Study on
Effects of Plug-In Electric Vehicles (PEV) on the Transmission Grid of North Macedonia (Final report)

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1 INTRODUCTION

In the past few years, battery technologies have seen an unprecedented development. At the same time, plug-in electric and hybrid vehicles (PEVs) have become an increasingly realistic alternative to traditional light vehicles. Plug-in vehicles can behave either as loads, which is usually referred as grid-to-vehicle (G2V) connection, but also provide power to the grid, a concept commonly known as vehicle-to-grid (V2G) connection.

By coupling these two large systems, PEVs and the electricity grid may improve the economics of system operation. From a grid perspective, PEV will create additional demand in the system, but may equally help to reduce peak loads ("peak shaving") when being charged flexibly. Similarly, PEVs can potentially contribute to ancillary services for power balancing. When also being used for V2G services, PEV may conceptually provide additional flexibility to the system, due to their inherent storage capabilities. Due to the small size and large number of PEVs, an efficient integration and use of PEVs will, however, require effective means for incentivisation and, potentially, optimisation and control.

Against this background, the current study serves to assess the possible impact of electric vehicles implementation in North Macedonia for the next two decades, i.e. until the year 2040. For this purpose, this report is structured as follows:

- Chapter 2 provides an introduction to different storage technologies, focusing on different battery technologies and potential applications, roles and location of storages in the power system.
- Chapter 3 gives an overview of the current status and future outlook on electric mobility in Europe, covering electric vehicles as well as public charging infrastructure.
- Chapter 4 develops a set of assumptions as required to studying the impact of e-mobility on the North Macedonian power system.
- Based on this background, chapter 5 finally presents and discusses the results of the technical, economic and regulatory analysis carried out under this project.

2 INTRODUCTION TO STORAGE TECHNOLOGIES

Large scale storage systems have been in use since the late 1900s as a buffer in case of a shortage of electricity. Over the years, storages have evolved and diversified. This has led to a myriad of different storage technologies, all with different characteristics and applications.

This chapter presents an overview of the different storage systems. Special attention will be paid to battery storage technologies with potential applications in electric vehicles. It is structured as follows:

- The chapter will start with an overview and classification of the different storage technologies available.
- This will be followed by additional detail on specifics of the different storage technologies, namely: their preferred application, the trade-off between power and energy, sizing, efficiency and costs.
- Moreover, we outline applications in the power system, operation models and sources for benefits and revenues to storage operators.
- Finally, we briefly comment on the potential scope, role and location of new storages, addressing separately different types of technologies.

2.1 Overview on Energy Storages

Electric energy cannot be stored directly. From a technical point of view, therefore, electric storage essentially comprises of three steps: the conversion of electric energy into another form of energy, the storage of this energy carrier, and finally the conversion into electric energy as needed.

When trying to capture the heterogeneity of storage technologies one can classify them either by the medium used to store energy or by the form in which the energy is stored. Mediums for storing energy may be solid, liquid or gaseous. And the energy may be stored in the form of:

- potential energy,
- mechanical (also kinetic) energy,
- chemical energy
- electrostatic and electromagnetic energy,
- thermal energy.

Figure 1 lists and classifies the main types of storages.

Figure 1: Classification of storage technologies

	Storage medium		
Energy type used for storing	**Solid**	**Liquid**	**Gas**
Potenial		• Hydro stoarge / PSP (water), • Gravity storage (water)	
(Electro-) chemical	• Solid state batteries	• Flow batteries	• P2G (hydrogen, methane)
Mechanical / kinetic	• Fly wheel	• LAES (air)	• CAES (Air)
Electrostatic / electromagnetic	• Capacitor		
Thermal	←	• Sensibel • Latent • Thermo-chemical	→

Source: DNV GL analysis

Potential energy storages

Hydro storage plants use the potential energy of water collected and/or stored in a reservoir. For power generation, the water is released to a turbine that is coupled to a generator. In the power sector, the term 'hydropower storage' traditionally refers to plants with an upper reservoir and which can be used for power generation only. In contrast, so-called pump storage plants (PSP) allow for the temporary storage of (electric) energy in the form of potential energy, i.e. in the sense of energy storage considered for this report. Pump storage hydro power plants (PSP) can be operated in reversible or 'pumping' mode, i.e. in order to pump water from a lower to the upper reservoir, such that this water can be used for power generation at a later time. By definition, pump storage plants always have an upper and a lower reservoir, whereas 'simple' hydropower storage have an upper reservoir only.

Pump storage is a mature technology, which has been used for almost a century. Its key advantages are the high available power (between a few and more than 1,000 MW) and ability to store relatively large volumes of energy, i.e. typically for 6 – 10 hours of operation at full load. Pump storage plants also offer round-cycle efficiencies of between 70% and 85%, high ramp rates and short reaction times. Traditionally, pumps storage plants have thus played a major role as peaking plants and for the provision of ancillary services. On the downside, the potential for (pump) storage plants is constrained by geographical pre-conditions, i.e. their electric capacity and storage capacity critically depend on the difference on altitude between the two reservoirs and reservoir size. Moreover, pump storage plants usually require high investment cost, which again are highly location-specific.

Gravity storage is a new approach that has been developed and that awaits testing in a demonstration project.1 The idea is to carve round and massive cylinders into the rock beneath a plane surface and to connect it with an electrically-driven water pipe system. Electricity is used for hydraulic lifting of the cylinder using water pumps. The rock mass acquires potential energy. It can be re-converted into electric energy when the water under pressure beneath the uplifted cylinder block is discharged back and drives a turbine. The economic advantage is reported to lie in the fact that, with increasing cylinder radius, the storage capacity increases more than the cost.[2] The nominal amount of construction cost and

1 See Heindl Energy

2 Capacity increases with the fourth power of the radius (r4), the construction costs however only increase with the square of the radius (r²).

the economies of scale favour larger installations, similar in size of PSP or even larger. Efficiency is expected to be approximately 80%.

Mechanical and kinetic energy storages

Mechanical (or kinetic) energy corresponds to the work needed to set an object into motion. Two main storage technologies fall into this category:

- flywheels
- compressed air storages.

Accelerated to high speeds by electric motors in a vacuum, flywheels store mechanical energy in the form of rotational energy. When braking the flywheel, the electric energy is recovered. Modern flywheels can achieve high efficiencies of up to 97%. They belong to a smaller power class (<1 MW) and are particularly suitable for network frequency regulation. Today, flywheels are in an advanced pilot phase on the threshold of commercialization.

Compressed air accumulators use mechanical energy when compressing air in a hermetically sealed cavity by means of pumps. When released, the outflowing compressed air is converted back into electric energy by means of turbines and generators. If the resulting process heat is recovered (adiabatic compressed air storage), efficiencies of up to 70% can be achieved; in turn, diabatic compressed air storage without heat storage are less efficient (ca.50%). Similar to pumped storage systems, compressed air storage serve is dependent on favourable geographical conditions. Moreover, the use underground caverns for CAES competes with an alternative use as gas storage. There are only two commercially used diabatic compressed air reservoirs with underground caverns worldwide. First demonstration plants with adiabatic storage are under construction.

(Electro-) Chemical energy storage

Chemical storages release energy in chemical reactions when the product has a lower or higher energy content than the reactant.

In particular, chemical energy in galvanic elements (batteries) is converted into electric energy.

Chemical energy is also the basis of power-to-gas technology, where electric energy is used to synthetically produce gases and convert electric energy into chemical energy.

Batteries

Batteries consist of electrodes (typically different metals) and electrolytes (typically a chemical compound that dissociates into ions in the liquid state). Suitable for storage are reversible galvanic elements in accumulators (also referred to as secondary cells), in which the (re) conversion of electric energy into chemical energy is possible. There are basically two classes of batteries:

- conventional batteries and
- (newer) flow batteries.

Common to both is that electrolytes allow ions to move between the electrodes, thus producing an electric current to flow out of the battery to perform work. In conventional batteries, energy is stored as the electrode material. In flow batteries, the energy is stored as the electrolyte not as the electrode material.

Conventional batteries

In conventional batteries, usually the electrolyte is liquid. The electrodes are immersed in different electrolytes. These are separated from each other but connected by an ion carrier pipe that allows for flows of ions between the two parts and that provides for the chemical branch to close the electric circuit. Depending on the two electrode materials' tendency to absorb or release electrons, they enable a reduction and oxidation reaction at the electrode. New ions are built that either dissolve in the electrolyte or combine with the electrolyte material. The ion carrier pipe allows ions to flow and balance the electric charge and concentration of the electrolytes, so that an electric current can flow between the electrodes outside the electrolytes.

Flow batteries

In (redox) flow batteries[3], two chemical components, usually separated by a membrane, are dissolved in a liquid – the electrolyte. The liquid electrolytes outside the battery cell are stored in external tanks. The conversion into electric energy occurs at the electrode immersed in the electrolytes where the chemical reaction (reduction and oxidation) takes place.

Similar to a conventional battery, the reactants have distinct tendency to absorb or release electrons. In one part of the cell, ions are reduced, in the other they are oxidised. Electricity is produced when the redox reaction is carried out and the electric flow is used as energy source. Electricity is stored when the reverse reaction is triggered. The membrane allows for the selective flow of ions, produced during chemical reaction, between the two segments to balance the concentration of negatively and positively charged ions and close the electric circuit.

Flow batteries separate the tanks where electrolytes and reactants are stored from the cell where the membrane and the electrodes are located and where the reaction takes place. They offer the advantage that the energy-storing electrolyte fluid can be exchanged and transported. Hence the battery can be almost instantly recharged by replacing the electrolyte liquid. At the same time, the spent material can be recovered for re-energization.[4] Moreover, power and capacity are separately scalable: the amount of electrolytes and the concentration of reactants prior to the reaction defines the capacity. The size, structure and the material of the electrodes and the membrane as well as the permeability of the membrane define the storage's power.

However, they require pumps to inject the electrolytes and reactants into the cells for producing the reaction. This implies higher complexity, cost, spatial requirement and weight.

Flow batteries are a type of battery that is still heavily being developed, with limited commercial application, as they are also more complex and currently costly to maintain. Multiple types of flow batteries exist, but vanadium redox batteries are the most common type. However, many other types are still in the R&D phase such as organic, semi-solid and membrane less flow batteries.

3 For example vanadium-based, abbreviation VRFB

4 http://energystorage.org/energy-storage/storage-technology-comparisons/flow-batteries

Power-to-gas

Chemical energy is also the basis of power-to-gas technology: electric energy is used to produce synthetic gases as energy carrier. Power-to-gas is the generic name for several technologies like power-to-hydrogen and power-to-methane.

- With power-to-hydrogen, electricity is used in an electrolyser to split up water into hydrogen and oxygen. Although volatile and highly reactive, hydrogen is a gaseous source of energy that can be stored in special tanks. It can be (re-) converted into electricity in fuel cells.

  Hydrogen can be added to a limited extent to natural gas and then transported in the existing natural gas networks and stored in natural gas storage. Alternatively, there are concepts that provide for the development of a dedicated hydrogen infrastructure for stationary and mobile applications.

- A more novel power-to-gas concept provides for further conversion of hydrogen into methane (power-to-methane). Methane, the prime component of natural gas, is less volatile and explosive than hydrogen, and the existing gas infrastructure can be used during transport and storage.

Conceptually, both power-to-gas technologies are designed for large-scale, long-term storage. The gas can be temporarily "stored" in the natural gas transportation and distributed network used to supply gas consumers, in underground pore and cavern storage facilities used for natural gas storage (bound to geographic conditions) as well as artificial, large tanks.

A problem of the two power-to-gas technologies is the high energy losses during the conversion processes: The efficiency in injection and withdrawal (i.e. gasification and reconversion) is in the range of 36 % - 45% for power-to-hydrogen and 27-36% with power-to-methane.

In addition, it should be noted that the conversion of synthetic hydrogen or methane into electricity is possible, but not mandatory. Methane - as well as hydrogen - can also be used for other purposes, such as in the provision of space heating. Strictly speaking, power-to-gas is not a storage technology, but the conversion of one energy source (electric current) into another medium (gas).

Electrostatic and electromagnetic energy

Electrostatic and electromagnetic energy is stored in electrostatic or electromagnetic fields. The energy stored corresponds to the work spent on the production of the respective field. While electricity storage based on electrostatic and electromagnetic energy is physically similar, the two applications presented here are limited and, moreover, in an early pilot phase.

Classical capacitors are based on the principle of storing electric energy in an electric field generated between capacitor plates. They have an extremely long life but can only store small amounts of energy. Electrochemical double-layer capacitors combine the capacitor principle with the electrochemical storage function of batteries: the electric field arises between a porous and thus enormously large surface of the solid electrode and the liquid electrolyte, which are separated by a thin coating. Electrochemical double-layer capacitors (sometimes also called supercapacitors) are suitable for very short-term storage for the stabilization of the frequency position but are not available are commercial scale yet.

Another possibility for use in the power supply system is the storage of electromagnetic energy in a magnetic field generated in a superconducting coil, which must be cooled to an extremely low temperature. The energy stored can be converted back into electric energy without delay. Similar to supercapacitors, coils could one day be used in frequency keeping.

Thermal and thermo-electric energy

Thermal energy is stored in the disordered motion of the atoms or molecules of a substance and represents a state variable. Heat energy is transferred from one material medium to another if there are temperature differences between the two media, i.e. they are not thermally isolated. In the form of useful heat, thermal energy serves to meet a final energy demand of household and industrial customers.

Thermal energy storage is an umbrella term that refers to several different technologies that utilize heat for storage instead of electricity. These systems use a variety of different media for storing the heat and come in many different sizes. This ranges from heat buffers for households, to large industrial installations or buffers for districts and cities. For storing thermal energy, three main approaches are available:

- Sensible heat storage
- Latent heat Speicher,
- Thermo-chemical heat storage

Sensible heat storage systems use the heat storage capacity of their storage medium, which changes its temperature when adding energy to the medium or releasing energy from it. The storage medium can be solid or liquid; examples are water or concrete. Sensible storage is the most common form of thermal storage, due to it being cheap and easy to install. Apart from water and concrete, but ice is becoming more prevalent for cooling applications. As sensible heat storage typically operates at low temperatures, it is inefficient to convert (back) into electricity. As a result, applications in EV are limited.

Latent heat storages are not based on the change in temperature but use the energy to transform the storage medium's state of aggregation, typically from solid to liquid state (and vice versa). This keeps the temperature constant and allows for much higher energy densities. However, this type of storage is much more expensive than sensible storage.

Some storages combine sensible and latent heat storage, i.e. they are able to store additional energy beyond its latent heat storage capacity in the form of a temperature increase.

