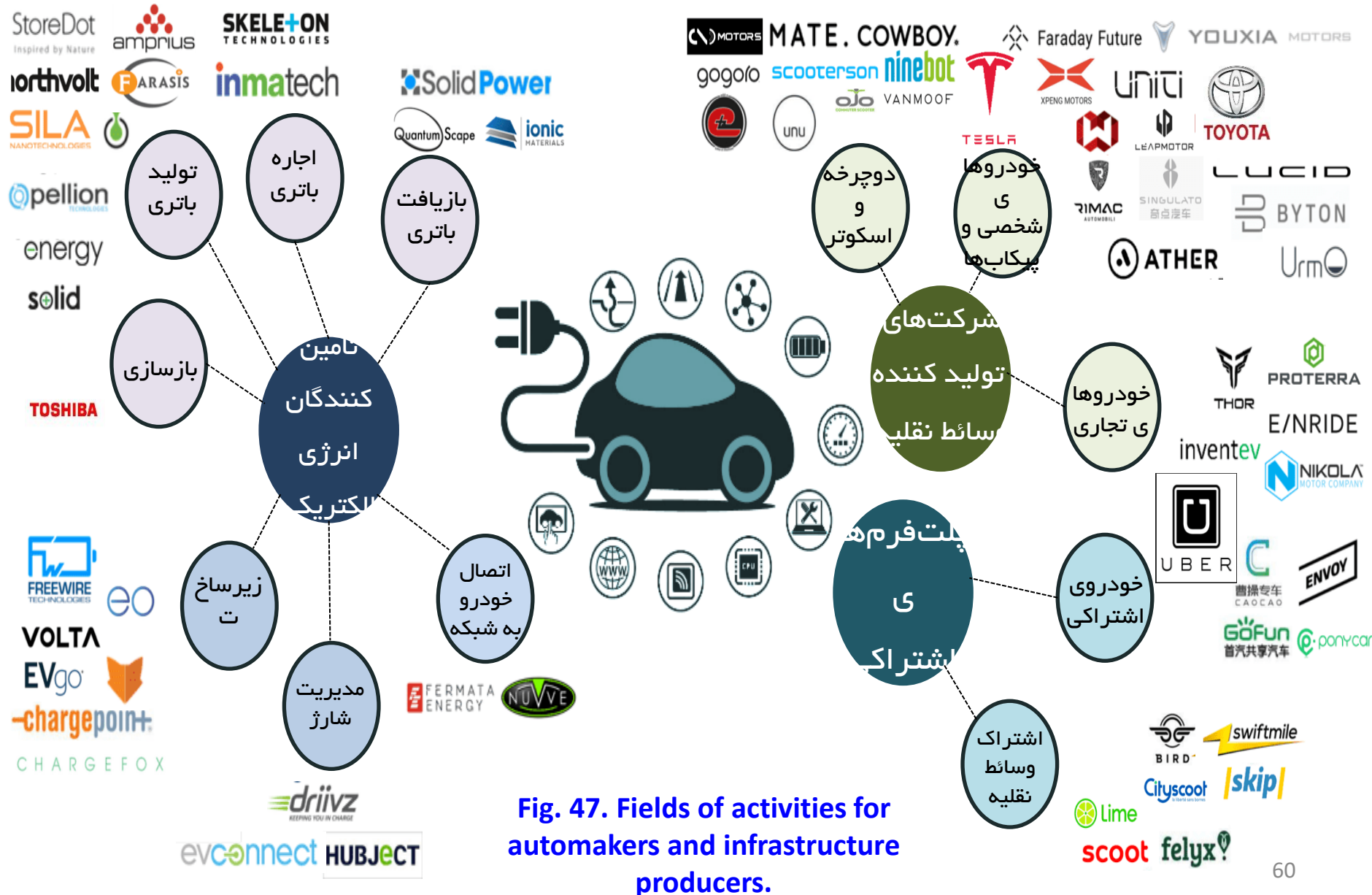


Fig. 47. Fields of activities for automakers and infrastructure producers.



Fig. 48. Fields of economical activities based on EV industry.