Thermochemical heat stores fall into two categories:

- Sorption storages (silicates or Zeolites) store the heat with the help of endo- and exothermic reactions. The most popular representatives of this class are storages in which the storage medium, e.g. Lithium bromide, absorbs water molecules and releases energy. In turn, energy is consumed for drying the medium.
- Chemical heat storages require energy for splitting up a chemically stable substance into several / two molecular components, in which the energy is stored. The energy is released when the components can form again the combined (initial) substance.

Thermal energy carriers can be used to store (temporarily) electric energy. Various applications are already available, others are currently being researched: electrothermal energy storage is a process based on the conversion of electric energy into thermal energy with subsequent re-conversion into electric energy. The heat medium used is water, which is stored in insulated tanks (sensible heat storage). It can then be stored for hours, possibly even a few days in a tank. To recover the electric energy, a heat engine is used to convert the thermal energy into mechanical energy and then - with the help of a generator – convert it into electric energy. Storing thermal energy increases losses and overall storage efficiency drops. Hence, electro-thermal energy storage are feasible as large storage facilities only, requiring a certain size to achieve an acceptable efficiency level (maximum 55%-65%).

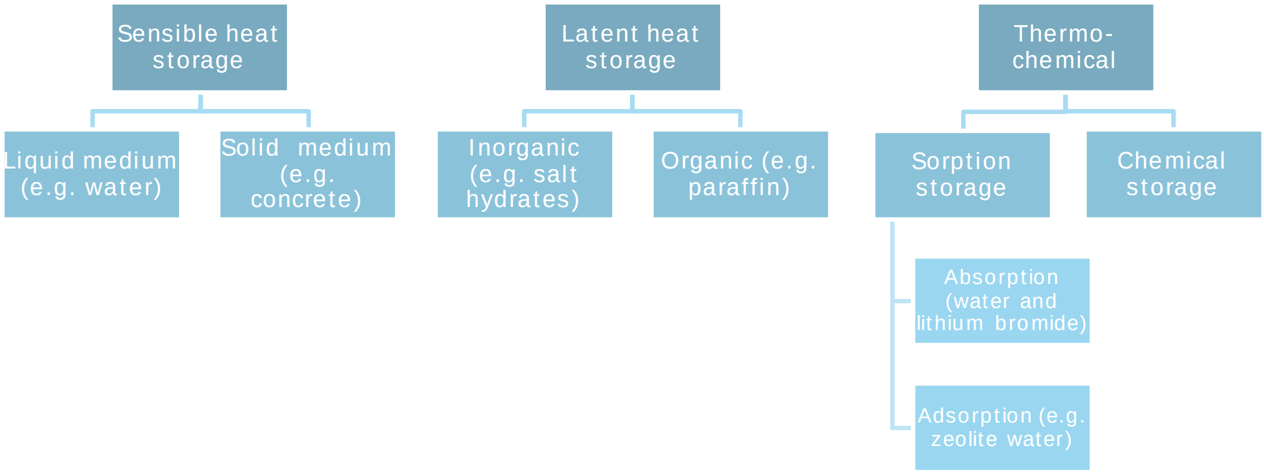

Figure 2: Types of heat storages

Source: DNV GL analysis

2.2 Characteristics and Comparison of Electricity Storages

In the section, we will put emphasis on the main storage technologies that allow converting electric energy into another form and re-producing electric energy when so needed. These technologies will be referred to as electricity storages. The focus will be on battery storages, whereas we will ignore thermal storages.

2.2.1 Technical Parameters of Storages

Storage technologies are characterised by and may be compared using various technical parameters, in particular the following ones:

- Energy storage capacity (measured in kWh): The maximum amount of energy that can be stored by the storage.
- The (maximum) discharge capacity or shortened storage capacity (in kW) determines the capacity of the storage unit during discharge (analogous to the (loading) charge capacity defined). It should be noted here that, in particular, the discharge capacity, e.g. depending on the state of charge, age or memory cycles (s.u.).
- Efficiency (expressed as a percentage) indicates the ratio of energy to be stored and thus records the memory losses. These arise when converting from electric to non-electric energy and vice versa. In addition, some storage technologies exhibit self-discharge (especially batteries) during extended storage periods, which must be taken into account during use. The efficiency is then to be defined in terms of a typical storage duration.

- The energy density (measured in kWh/t, kWh/m^3, Wh/l) indicates the storable amount of energy per mass or volume unit of a storage. Analogously, the power density (measured in kW/kg or kW/m3) is defined, which indicates the (maximum) power per mass or volume unit. Both quantities play a role in terms of the space requirements of energy storage; but also important is their relative ratio, as there are more powerful and more energy-intensive storage applications.
- The response time and the regulation speed indicate how fast the energy storage device can start unloading when needed or when the maximum performance is reached.
- It should be distinguished from the duration of use and / or the charging and discharging time, which results directly from the combination of energy storage capacity and charging / discharging power, and determines the period of time over which the corresponding power can be provided. In addition, in the application, the storage duration is relevant, i.e. the time between loading and unloading the storage. It is, of course, determined by the specific needs

2.2.2 Comparison of Battery Technologies

Battery technologies differ in various aspects. The combination of these characteristics as well as the progress achieved to improve qualifies them for different applications. The key parameters are:

- Power, capacity and energy density
- Efficiency
- Optimal (dis)charge level
- Storage cycles / lifetime

Batteries are completely modular and can be designed with either a focus on power or energy. As such, battery systems are typically developed and applied by making use of the trade-off between specific power (W/kg) and specific energy (Wh/kg).[5] As is often the case, it is impossible to have it all. When increasing the specific energy, the specific power will decrease – and the other way around. This trade-off is made visible using Ragone plots, as can be found in Figure 3 below. Research and progress (try to) move these available curves up until limitations are encountered.

For example, lithium-ion and nickel-cadmium batteries have e.g. over a very high power density, the latter only over a low energy density. Conversely, sodium sulfur and zebra batteries offer high energy but only limited power density. Similarly, significant differences in terms of efficiency and the number of possible storage cycles can be seen.

The desired application of the storage determines the required capacity and power, and, thus, the weight and spatial requirement, being also important criteria especially for vehicles.

5 The ratio between power and energy is classified as the C-rating. A C-rating of 1C indicates that a battery discharging at full power will be depleted in 1 hour. Similarly, a 2C rated battery will be depleted in 0.5 hours, and a 0.5C battery in 2 hours.

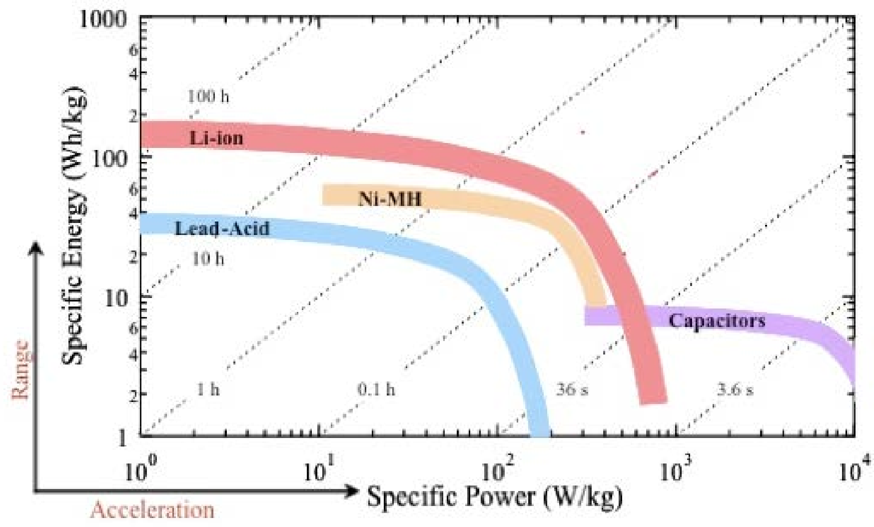

Figure 3: Ragone plot illustrating the trade-off between specific power and specific energy

Source: Energy Storage Sense, "Compressed Air Energy Storage (CAES)". [6]

The lifetime of batteries is measured in cycles, i.e. by the number of infeed and outfeed operations until the end of functionality. From the expected annual number of storage cycles, the expected lifetime in years can be derived. The number of cycles is important not only for the assessment of the cost of capital, which are amortized over the lifetime, but also in terms of the expense associated with the exchange.

Batteries are also different in terms of maximum depth of discharge: many batteries should not be fully discharged to conserve materials. The degree of discharge thus determines the usable range of the storage capacity.

A major advantage of batteries over other power storage systems is that batteries are more scalable, i.e. by interconnecting individual battery cells, a correspondingly higher storage capacity or capacity can be achieved. As a result of the differences among battery types, their dissemination varies. Some batteries are already partly used today as stationary power storage, e.g. lead-acid batteries, whereas some others are still in the development phase.

- Lead-acid batteries, built from lead electrodes and acid electrolyte, are already being used in the stationary sector, for example to provide minute reserves. The batteries with have a comparatively long service life - the number of cycles, however, ranges only in the range of 1000 to 3000. Disadvantages are also the low energy and power densities of the material. Improvements are currently being researched.
- Widely used in consumer electronics, lithium-ion batteries have a high energy density. Chemically, the electrodes are based on lithium cobaltates, lithium magnates, lithium-Iron phosphates and lithium polymers. With a low discharge rate (20-40%) they achieve a particularly high durability (more than 20,000 cycles), but even with 80% recovery, the number of cycles is still at 4,000 to 10,000 cycles. Another advantage is the high efficiency of up to 95%.

6 Available: http://energystoragesense.com/compressed-air-energy-storage/. [Accessed 8 January 2018].

- Nickel-metal hydride and nickel-cadmium batteries are very robust (for example, they can be used at very low temperatures) and have a high energy density but have a comparatively poor efficiency of less than 90%. In addition, they are significantly more expensive than lead-based batteries, not least because of the low durability (600 to 1200 memory cycles). The use of nickel-cadmium batteries in the EU has also been severely limited due to the toxicity of the material.
- The zebra battery is based on liquid sodium and nickel as electrodes and sodium chloride as electrolyte. It has a high energy and low power density. Their stationary use is so far in medium size. At present, particularly long-lived variants are being researched, since the number of cycles has so far remained limited with 2000. One advantage of the Zebra battery is its high efficiency.
- Sodium-sulphur batteries can store larger amounts of electricity and are therefore also used in medium sizes. The electrolyte is not liquid but solid and cold. When used, the mass is heated to 270-350 ° C and liquefied. The operating temperature can be maintained in continuous operation by the resulting heat produced in the reaction. The long life of 10,000 to 15,000 cycles is a major advantage of the technology, as is the high energy density.

Table 2 below summarises the key technical capabilities and constraints of battery technologies.

Table 1: Comparison of different battery technologies

Battery Type	Energya (W h/kg)[a]	Energya (W h/kg)[a]	Specific Power[b] (W/kg)	Energy Efficiency (%)	Life Cycle (no. of cycles)	Operating Temperature (°C)	Cost (US $/kWh)
Lead-acid	30–50	60–100	200–400	70–90	2000–4500	-20–60	120–150
Ni-Fe	30–55	60–110	25–110	75	1200–4000	-10–45	150–200
Ni-Zn	60–65	120–130	150–300	76	100–300	-10–50	100–200
Ni-Cd	40–50	80–100	150–350	60–90	2000–3000	-40–60	300–350
Ni-MH	50–70	100–140	150–300	50–80	500–3000	-40–50	150–200
Ni-H2	60–70	100–120	150–350	80–90	6000–40000	-20–60	300–400
Zn-Cl2	65	90	60	-	200	-	–
Zn-Br2	65–75	60–70	90–110	-	300	-	150
Fe-Air	60–75	100	60	300–600	-	-20–45	–
Al-Air	190	190	16	50–80	-[c]	–	-
Zn-Air	230	269	105	60	-[c]	90–120	-
Na-S	100	150	120	80	2500–4500	300–350	250–500
Na-NiCl2	86	149	150	80	2500–3000	250–350	160–300
LiAl-FeS	130	220	240	80	&	1000	375–500
LiAl-FeS2	180	350	400	-	1000	375–500	–
Li-Polymer	155	200	315	70	1200	-20–60	125
Li-Ion	120–140	240–280	200–300	70–85	1500–4500	-20–60	150–1300

a: At 80% depth-of-discharge; b: at 3-h discharge rate; c: Mechanical recharge. M- Merits. D- Demerits.

Source: found in "Review of energy storage systems for electric vehicle applications: Issues and challenges"; M.A. Hannan et al., 2017

The modular and scalable structure of batteries (allowing even for posterior adjustments) and the flexibility of operational limits (e.g. power and capacity as a function of the energy density) makes battery systems very flexible: they can be adapted to fit nearly every application. Yet, this makes it difficult to compare different battery systems. This is especially the case from an economic perspective, as the cost cannot be separated from the application.

2.2.3 Batteries versus Other Technologies

Size of storages

Altogether, electricity storages cover a wide spectrum in terms of size, i.e. storage power and storage capacity. Yet, not all technologies cover the entire spectrum, but are available in certain sizes (ranges) only, due to spatial requirements, dependence on the presence of favourable geological conditions, technological progress and maturity, and other reasons

The applications for which energy storage can be used differ significantly. As a result, the requirements for storage solutions differ in return. Some applications require a high amount of power (e.g. providing black start support), whereas others require high energy content (e.g. capturing a surplus of wind energy production). Some technologies have a higher specific power or specific energy as a result of their design, whereas others are modular and could be used both ways. Most technologies have an energy to power ratio that is mainly dependent on design.

Figure 4 depicts in which sizes the different electricity storages are available.

- For large-scale storage systems, on the other hand, only compressed air and pumped storage tanks are available as alternative to large scale batteries. A few pumped storage tanks are also suitable for weekly storage; they must then have sufficiently large upper and lower reservoirs.
- For seasonal storage, on the other hand, only the two power-to-gas technologies are eligible (hydrogen and methane-based), which are still in the pilot phase of their development.
- Nowadays, batteries can be built as stand-alone installations or as a combination of different units to cover a wide part of the size spectrum. Batteries differ from storage hydro power plants and compressed air storages in the flexible size and the modular architecture of batteries and the (variable) trade-off between power and capacity that batteries offer. Both are usually not supported by storage hydro power plants and compressed air storages.
- In the small size segment requiring almost instantaneous response and small capacity, supercapacitors and coils are the only available technologies.

For e-mobility, relatively small power in the range of 3-500 kW and a capacity that allows for multi-hour trips are required.

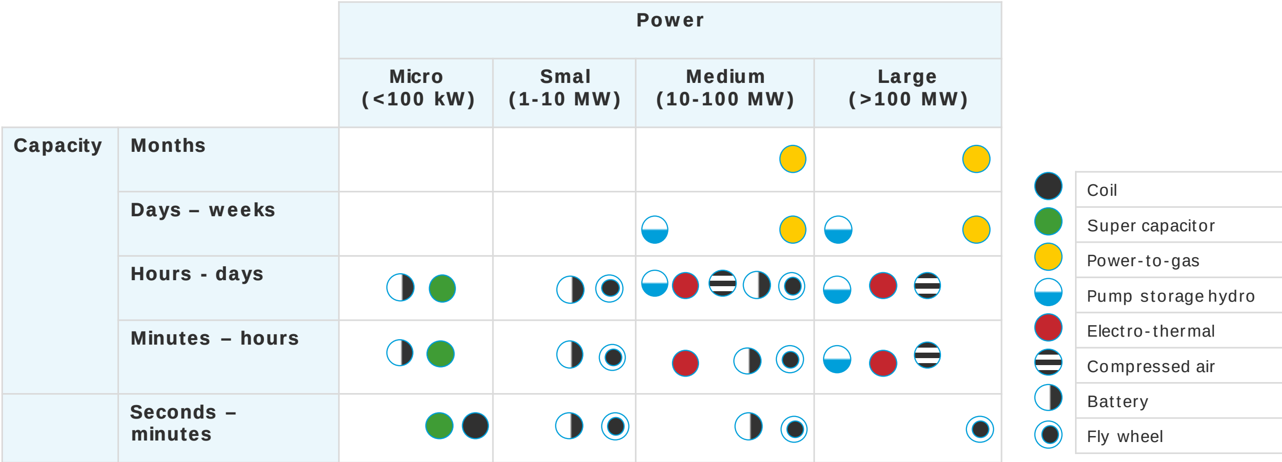

Figure 4: Energy to power ratios for common storage technologies

Source: DNV GL analysis

Efficiency

While most storage technologies are relatively efficient, there are still differences. Overall, efficiency ranges between 50% and 98%. Supercapacitors are most efficient, together with modern lithium-ion batteries and flywheels. This is one of the reasons these three technologies are mentioned most often in combination with powering electric vehicles, as high efficiency is necessary for good fuel economy.

Large systems that depend on mechanical or kinetic energy, such as pumped hydro and compressed air, are the least efficient technologies.

Thermal storages have a medium efficiency. Sensible storage has a wide range of potential efficiencies, as it is very dependent on the material used and the temperature the heat is stored at. Molten salt is more efficient as a result of its more constant temperature, especially when not converting energy back into electricity.

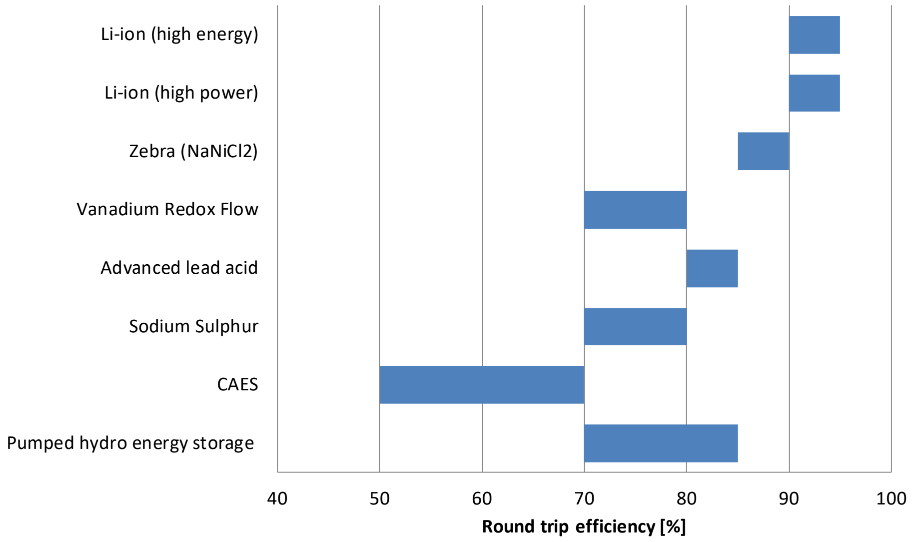

Figure 5: Round trip efficiency of different storage technologies

Source: DNV GL analysis

Lifetime

The lifetime of storage technologies plays a role both with regard to the intended use in the power system and for the costs: If replacement investments are technically difficult to implement, for example because uninterrupted operation must be ensured, more durable storage technologies are advantageous. The lifespan, especially for batteries, depends crucially on the frequency of use. For comparison, Figure 6 illustrates the lifetime of different technologies.[7]

In battery technologies,

- sodium sulphate and vanadium redox flow batteries, which are over 30 years old, have the longest lifetime expectation (which corresponds to more than 10,000 cycles).
- The second most durable technology is sodium nickel chloride (zebra) battery (eleven years), followed by lithium-ion batteries, which are more durable when designed for performance.
- Lead-acid batteries tend to have a shorter lifetime, explaining the ongoing research on prolonging its usual lifetime.

Compressed air and pumped storage units, on the other hand, have a significantly longer life time than batteries. They are only limited by the lifespan of the pumps and generators: The structural components, i.e. the prepared caverns and upper and lower tanks, are basically permanently operational with appropriate maintenance.

[7] Assuming one charge cycle per day (with optimum discharge).

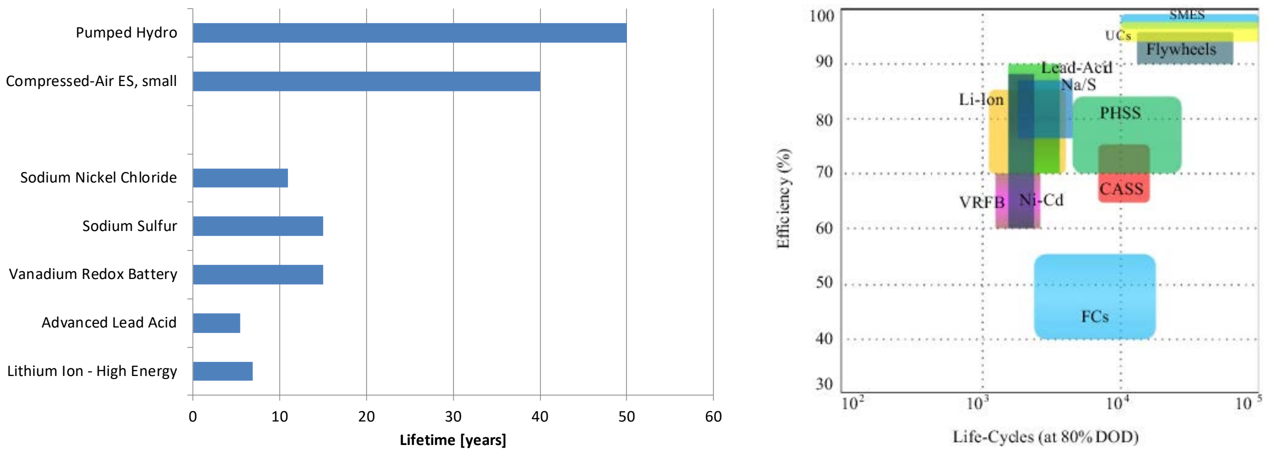

Figure 6: Approximate lifetime of electricity storages (left), combined and life cycle and efficiency comparison of different technologies (right)

Source: DNV GL analysis (left); right part: found in "Review of energy storage systems for electric vehicle applications: Issues and challenges"; M.A. Hannan et al., 2017

Cost

The main parameters that determine the total cost of storages comprise of

- the cost of capital of storage facilities (i.e. the cost of materials, installation, and storage operating system), being the main cost factor for most technologies.
- the (technical) life of the storage facility, determining the depreciation of the cost of capital. Especially in chemical storage, it depends on the intensity of use of the memory, i.e. the number of injections and withdrawals is more important than the period of use
- system cost of storage, including all installation and operation costs, in particular grid and land costs, and the costs of the licensing procedures, in excess of the capital costs of the storage facilities.
- operational costs, which are determined by the efficiency of the storage, determining not only the technical but also, as a consequence, the economic losses of the storage process, based on the monetary value of the stored electricity.

In addition, it is important to note that the cost may be referred to various reference parameters. On the one hand, adding up the cost of capital, operating and system costs over life with meaningful discounting gives the total cost of ownership ("total cost of ownership"). This is of particular interest for comparing different storage technologies.

Depending on the application of the storage, the total cost of ownership can be set in relation to its power and capacity. In addition, the ratio total cost of ownership to lifecycle energy (i.e., injected and withdrawn) is also be a relevant performance indicator and basis for comparing the total lifetime cost of different storages.

Figure 7 shows the typical ranges of the cost of capital per kW, with and without network installation costs, for various storage technologies.[8] According to the graph, the specific capital costs of compressed air and pumped storage systems are in the lower range of the specific costs for battery technologies.

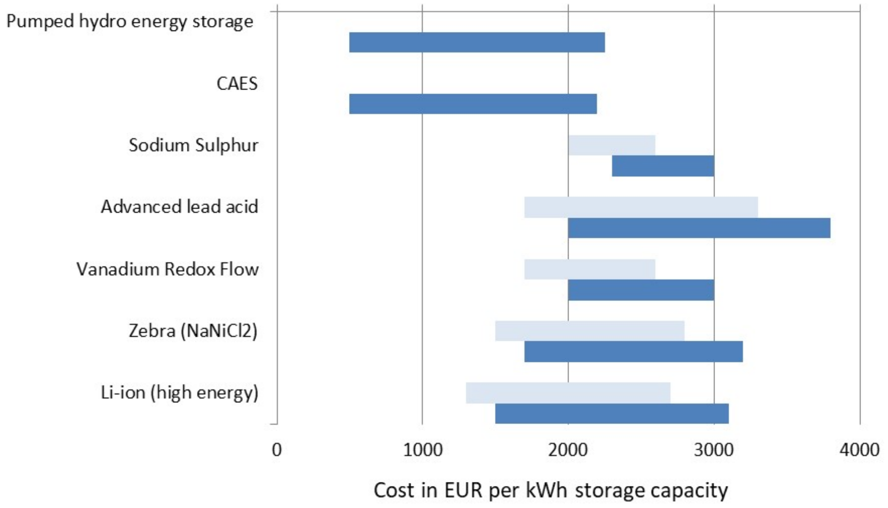

Figure 7: Typical cost of capital ranges for electric storage

Source: DNV GL analysis

Yet, costs are typically given in EUR/kWh referring the TCO to the installed storage capacity, as this is the most tangible and because of the higher abundance of applications that require energy over power. Unfortunately, this makes it more difficult to compare cost across the board. Figure 8 depicts the specific TCO cost in €/kWh storage capacity. It shows a somewhat reverse correlation with energy efficiency: large, low efficiency technologies such as compressed air and pumped hydro are the cheapest, whereas other technologies are significantly more expensive. This is especially the case for flywheels and supercapacitors, as these tend to suffer from low energy density. Supercapacitors in particular could however see a significant drop in price over time, as more energy-dense materials could increase the capacity tenfold or more without increasing costs.

8 To normalize the comparison, a discharge time of 4 hours was assumed. Since capital costs without installation are not meaningful for compressed air and pumped storage, they have been omitted in the corresponding figure.

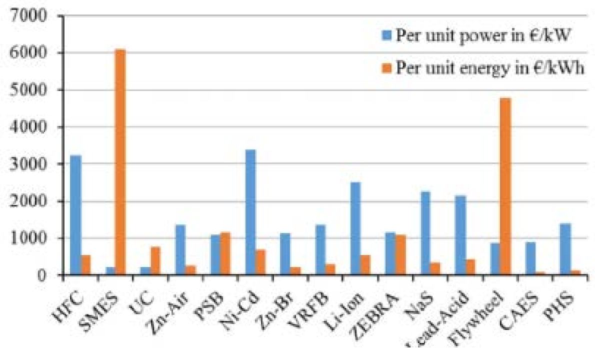

Figure 8: Total capital cost of large-scale storage

Source: found in “Review of energy storage systems for electric vehicle applications: Issues and challenges”; M.A. Hannan et al., 2017

However, the comparison of the cost of capital per kW or kWh of storage capacity alone is inadequate with regard to the assessment of the use of the technologies in the electricity system. Comparing technologies by their specific total cost of ownership, i.e. total life time cost relative to the assumed number of cycles is more appropriate, but at the same time for difficult to determine as it requires more assumptions (like deprecation and life time, efficiency). Due to the importance of technical parameters and the application of the storage on the total cost of ownership, it becomes evident that the assumed storage application has a large influence on the TCO, even when using the same technology for distinct applications.

Maturity and dissemination of storages

A visual representation of the maturity of different storage technologies can be found in Figure 9. Three phases of maturity are typically recognised:

- Research and development
- Demonstration and deployment
- Commercialization

Among the technologies discussed, only pumped hydro and certain forms of thermal storage are classified being in the commercialization stage. Many of the other technologies are still in the R&D phase. In turn, different battery technologies have moved into the deployment stage, like lithium-based batteries. Additionally, flow batteries are in the demonstration phase or at the edge of being deployed broadly.

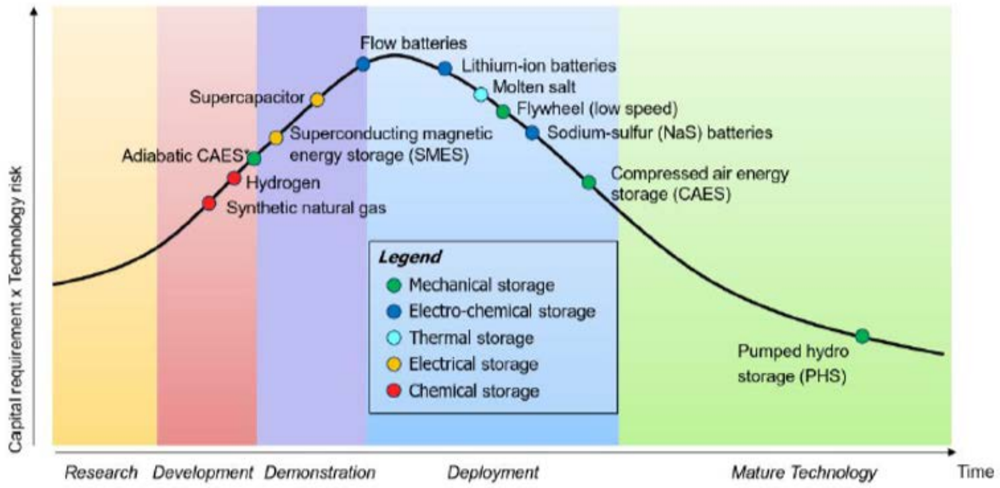

Figure 9: Storage technology maturity

Source: AECOM Australia Pty Ltd, "Energy Storage Study: A Storage Market Review and Recommendations for Funding and Knowledge Sharing Opportunities," July 13, 2015. [9]

As Figure 10 shows, pumped storage power plants are widely used in Europe, whereas other technologies have a marginal dissemination only. Among the novel technologies, lithium-ion battery projects have been mostly developed so far.

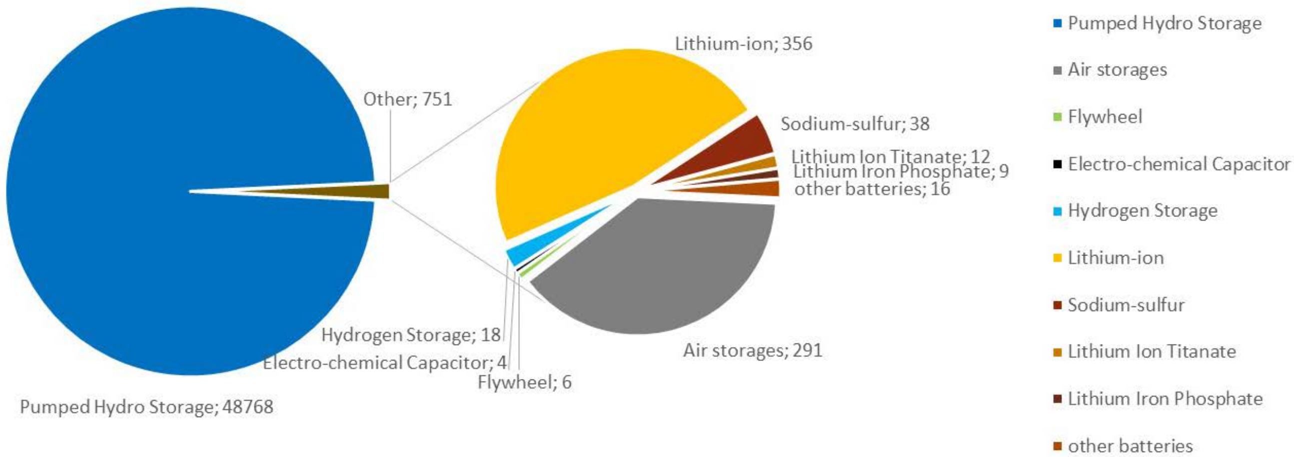

Figure 10: Operational storages by type and MW installed in Europe[10]

Source: DNV GL analysis, data www.energystorageexchange.org

It should be noted that Figure 10 covers mainly stand-alone installations (with different sizes).

Apart from that, there is a fast-growing small-scale battery sector. In the small consumer sector, batteries are used to increase the level of self-supply from distributed generation produced in the local

9 Available: http://arena.gov.au/files/2015/07/AECOM-Energy-Storage-Study.pdf.

10 Large flywheels used at research institutes have been neglected.

proximity. As an example, in Germany it is estimated there was 600 MWh with 280 MW solar PV storage installed by the end of 2017. About 2/3 of the total stock has been built without funds from the public investment support programme, which started in 2013. 90% of storages are installed at the time the solar PV installation is commissioned, only 10% are added retrospectively. While at the start of the solar PV storage boom, 2/3 of all storages used lead-acid modules, almost all new storages installed nowadays use li-ion technology.[11]

2.2.4 Storages for Electric Vehicles

Electric vehicles pose specific challenges to batteries. What probably most counts is storage capacity (range), (discharge) power, weight (being the result of components energy density), space required / available, safety, cost, operational range between the optimal charge and discharge level, and aging of the battery.

For instance, vehicles usually offer only limited space for accommodating the battery. Moreover, as the batteries tend to be quite heavy, they make up a considerable portion of the car's mass, requiring more energy the higher the car's weight is. Contrary to that, spatial and weight concerns are largely negligible in stationary battery projects.

As another example, the energy density and the trade-off between power and capacity also plays a role in electric vehicle batteries. On the one hand, there is the issue of range anxiety (mitigated using high specific energy), on the other hand there is the demand for a performance that is at least equal to that of a fossil powered vehicle. Different manufacturers have different approaches for this. For example, a 100 kWh Tesla Model S has a similar range as a 60 kWh Opel Ampera-e. Similarly, this will affect the expected capacity at which the different vehicles types will be charged.

Today

Since the early start of the automotive era, several battery technologies have been used and have replaced each other as soon as PEV appeared and attracted public interest. The most frequently used technologies have been

- Lead-acid batteries,
- Nickel metal hydride (NiMH) batteries,
- Zebra
- Lithium-ion (Li-ion) batteries

Their deployment and characteristics are as follows:

- Lead-acid battery technology is the oldest battery type. Used in the first electric vehicles in the 19th century, its purpose was limited to conventional engine starter batteries in the decades thereafter, powering then the first generation of modern PEV in recent decades.

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[11] See "Wissenschaftliches Mess- und Evaluierungsprogramm Solarstromspeicher 2.0, Jahresbericht 2018" (Scientific solar PV storage monitoring and evualtion progarmme 2.0, annual report 2018), see http://www.speichermonitoring.de/

Lead acid battery technology is a well-understood technology and provides for high availability and limited cost. It is still used widely for backup power due to their low cost, but it is unsuitable for modern vehicles due to low energy density and the fact that capacity varies based on the discharge speed (Peukert's law).

Lead acid batteries also become expensive as they have a shorter life than the vehicle itself, typically needing replacement every 3 years. Other disadvantages are its a poor specific energy (34 Wh/kg), limited efficiency (70–75%), the decrease of storage capacity with lower temperatures, and the requirement to run a heating coil thus reducing efficiency and range considerably.

- The second generation of PEV built around 2000-2010,[12] used mainly Nickel-metal hydride batteries (Ni-MH). Its virtues are
    - about double the energy density of lead-acid batteries (30–80 Wh/kg), and high power offering travelling ranges of 300 km (subject to using batteries with 70 Wh/kg specific energy)
    - its potential longevity, when used properly (>160,000 km),
    - smaller space required and lighter weight, leading to reduced energy cost
    - increased lifecycle (until 80 % Depth of Discharge DOD).
    - energy recovery from breaking
    - thermal properties (operating temperature starting from – 30 °C up until + 70 °C),
    - safety

  Equipped with an energy density close to that of lithium-ion batteries and competitive with lithium ion in some respect,13 NiMH batteries suffer from voltage depression.

  Other disadvantages entail poor efficiency in charging and discharging (60–70%, i.e. less than lead-acid) and limited capability to operate well with more extreme temperatures with high self-discharge (exacerbated in high temperature environments) and poor performance in cold weather.

- Na-NiCl2 batteries, also known as ZEBRA batteries, (Zeolite Battery Research Africa) offer a relatively high energy density (90 - 120 WH/kg), increased cycle life, and constructive robustness (allowing for utilization in harsh environments, their performances not being affected by low temperatures), comparably low price. Its majour disadvantage is increased internal operating temperatures (270 °C -350 °C), requiring the continuous of the car to avoid freezing the battery electrolyte.[14] This is one of the reasons why the ZEBRA technology has been used in concept cars and buses in urban public transportation only, while a wider deployment stalled.

- Most PEV sold today use li-ion technology (3rd generation). Li-Ion cells offer high energy density and increased power per mass battery (800 - 2000 W/kg), and specific energy (100 - 250 Wh/kg), allowing for reduced weight and dimensions at competitive prices, Li- ion batteries also lack the memory effect, resulting in increased life cycle, and are good at retaining energy (with a

12 General Motors EV1 and the original Toyota RAV4 EV

13 Currently it's most notable for being used in the Toyota Prius hybrid.

14 In case the car is not used, maintaining the system at the operating temperature can be possible through an external heating system, which consumes 90 Wh power from the battery. In contrast, 12 to 15 hours are needed in order to defrost the battery and to bring it back to its functional parameters.

self-discharge rate of 5% per month, i.e. an order of magnitude lower than NiMH batteries). The technology's downsides include limited autonomy, high operational temperature (affecting performance) and concerns regarding the overcharging and overheating of these batteries and risk of fires due to heat production.

It should be noted that there are several types of Li-ion batteries based on similar but certainly different chemistry.

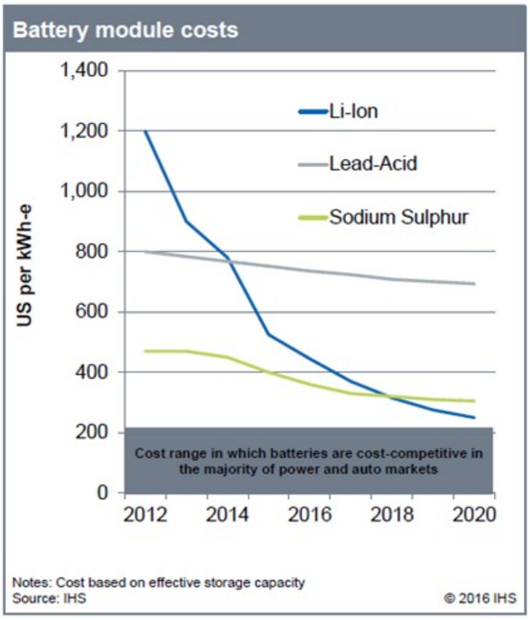
Other battery types have been tested or are subject to research, including primarily different batteries similar to conventional batteries but also flow batteries.

For instance, historically mainly used in household appliances, Nickel-cadmium batteries (NiCd) are also available in larger versions for e.g. UPS and emergency lighting. In electric vehicles, the technology has been used mainly by amateurs converting their own cars and for smaller vehicles such as golf carts and airport trollies. They are considered unsuitable for modern vehicles due to high self-discharge rates (~10% per month), toxicity of cadmium and the memory effect (a.k.a. lazy batteries)

In turn, alternative fuels and energy sources have been less developed so far. For instance, the use of supercapacitors in electric vehicles has long been seen as an application with high potential. Supercapacitors were even declared to be the future of EV instead of batteries before PEV sales numbers started to increase rapidly some years ago. Supercapacitors provide a number of advantages, such as a potential for significantly faster charging (predicted to be around 30 seconds for a car) and the lack of dependency on rare earth materials such as lithium and cobalt. However, the main downside for now has been a lack of energy density, limiting the range. As such, supercapacitor application in practice is limited to a number of busses in Shanghai, that charge every few stops, and for capturing regenerative breaking energy in the Mazda 6. Research into higher energy density capacitors has been promising, but whether this will translate to commercially available vehicles remains to be seen.

Outlook

At present, li-ion technology is the dominant battery technology in the EV sector and for other applications (see below on maturity and deployment of technologies). Prices for lithium-ion have dropped significantly, and are expected to keep doing so. Battery prices have already approached the 200 €/kWh level, and producers are aiming for the 100 €/kWh level soon. However, these cost reductions are mostly achieved for large battery systems up to 100 MWh, whereas car batteries with 100 kWh – relevant size for electric vehicles - are still in the range of 600 €/kWh. Yet, it is fair to assume the downward trend in li-Ion battery prices will also lead to EV price reductions. Thus, EVs are expected to reach cost parity with the internal combustion engine powered car by 2024, which could significantly increase the speed of adoption (BNEF, 2018).



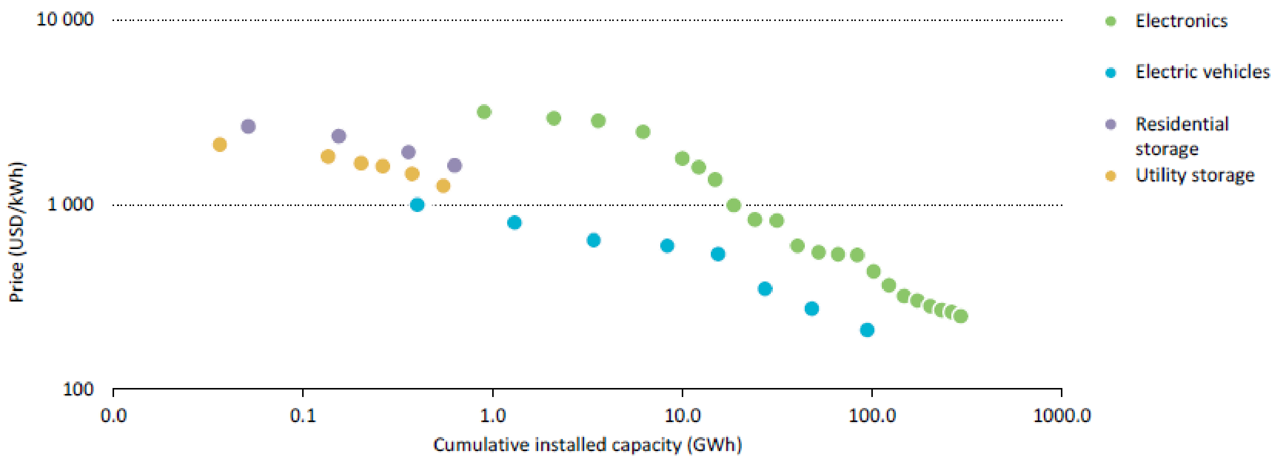


Figure 11: Historic and projected costs of batteries per kWh (top), and cost of lithium-ion as a function of capacity[15] (bottom)

Source: down: IEA, adapted and updated from Schmidt et al. (2017).

All PEV battery technologies correspond to a significant (25–50%) portion of the final vehicle mass. And, common to all batteries, their energy density is considerably lower than conventional fuels. So, while PEV save weight compared to conventionally fuelled cars due to the absence of mechanical components in PEV, they tend to lead to higher masses, overall, to allow for a minimum autonomy.

Hence, Research and development today looks for a better “charge to weight” ratio. Whether the li-ion technology will remain the first choice, is doubtful. It is expected that it will encounter an energy density limitation soon (see Figure 12 below).

15 Axes are on a logarithmic scale. Electronics refer to power electronic batteries (only cells); electric vehicles refer to battery packs for EVs; utility and residential storage refer to Li-ion battery packs plus power conversion system and includes costs for engineering, procurement and construction.

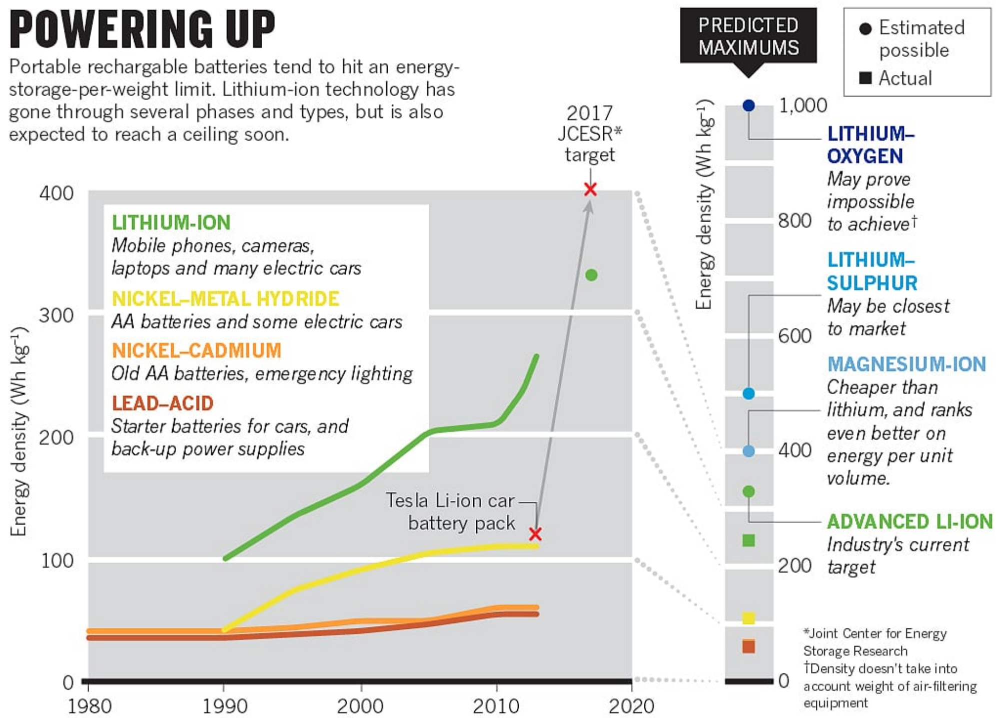


Figure 12: Development observed and expected for li-ion batteries and alternatives

Source: Van Noorden, R.: A better battery. In: Nature 507, S. 26-28, 2014, nach: Zu, C.X. & Li, H.: Thermodynamic analysis on energy densities of batteries. In: Energy Environ. Sci. 4, S. 2614-2624, 201

Hence, alternative technologies are being developed that do better at the same or similar cost as Li-ion. They will probably offer a high storage energy capacity, an extended lifespan and a better ratio of storage capacity to storage power. Among the technologies looked at are advanced batteries based on lithium-ion polymer, Lithium vanadium oxide, Li–air, MH–air, magnesium ion, solid state batteries and flow[16] batteries, inter alia. To this add, research and development of alternative concepts in the following areas:

- Alternative fuels and technologies, like fuel cell and hydrogen, etc.
- Hybrid system, combining batteries and other technologies, like ultracapacitors
- Alternative charging technologies, like induction

16 One famous research example is the nanoFlowcell, which is currently being developed as a redox flow battery for use in electric vehicles. Despite having a much lower voltage than other EV batteries (48V compared to ~350V for the Tesla Model S), nanoFlowcell claims to achieve similar power outputs. This is mainly the result of a claimed tenfold increase in the electrolyte energy density.

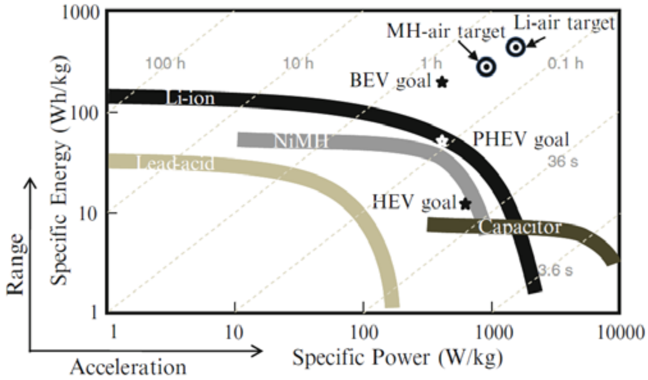


Figure 13: Regone plot of a few electrochemical energy storage devices used in propulsion applications

Source: R. Garcia-Valle and J.A. Pec¸as Lopes (eds.), Electric Vehicle Integration into Modern Power Networks, Power Electronics and Power Systems, DOI 10.1007/978-1-4614-0134-6_2, # Springer Science+Business Media New York 2013

2.3 Application, Role and Location of Storages in the Power System

The market set up, the regulatory background and the storage technology's features may allow for or provide incentives for several options for the implementation and operation of storage projects, like

- Services and applications to be provided and the market (segment) addressed
- Location
- Ownership and operation of the storage
- Source, level and structure of revenues streams to be generated

2.3.1 Use Cases

Generally, storages can be used for many applications in the power system. As illustrated by Figure 14, these can be divided into providing either ancillary services to network and system operators or services related to trading and participation in the commercial (wholesale) market. Moreover, potential applications may be structured by the size of the market role to which they serve, or its regional scope.

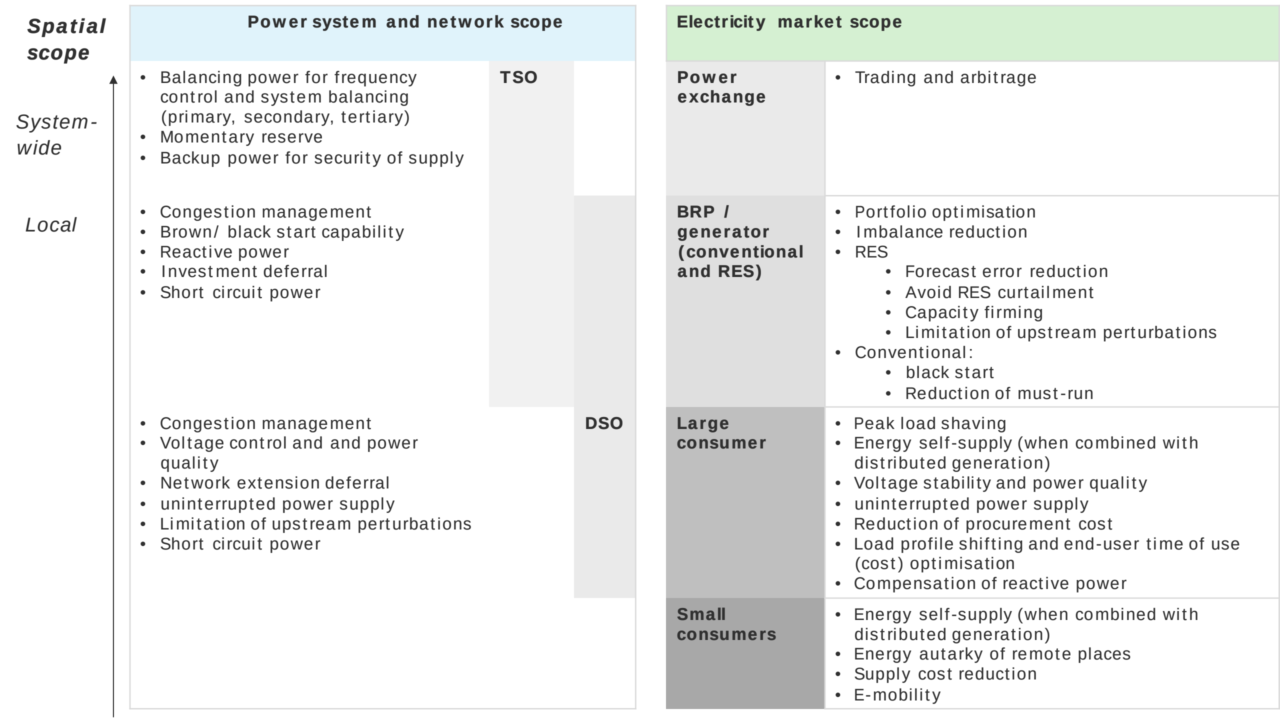


Figure 14: Range of electricity storage applications by market segment and storage user

Source: DNV GL analysis, based on EASE and BVES

Services to system and network operators may be required on a system level or with a more local focus. Frequency containment and system balancing services and products have a system wide effect and are at the discretion of the TSO. Apart from that, both TSO and DSO may seek services that become effective on a local level like reactive power, investment deferral, etc. It should also be noted that similar services may be asked for by operators of dedicated, privately operated electricity networks, e.g. at larger industrial areas, that are not part of the networks for public electricity supply.

Different to that, storages may serve the flexibility need of various market participants. Depending on the service, the locational proximity of the storage to the consumer or generation installation is essential for the storage being effective where required; for some other applications, local proximity is not required but the storage can operate independently.

We note that not all applications and services may be eligible in all countries. Depending on the regulatory background, the need for (storage) flexibility and the market setup, some applications may disqualify for regulatory constraints or missing economic scope.

Due to their technical characteristics, storage technologies are suitable for different applications but not all. This is dependent on a number of factors, such as energy density, power, response time and costs. Figure 15 assigns electricity storage technologies to applications and functions in the power system.

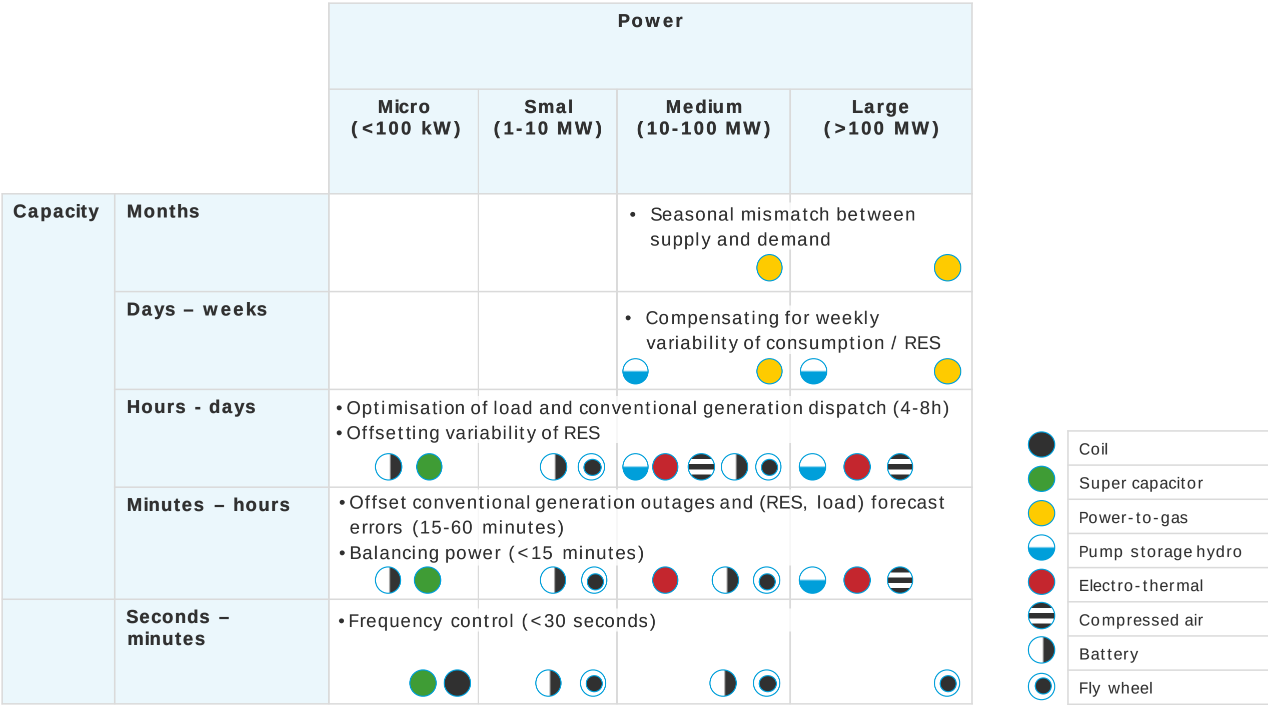


Figure 15: Potential classification of storage technologies by type, size and use case

Source: DNV GL analysis

Figure 15 suggests, from a technical point of view, the following applications by storage technology:

- Large-scale storage systems, incl. compressed air and pumped storages, can be used for load and production shifting as well as for the provision of control power. A few pumped storage storages are also suitable for weekly storage, provided they have sufficiently large reservoirs.
- For seasonal storage, power-to-gas technologies are eligible (hydrogen and methane-based), but need to further develop and pass the pilot phase. This also has cost reasons: In the case of seasonal storage, the number of storage cycles is very low, so that the investment costs must be recovered from comparatively few storage operations, which is a significant problem with capital-intensive (storage) technologies.
- Electromagnetic and static energy storage, i.e. coils and supercapacitors, are promising technologies for frequency maintenance because of their fast response time, low energy losses, and durability. Yet, they have to see significant drop in cost before they can be used.

  In contrast, flywheels are occasionally used in frequency control today; They also have very high efficiency and short reaction time. However, flywheels, as well as coils or capacitors, are no candidates for long-time energy storage because of the small storage capacity.
- Battery technologies have a relatively wide range of application functions due to their modular structure: They cover not only the spectrum of primary and secondary control power as well as load and production shift, they are also probably the sole technology that meets the need of small and medium size market participants.

  While this makes battery systems very flexible – they can be adapted to fit nearly every application – it makes it difficult to compare different battery systems. This is especially the case from an economic perspective, as the cost can't be separated from the application.

While these advantages are generally ascribed to batteries, they differ in their technical capabilities and eligibility by application, as the following table illustrates.

Storage Segment	Storage Type	Storage Duration[1]	Lead-acid	Ni-Cd	Li-ion	NaS	$NaNiCl_2$	Flow
Fast-acting storage	Power quality	<1 min	🟢	☹	🟢	🟠	🟠	🟢
	Power system stability	1 – 15 min	🟢	🟢	🟢	🟢	🟢	🟢
Power storage		15 – 60 min	🟢	🟢	🟢	🟢	🟢	🟢
Energy storage	Daily	6 h	🟢	🟠	🟢	🟢	🟢	🟢
	Weekly	30 – 40 h	🟠	☹	☹	🟢	🟢	🟢
	Monthly	168-720 h	☹	☹	☹	🟠	🟠	🟠

I: This refers to the length of the service provision.

🟢	Very suitable
🟠	Less suitable
☹	Unsuitable

I: This refers to the length of the service provision.

Figure 16: Comparison among different electrochemical storage systems for the different discharge times corresponding to the different energy storage applications

Source: EASE/EERA: "European Energy Storage Technology Development Roadmap", 2017 UPDATE

As an example, Table 2 below shows a more detailed assessment of whether electricity storages qualify for different applications in Germany. It covers both the technical and the economic viability for storages providing a wide range of potential applications. As legal and regulatory provisions as well as economic incentives vary from one country to another, some applications may be eligible and pay off in some countries only.

Table 2: Storage application evaluation matrix in Germany

Applications								
Area	**Application**	**Batteries***	**Pump hydro storage**	**CAES / LAES**	**Flywheel**	**SMES**	**Capacitors**	**Power to gas****
System, network or BRP*** services	Avoid RES curtailment	+	+	+	-	-	-	+
	Must-run reduction of conventional generation	+	+	+	+	-	+	-
	Ramping	**0/** (Redox flow) **/** + (other)	+	**0**	+	**0**	+	+
	Momentary reserve	+	+	+	+	**0**	+	**0**
	Primary control	**0/** (Redox flow) **/** + (other)	+	**0**	-	**0**	**0**	+
	Secondary / tertiary control	+	+	+	-	-	-	+
	Firm power / backup power	+	+	+	-	-	-	-
	Short circuit power	+	+	+	+	-	+	-
	Congestion management / re-dispatch	+	+	+	**0**	-	-	**0**
	Black start / Restoration services	+	+	+	**0**	-	-	-
	Reactive power	+	+	+	+	+	+	**0**
	Voltage control	+	+	+	+	+	+	**0**
	peak shaving	+ (Redox flow) **/** **0** (other)	+	+	+	+	-	-
Industrial processes	Residual heat use in industrial processes	**0 (**Natrium-sulfur / Natrium Nickel) **/** - (other)	-	+	-	-	-	-
	Mechanical energy recovery / transformation	+	-	-	+	-	+	-
	Alternative fuel	-	-	-	-	-	-	+
Buildings and small consumers	Decoupling of power, heat and cold generation in micro-CHP	**0**	-	-	-	-	-	-
	Day/ night compensation	+	-	-	-	-	-	-
	Seasonal compensation	+ (Redox flow) **/** **0** (other)	-	-	-	-	-	-
	Energy autarky	+	-	-	-	-	-	-
Mobility	Mechanical energy recovery / transformation	+	-	-	+	-	+	-
	Alternative fuel	+	-	-	-	-	-	+

*"**+**" means typical or favourable; "**0**" means possible application; "**-**" means technically or economically infeasible; * in particular Li-ion, Natrium-sulfur / Natrium Nickel, Lead-acid, and Redox-flow; ** incl. hydrogen, methane, fuels; ***BRP – balance responsible party*

Source: based on BVES

2.3.2 Location

To meet the operational requirements of storage applications, storages need to provide a certain power or capacity, or both at the same time. Hence, it is evident that the application the storage will be used for determines the storage size and, thus, the network level it will be connected to. Indirectly it also determines whether the storage is a stand-alone asset or will be / may be connected to another infrastructure asset, like network assets, a generator (e.g. RES) or a consumption facility.

- Similar to generators and electricity consumers, larger storages will be connected to the high or medium voltage network or and small storages will be hosted on the low voltage network.
- Moreover, some storage technologies, except for CAES or (pumped) hydro power storages, may be constructed rather independent from geological / natural pre-conditions and may be operated as stand-alone storages or be attached to another electricity asset.
- Large-scale storages, like CAES and hydro storages, are constrained to specific locations and, due to geological constraints, are limited in their power and the capacity. However, due to their high investment cost, only large installations pay off. Hence, projects tend to have a considerable size and are implemented as stand-alone installations.
- Some storage applications, like those combined with generation, small or large electricity consumers and DNO assets, require the storage to be located nearby to be effective where the storage user is.

  What is more, technical, regulatory or other reasons may impede the storage to be placed further away. In fact, where technical reasons prevail, the local proximity of the storage asset and the storage user is a must, like in the case of storages ensuring uninterrupted power supply of a specific (industrial) consumer. Where storages are used for economic reasons, regulatory and economic incentives are decisive on whether storages are built next to the storage users and these have physical access to the storage, or whether the users have access to a "virtual" storage that is located elsewhere or may be even combined from different smaller, distributed storages.
- Virtual power plants (VPP) offer a compromise or an alternative: integrated into an VPP, the storage may be operated such that it combines functions for individual parties with a specific locational scope, on the one hand, with wider system and market applications, on the other hand.

The following table provides some examples on whether they are operated in an integrated mode with another asset (i.e. attached to DNO assets, a generator or a consumer facility), differentiating storage projects by their scale.

Table 3: Typical relation between storage size and operating modes

Typical size	Operating modes		Examples
	Stand-alone	Integrated	
Very large (>50 MW)	✓		CAES, pump hydro storage
Large (1-100 MW)	✓	✓	Batteries (e.g. Li-ion)
Medium: 0.1 – various MW		✓	• DNO operated storage • industrial consumers + battery • utility-scale DG + battery
Small: Various kW		✓	• Households: small DG + battery • E-mobility • Community storage

DG - Distributed generation

2.3.3 Operating Models

Storage operation models may be classified as regards the parties that are involved in the ownership, operation and use of the storage, as illustrated in Table 4 below. For simplicity, ownership and operation are combined. In general, storages may be owned/operated by the TSO / DNO or a market participant. Moreover, the storage may serve the needs of various parties, considered the storage users, such as the TSO /DNO, the operator / owner itself or another market participant (except for the combination a TSO/DNO operated storage providing storage services to specific / selected system users).

Table 4: Overview of storage operating models

Model	Owner / operator	User	*Example*
1	**TSO / DNO**		*DNO owned and operated storage for ensuring power quality, congestion management, network investment deferral, etc.*
2a	**Market participant** • Option 1: dedicated storage, operated (primarily) according to TSO/ DNO needs	**TSO / DNO**	*Ownership and operation outsourced to third party for regulatory requirements (unbundling), but storage has (primarily or exclusively) TSO / DNO function*
2b	• Option 2: freely dispatched storage with some TSO /DNO services		*Storage combines market and TSO / DNO applications*
3	**Market participant**		*stand-alone or user-attached storage, used for different applications, e.g. trading & arbitrage, power quality, peak shaving, etc*
4	**Market participant A**	**Market participant B**	*Storage service for third parties, incl. portfolio services for other BRPs, VPP integrated storage, etc*

Source. DNV GL

The difference between Model 2a and Model 2b is that, in Model 2a, the storage has exclusively TSO/ DNO functions and the construction, dimensioning and operation has been triggered and is highly influenced by the TSO / DNO, while the operation and ownership is outsourced to a third party for regulatory reasons (unbundling). In Model 2b, the independent storage operator can freely decide on the services provided. This is especially true when the decision to build the storage is not triggered or taken by the TSO/ DNO, the network service provided by the storage does not have priority over other applications and the operator may cancel, resume or renovate the service agreement later on.

TSO / DNO operated storage

Ownership and operation models for T&D storages (referring to storages owned / operated by a TSO or a DNO) are primarily a function of the available regulatory background and provisions in the power sector.

In the EU, unbundling requirements apply to TSOs and DNOs and constrain the viability of T&D storages. According to them, network operators may not own or control generation assets and become active in competitive segments and the market. Moreover, TSOs have to select one out of three regulatory models and need to implement the corresponding unbundling requirements (see Table 5). Following the available TSO operation models means the ISO is not the owner of the grid asset. In turn, independent asset owners (ownership unbundling) and ITOs can own and operate grid assets.

So, whenever storages are considered (similar to) generation assets, storage operation and ownership by TSOs or DNOs is excluded due to requirements to separate grid assets from generation asset, irrespective of the regulatory model selected by the TSO. However, the regulatory framework is not entirely clear on the role and definition of storages, and the application of unbundling.[17]

Table 5: Unbundling models for transmission and system operation in the EU

Independent system operator (ISO)	Ownership Unbundling	Independent transmission owner (ITO)
• Fully unbundled system operator • No ownership of grid assets	• Unbundled from an integrated company • Ownership of grid assets	• Part of an integrated company, but independent subsidiary and operation in various terms ("Chinese walls") • Ownership of grid assets

Source: DNV GL analysis

This offers various options for storage ownership and operation by a TSO:

- Ownership and operation by a transmission and storage asset owner, providing purely system and network services to the independent ISO,
- Ownership and operation of the storage by the OU / ITO, subject to exceptional regulatory permit and exclusive use of the storage for system and network services,
- Ownership and operation outsourced to a third party (see Model 2a in Table 4 above).

Whichever of the former three options is selected, TSO / DNO owned and operated storages provide for exclusive access to the storage flexibility by the TSO / DNO, i.e. the storage shall only provide services that are sought by the TSO / DNO for system and network functions. Applications in wholesale or retail markets are not allowed.

An exception to this rule is when option 3 above is selected and the independent storage owner / operator (not the transmission asset owner under the ISO model) on purpose dimensions the storage so that it can provide additional market services without compromising services sought by the TSO / DNO.

While the ISO model has been hardly selected by European TSOs and the third option mentioned above is probably mostly preferred by TSOs and regulators, the second option has not been entirely banned by European regulation and has been implemented in some European countries, as the examples of Spain and Italy show (see Box 1 below).

In the light of a still unclear regulatory situation, the EU regulation will probably be amended soon based on the "Proposal for a Directive of the European Parliament and of the Council on common rules for the internal market in electricity" [18].

It defines 'energy storage', in the electricity system, as installations deferring an amount of the electricity that was generated to the moment of use, either as final energy or converted into another energy carrier.

[17] See "Business models for flexible production and storage", insight energy, Policy Report, December 2015

[18] COM/2016/0864 final/2

Moreover, the regulation proposed suggests several provisions on the ownership and operation of storages by DNOs and TSOs in exceptional cases. DNOs and TSOs may own, develop, operate or administer storages (TSOs also assets used for providing non-frequency ancillary services) only if

- third parties have not articulated, following an open and transparent tendering procedure, their interest to own, develop, manage or operate storage facilities
- the facility is essential for the efficient, reliable and safe operation of the network and system, and they are not used to sell electricity to the market
- approval by the national regulatory authority is available

While the EU proposal aims for further clarification on storages in the hands of network operators, storage operation still provides for a key regulatory challenge: even storages with purely TSO / DNO functions require some market integration of the energy volumes stored in or released from the storage. In other words, the energy stored, e.g. during congestion management, needs to be incorporated into the power system. Releasing the energy should not be at the sole discretion of the TSO/ DNO, should not be carried out without the involvement of market participants and should comply with formal power market rules, unless energy volumes are quite small, discharge may be allowed with the exceptional approval by the regulator and available mechanisms, like balancing power, are used to mitigate the impact of the energy when released to the system.

In the light of the regulatory difficulties for network / system operators to implement storage projects on their own, the alternative model with ownership and operation outsourced to a third party is often selected. In this model, the storage asset is owned by a market participant. Under a bilateral agreement with the TSO /DNO, the storage delivers network services. The expenses incurred by the TSO / DNO qualify for recovery through network usage charges. The storage operator keeps the control of the storage and can, according to the agreement terms, potentially combine the network service with complementary market services and applications. Such projects can be under a Build & Operate tender by the TSO / DNO and have been implemented by U.S. network / operators.

The more degrees of freedom the storage operator has under the network service agreement, the more Model 2a (see Table 4 above) will become similar to Model 2b.

Box 1: European examples on ownership and operation of storages by TSOs

In **Spain**, there is currently no specific legal basis for electricity storage in general and for use by network operators. One exception is pump storage hydro power plants for which legislation has authorized in specific cases ownership by the TSO.

This refers to the case of the PSP Chira-Soria (200 MW, approx. 250 million euros in construction costs) located in Gran Canaria, so far relying in terms of energy supply on two conventional power plants. The project development was tendered and given to Endesa in 2011.

After Endesa had started the project planning, disputes over the project's expected regulated profits and the project development status started among the regulator, the regional government and Endesa.

After further delays in the project development, a new legislation was introduced: pump storage hydro power plants on Spanish islands and exclaves can be attributed to the purpose of security of supply, system security and the integration of volatile renewable energies. They are, then, to be owned by the operator of the electricity system (TSO). Power plants, which prior to 1.3.2013 were owned by any operator or planned by an investor, may be subordinated to these provisions by decree of the Ministry of Energy.[19]

Endesa invoked the incompatibility with European and national legislation and the incompatibility of electricity transmission and generation. Despite Endesa's objections, the final sale of the project to REE in 2014 on the basis of a ministerial decree on the ownership transfer put an end to the difficult negotiation process on the conditions of the asset transfer.[20]

The Chira-Soria case may be a blueprint for the operational setup of additional 300 MW of hydro storage capacity planned on the Canary Islands.

In **Italy**, network operators may build and operate "mobile" storages to ensure system security and system optimization. The legal basis provides for the possibility that the network operator proposes storage in its network development plan, if it is demonstrated the storage's purpose is to better accommodate electricity production from volatile generation sources in the power network (dispatch) while ensuring system security. The storage must be required to ensure the security of the national electricity system and its proper functioning, maximum use of renewable energy sources and procurement of resources for dispatching services. Operation of pumped hydro storage plants is excluded.[21]

Furthermore, the regulator is required to develop appropriate regulations that ensure the adequate compensation for the investment of the network operator.[22] The final requirements issued by the regulator clarify that storage ownership and operation is not only granted to the TSO but also to DSOs.[23]

Under the umbrella of its new storage project company, Terna Storage, the TSO implemented various multi-MW projects in Southern Italy and Sardinia island. In the South, the system integration of large volumes of wind power generation (improved dispatch, reduction of curtailment, network impact reduction) is enabled by several battery storages. In Sardinia, two battery storages (about 40 MW) provide control power for frequency regulation.

In **California** (USA), there are no requirements on unbundling of network business (ownership and / or operation) and competitive segments, such as the supply of end customers, compared to the EU. Power supply and network and system operation are thus combined by (a few) large vertically integrated companies. In the absence of a clear regulatory separation of the business areas of these companies, the regulatory separation of costs and benefits of the different business activities of the vertical integrated company is crucial.

A specific storage legislation obliges the integrated companies to increase their level of access to storage capacity according to a specific deployment path by procurement of storage power. The deployment path differentiates between the connection level storages, including storages connected to the transmission network, the distribution network and or at end-customer level (behind-the-meter). The companies are allowed to hold up to 50% ownership across all storage projects.

Storages that are (partially) owned by the network operator may not sell energy on the market. Other storages that are built and operated by third parties provide specifically defined network / system services to the network operator can complement their application mix in a multiple-use approach and

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19 Law 17/2013 of 29 October 2013, Art. 5

20 Arrangement IET / 728/2014 dated 28.4.2014

21 See "Business models for flexible production and storage", insight energy, Policy Report, December 2015

22 DECRETO LEGISLATIVO 3 marzo 2011, n. 28, Art. 17.3 und 17.4.

23 DECRETO LEGISLATIVO 1° giugno 2011, n. 93. Art. 36, par. 3

optimise the operation, as long as the (primary) network service is not impaired.

Source: DNV GL analysis

Storage operation models for market participants

Asset operation models usually include, inter alia, construction, ownership, operation and usage (of the flexibility).

Focussing on the more persistent functions and excluding construction, storages will have an owner, operator and one or various users. With user we refer to the market participant who uses the storage flexibility and incurs its benefits, e.g. a market participant who procures a service from the storage. Figure 17 outlines several options for combination of these roles and gives examples where they apply.

When observing Figure 17, it should be noted that not all storage technologies are eligible or are feasible with any of the models mentioned. Depending on the type of storage and its application(s) as well as the regulatory background and market environment, the storage owner will select the most appropriate organisational model. Moreover, Figure 17 suggests that, except for the multi-service / multi-user model, there is usually just one user. However, as storages (still) have high CAPEX, OPEX or both, they tend to combine different applications to have several revenue sources, which often involves various users of the storage flexibility.

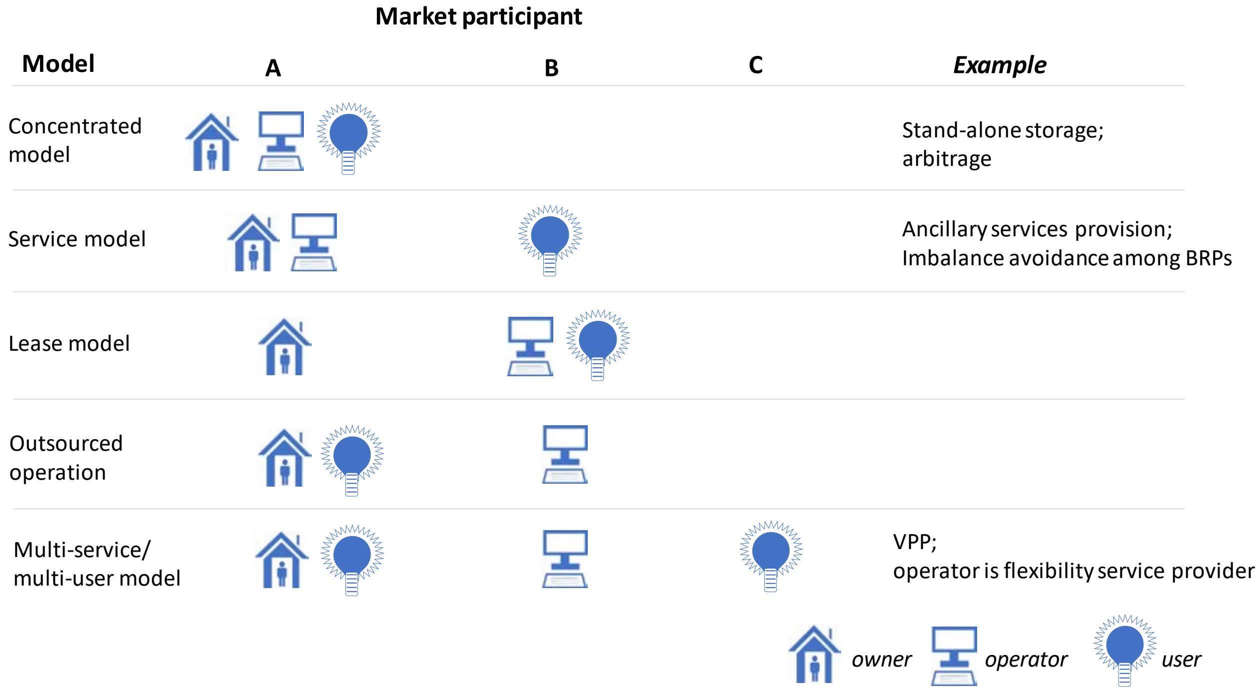


Figure 17: Illustration of storage operating models by market participants

Source: DNV GL analysis

2.3.4 Revenue Streams and Economic Benefits from Storage Applications

In general, the provision of applications and services may give the storage operator or owner one or more monetary benefits. Benefits may comprise of either revenues or savings compared to alternatives to the storage (opportunity cost).

Revenues are generated when services are provided to other system users and market participants and against payment. Benefits are generated when the operator and user coincide and the storage may replace more expensive alternatives. For instance, a T&D storage is able to provide system services and thus replace procurement of ancillary services from system users or avoid infrastructure investment. Moreover, storages may be used for network deferral. In the hands of a BRP, the storage may generate revenues from wholesale market trading or provision of ancillary service, or reduce the BRP's imbalance cost. In turn, a small consumer can use a storage in combination with DG to replace a high share of its energy consumption, previously bought from a supplier at a higher tariff, by electricity from own generation.

Where applications serve a market, they produce (market) revenues either in an organised market or in a non-organised market (based on bilateral agreement). In organised markets, like the power exchange or markets for balancing services and regulation power, market prices are determined, which will be the basis for the income of the storage operator.

In many cases, however, storages serve the needs of its owner / operator and are not used to provide services to third parties. So, there is no explicit revenue for the services provided but the storage operator / owner saves cost and enjoys other benefits.

Based on Figure 14 above, Figure 18 illustrates the spectrum of possible revenue streams by type and user of storage applications.

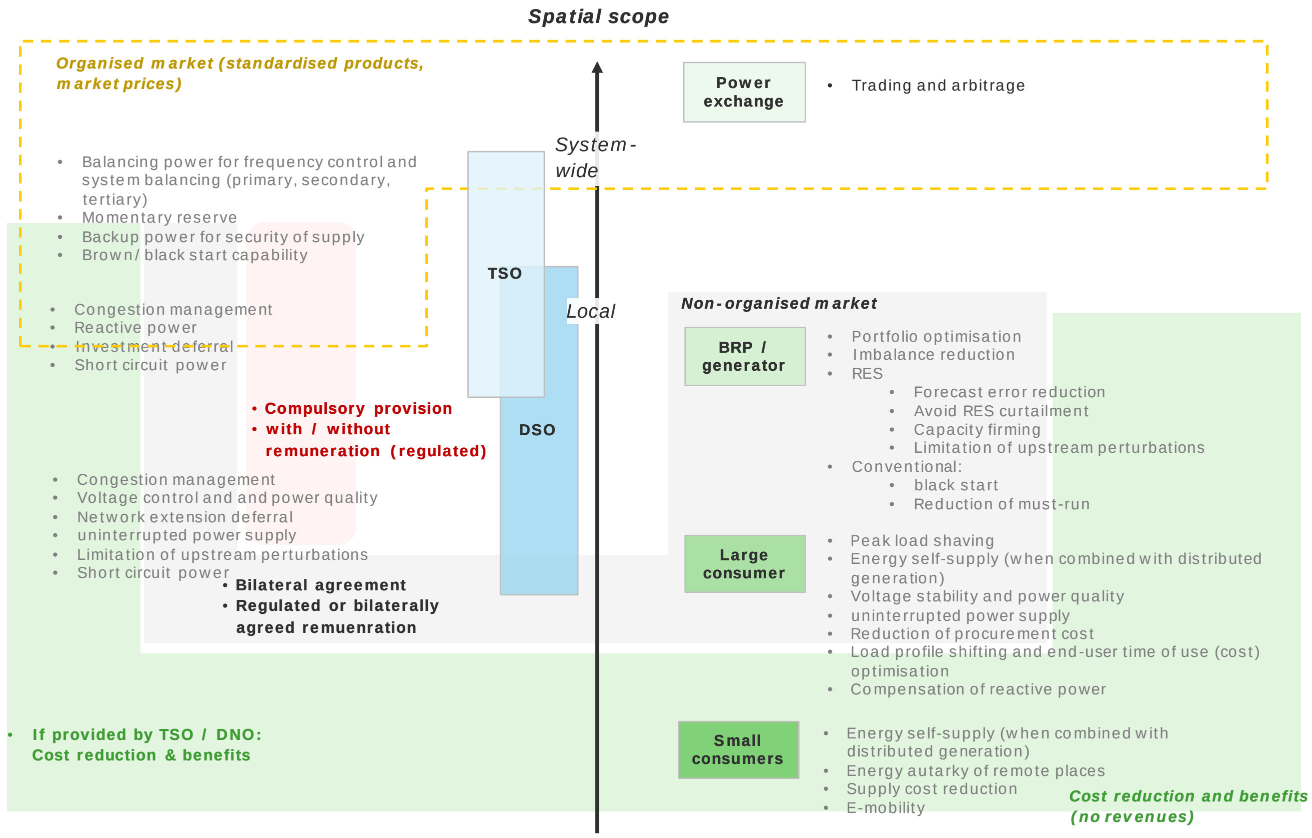


Figure 18: Illustration of revenue streams for storage applications

Source: DNV GL analysis

The figure shows that organised markets, including standardised products and market-based revenues for market participants, are usually available for wholesale market trading at the power exchange and non-locational ancillary and system services, like frequency regulation or back-up power for security of supply.

With services delivered by storages to power system and network operators, seldom organised markets are available, especially locational services. More often, these services are provided by system users under compulsory schemes or bilateral contracts. Revenues may be absent, regulated (tariff) or bilaterally agreed. It should be noted that compulsory provision, bilateral agreements and organised markets usually co-exist for the procurement but are applied to distinct services.

Moreover, it should be noted that organised markets are planned to be expanded from frequency regulation and system balancing to other services required by the TSO. In addition, some countries are considering the introduction of regional flexibility markets for DNOs in the medium-run to long-run.

In case the system / network operator provides the service from an own storage, it does so to reduce cost and avoid higher opportunity cost, e.g. for network extension. This corresponds to the T&D storages discussed above.

With storage applications that are used by market participants, revenues are gained based on bilateral agreements, i.e. non-organised markets, in case the storage service is offered to third party. There is a wide range of services, like portfolio balancing to avoid imbalances, that is provided to third parties on the basis of a bilateral contract, which will be remunerated subject to the bilateral service contract.

If the storage flexibility is used by the owner / operator, then it does so for reducing its cost, incurring other non-economic benefits or avoiding higher opportunity cost.

It should be noted that for all these applications regulatory provisions and price / tariff elements (taxes and levies) provide incentives that are often key for the storage's business case. This means that regulatory incentives are a driver for all storage applications, including the different market segments on the power market.

2.3.5 Role, Drivers and Location of Electricity Storages in the Power System of the Republic of North Macedonia

The Republic of North Macedonia has about 1.2 GW of installed hydro storage power, distributed over more than a dozen of locations. However, there is no reversible electricity storage, like pump hydro storage, in place at present. We will therefore comment briefly on the potential scope for electricity storages and outline drivers, locations and the role of electricity storages in the power system of the Republic of North Macedonia.

- To start with, large storages, like PSP and CAES, depend on the availability of appropriate geological conditions. For CAES, underground caverns need to be available and need to offer adequate geological formations. For PSP, geological pre-conditions need to allow for building a higher and lower reservoir and sufficient natural water resources need to be present in the proximity of the project location to be captured by the reservoirs. As a result, potential locations of PSP and CAES are resource-driven, and we assume the potential for new PSP and CAES storages has been abundantly studied and is well known. Moreover, we assume that the need for new, large-scale storages, being the key driver for new projects, has been studied by MEPSO and other interested stakeholders in the energy system of the Republic of North Macedonia.
- Even if the costs of P2G were reduced and this technology became available at competitive cost levels, its need and potential locations would still depend on the availability of large volumes of cheap energy and/or potential applications. In general, one may envisage two options for potential locations:
    - First, P2G installations can be placed close to where large amounts of electricity from RES are produced. With P2G nearby, RES generation will be stored if electricity network capacity is insufficient and there is the risk of RES being curtailed.
    - Alternatively, P2G may be placed close to consumers, in case its primary purpose is the supply of alternative fuels or substitute natural gas or other conventional fuels for heat provision.
    - Hence, the scope and location of P2G is driven by RES resources and need-driven.
- The deployment of medium-size and large batteries is a function of the need for additional flexibility in the power system or by the need of individual system users for specific applications. Batteries are mobile and can be placed and moved as needed. Moreover, they are scalable and may be combined in numbers and from different locations.

  If the battery's use case is to provide system services, it is not constrained by location and may provide the service from anywhere. In turn, the delivery of locational services to DNOs or TSOs, like reactive power or congestion management, limits the project to certain locations and areas.

However, from what we know today it may be concluded that the power system of the Republic of North Macedonia will, in the next decades, dispose of sufficient operational reserves in conventional power generation for system balancing. This clearly limits batteries' scope to provide system balancing services.

Where batteries are deemed to serve the need of specific system users, like generators or large consumers, they will be placed in the proximity of that network user. One example are batteries attached to RES, like wind and utility scale ground-mounted solar PV.

As a result, the need and the location of the storage is primarily driven by its application.

- Small-scale batteries will probably be used both by small generators of electricity from distribute generation (e.g. solar PV) or in electric vehicles.

  The use of batteries combined with small-scale distributed generation (DG) will aim for reducing the cost of electricity consumption and increasing the level of energy self-sufficiency of prosumers. The scope of this use case depends on the penetration by DG, the price of the DG asset and the batteries, and other parameters, including income of consumer, electricity tariffs, availability of appropriate areas e.g. roof surface for solar PV, amongst others. As a result, it is fair to assume the deployment of batteries for this use case will be roughly a function of population distribution. In the case of solar PV, irradiation is also key. Both parameters will constrain the deployment of batteries to certain areas.

  The deployment of electric vehicles depends on the future need for mobility services by individuals as well as in the small commercial and transportation sector. Moreover, the total cost of ownership of an EV, including CAPEX and lifetime OPEX, compared to the cost of vehicles using conventional and alternative fuels will be the key criterion for choosing an electric vehicle. Electric vehicles that will be used by individuals or in the commercial / service sector will be mostly located where people live. In the transportation sector, electric vehicles will be used along the main transportation routes.

Table 6 summarises the key drivers for the main storage technologies.

Table 6: Summary of drivers and potential locations for electricity storages in North Macedonia

Technology	Driver for deployment	Potential locations
PSP, CAES	1. Natural resources • PSP: amount of water; difference in altitude for building reservoirs • CAES: geological formations and availability of caverns 2. Demand for large storages in the power system	Limited to locations with appropriate natural resources
P2X	1. Availability of natural resources (RES) 2. Demand for storing (large) amounts of RES power, or gas as (alternative) fuel	2 options: • Close to areas with high wind power penetration • Close to high consumption of gas (methane, hydrogen)
Batteries (medium, large)	1. Considerable need for additional flexibility in the power system (ancillary services) or on a regional / local level 2. Specific need by individual network users (RES, large industrial consumers) 3. Remuneration of flexibility	• Variable (system services to the TSO) • Otherwise constrained to specific applications with local focus or specific network users
Batteries (medium, large)	1. E-mobility: Need for mobility services and cost of alternative / conventional technologies for individuals or in the commercial / service sector and transportation sector	Population-driven
	2. DG-attached battery: local solar PV potential, electricity supply tariffs compared to cost of DG+battery technology bundle,	Population-driven

Source: DNV GL analysis

3 STATUS QUO AND OUTLOOK TO ELECTRIC MOBILITY IN EUROPE

3.1 Types of Vehicles and Drive Trains

In general, one may differentiate between the following electricity-based technologies for driving vehicles:

- Battery electric vehicle (BEV)
- Hybrid electric vehicles (HEV)
- Plug-in hybrid electric vehicle (PHEV)
- Range extender electric vehicle (REEV)
- Plug-in electric vehicle (PEV)

Battery electric vehicles are defined as purely electrically driven cars the energy of which stems from its battery packs and thus has no internal combustion engine, fuel cell, or fuel tank. It is, today, usually recharged by a plug-in charging device.

HEV combine a (usually) conventional fuel tank with a battery. It will usually be able to charge its own batteries using the conventional fuel engine. Depending on the technology, the conventional fuel is partially or completely converted into electric energy and to recharge the batteries, which power the electric motors. In other types of hybrid vehicles, the conventional fuel engine drives the wheels directly, but an additional battery/motor combination adds some electric drive.

PHEV and REEV combine a conventional hybrid electric vehicle, having an electric motor and an internal combustion engine (ICE). The range limitation of the comparably small battery is compensated by a conventional fuel tank. In a REEV car, the conventional fuel is burned to drive the electric motor, corresponding to a serial combination of the conventional tank and the battery. In the PHEV, both energy sources operate in parallel mode, with the conventional motor drives the wheels directly. The PHEV and REEV approach provide for a plug to connect to the electric grid.

PEV means any motor vehicle that has a charging plug for connecting to an external electricity source and the electricity stored in the rechargeable battery packs drives or contributes to drive the wheels. PEV thus is the generic term for BEV, PHEV and REEV while HEV are not encompassed due to their lack of connectivity to an external power supply.

This study looks at BEV, PHEV and REEV, as they provide for a connection to the power grid, while the term PEV will be used as substitute for referring to the sum of the different technologies.

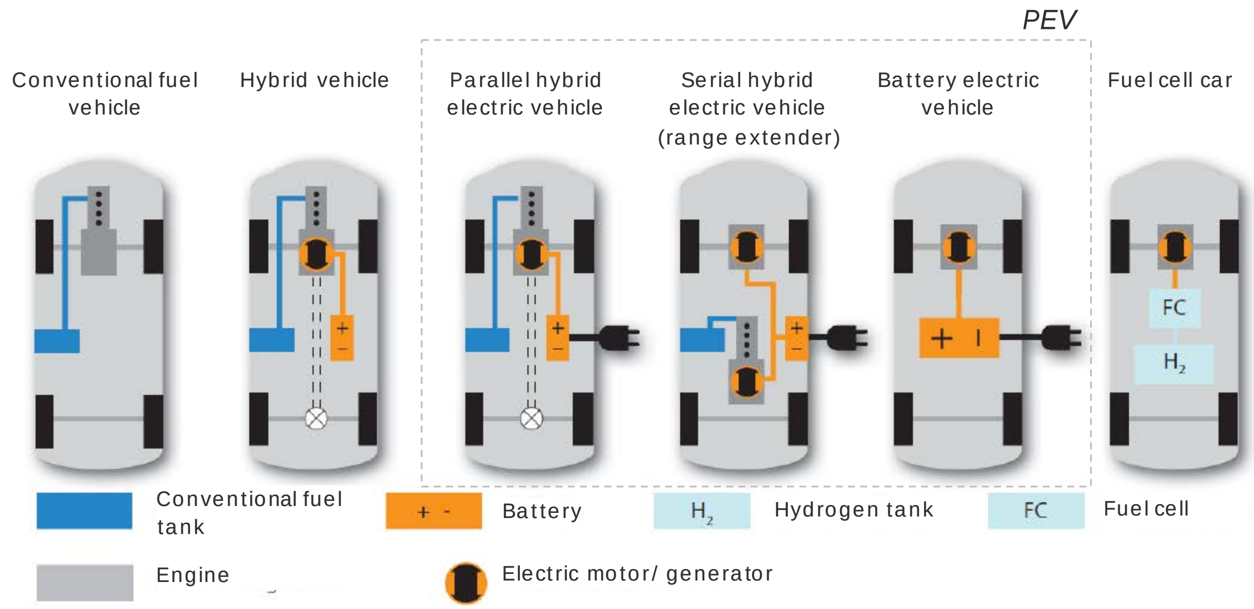


Figure 19: Vehicle concepts

Source: Strukturstudie BW^e mobil[24] (adapted)

3.2 Charging Technology, Requirements and Standards

Charging approaches comprise of different elements including

- Current type
- Charging infrastructure, including plug types provided in the car and at the power source as well as the cable / charging mode
- Electric parameters (current, power) as a function of the charging infrastructure.

These design parameters are unrelated.

First, charging uses either alternating current (AC) or direct current (DC). As batteries require the energy to be stored as DC, some conversion of AC current supplied by the public network is needed. With AC charging, a rectifier must be available in the car to control the charging process.

For AC charging, 1-phase or 3-phase charging is possible and power values are usually limited to the range 3-43 kW. For instance, in Germany, AC charging provides for slow charging at 3.7 kW (1-phase), at most 43 kW (3-phase) and various other power values in between (e.g. 7kW, 11 kW, 22 KW). Slow charging up to ca. 3.7 kW is most often used today. These low power levels are typical of residential charging points.

With DC charging the charger and rectifier must be available outside of the car, i.e. at the power supply. Yet, each of them is flexible enough to support various combinations of power level supplied by the

24 DLR, „Der Pkw-Markt bis 2040: Was das Auto von morgen antreibt“, Szenario-Analyse im Auftrag des Mineralölwirtschaftsverbandes; 2013

charging station (expressed in kW). DC charging allows for higher charging power and lower charging time.

According to the EU Directive 2014/94/EU, “normal” charging refers to AC charging at up to 22kW. Higher charging power, be it AC up to 43 KW or DC, is defined as “fast” charging.

Moreover, for AC and DC charging, different infrastructure setups, both at the car and at the power source, and charging modes are available. At the car, the plugs mentioned below are usually available in Europe; and usually there is one of them, sometimes two distinct ones.

Table 7: Overview and features of charging approaches and plug types for PEV charging

Plug		AC / DC	Explanation
Type 2[25] (also known as Mennekes)		AC	• Default standard for most of the vehicles sold to date in Europe • re-charge battery electric vehicles at power rates from more than 3.7- to 43 kW (e.g. 22 kW at home) in AC, or <35 kW in DC • Re-charging power depends on national standards.
CCS (Combined charging system) Combo2[26]		AC, DC	• Based on Type 2 (VDE) AC charging connector • CCS combines slow or advanced AC charging (up to 43 kW) with DC fast charging. • full compatibility with the SAE specification for DC charging and additional pins to accommodate fast DC charging at 200–450 Volts DC. • At present, most CCS chargers allow for 50-100 kW, while it could also provide for 200 kW. Advanced CCS is expected to allow for re-charging at up to 350 kW in the future.
Chademo ("CHArge de MOve")		DC	• allows for charging with up to 50-62.5 kW of high-voltage direct current via a special electric connector (2.0 version allows for power values of 200-400 kW) • Usually used in Asia: to enhance compatibility with European charging scheme often ensured by Chademo/ Type 2 conversion cable or additional Type 2 plug in the car plus Type2 / household plug conversion cable
Tesla SC (Tesla Supercharger)		(AC), DC	• Modified version of the Type 2 plug • At dedicated DC fast-charging station, up to 135 kW is available • Proprietary standard for Tesla cars, not available to other car types

Source: DNV GL analysis

Usually, electric vehicles have downward compatibility in the sense that they may also be charged at lower power, as long as the same standard is used. Often vehicles are compatible with only one/ few of the aforementioned charging technologies, but not all.

At the charging point, different plugs may be found. Charging points may comprise of typical household and small end consumer plugs (and variants) or specifically designed wallboxes and charging stations

25 Based on IEC 62196

26 IEC 62196 Type 2 and DC

(providing one or different loading charging standards). Domestic sockets can also sometimes be found at public charging stations. This charging method is available for all electric cars.

Charging points may or may not be compatible with the car's plug, as not all charging points offer all standards.

The following graph illustrates the main features of the general charging approaches.

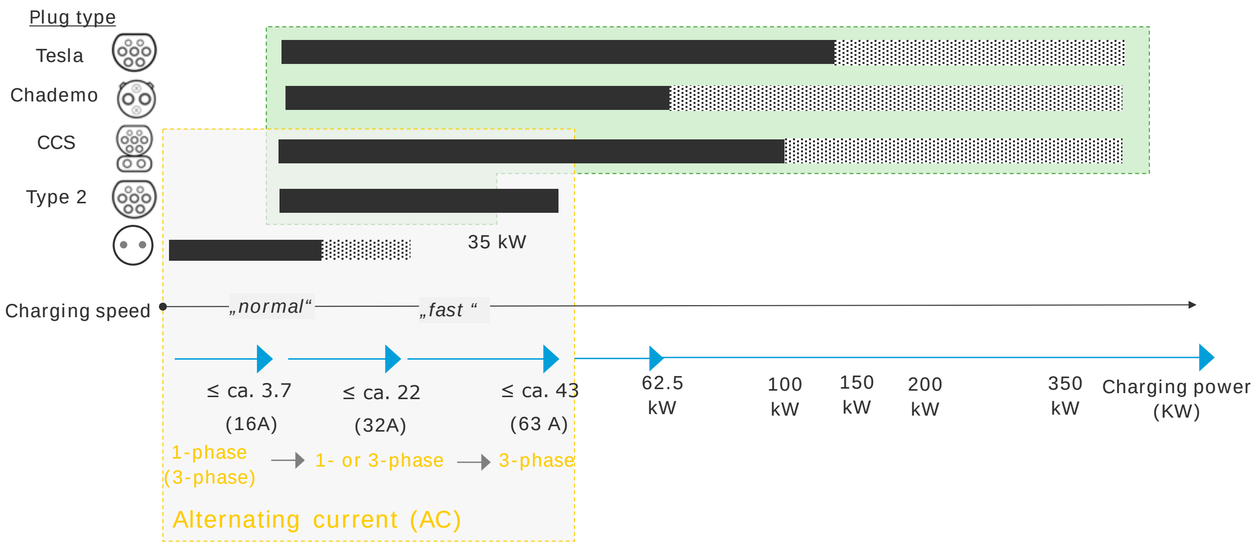


Figure 20: Overview of charging technologies / approaches, plug-types and charging power

Source. DNV GL

Power sources or the car may provide for the charging cable, allowing for the following setups:

- A: cable integrated / provided by the PEV
- B: mobile cable connecting the PEV and the charging point with 2 distinct or 2 identical plugs
- C: cable integrated into the charging point

Apart from that, charging is classified in four different modes that define the capability of the charging cable and the security and information features allowed or required between the car and the power source.

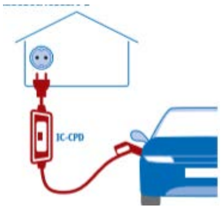
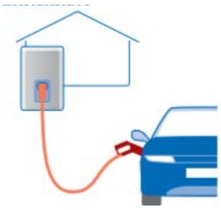
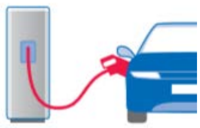
Mode 1		• AC charging (1- or 3-phase, up to 16A) via a usual household plug or industrial plug, using common sockets and cables • No communication between charging point and PEV • No fault current protection in the cable integrated • Seldom used as it requires Residual Current Device control at the charging point (seldom available at consumer premise) • No V2G capability
Mode 2		• AC charging (1-phase or 3-phase, up to 32 A) via a usual household or industrial plug (uses a non-dedicated socket) • Cable provides for "In Cable Control and Protection Device" (ICCPD) for fault current protection • Communication between charging point and PEV possible • No V2G capability
Mode 3		• AC (1-phase or 3-phase, up to 63A) charging using a special plug socket and a dedicated circuit to allow charging at higher power levels • ICCPD integrated in charging point • Type 2 plug • V2G capable
Mode 4		• DC charging with offboard charging device • charging plug type(s) depends on charging point • ICCPD integrated in charging point • V2G capable

Figure 21: Overview of charging modes

Source: VDE[27]

For recharging the battery at a conventional home or industrial[28] socket, Mode 2 connections have usually been used. Communication and protection between vehicle and charging port is provided via a box connected between the vehicle plug and connector plug (ICCB In-Cable Control Box). The cable also provides two distinct plugs to connect the PEV's plug with the conventional domestic or industrial site socket. This mode does not foresee any V2G capability, whilst current and future PEV can be expected to support either mode 3 or mode 4. For these reasons, for instance German industry associations clearly recommend using either mode 3 or mode 4 connections.

Mode 3 charging is mostly used to connect the charging station and the electric car at public charge stations or home / workplace wallboxes. In Europe, the type 2 plug has been set as the standard.

Mode 3 and Mode 4 charging requires special plug socket, a dedicated circuit and dedicated charging equipment. Mode 3 and Mode 4 cables also provide for V2G and load management capability, while Mode 1 and 2 do not.

27 "Der Technische Leitfaden Ladeinfrastruktur Elektromobilität", Version 2, 2016

28 CEE sockets, like AC 1-phase blue socket (<3,7 kW (230 V, 16 A), 3-phase red socket, CEE16 (<11 kW, 400 V, 16 A), CEE32 (<22 kW, 400 V, 32 A)

In the light of a long standardisation process in the international arena, the EU adopted a specific regulation on the development of a common framework of measures for the deployment of alternative fuels infrastructure. The Directive sets out minimum requirements for the building-up of alternative fuels infrastructure, including recharging points for electric vehicles. It must be implemented by means of Member States' national policy frameworks, as well as common technical specifications, amongst others.

According to the Directive, Member States shall ensure that slow and fast charging points for electric vehicles deployed or renewed as from 18 November 2017, comply at least with the following technical specifications:

- AC normal power recharging points for electric vehicles, used for normal or high-power recharging points, shall be equipped, for interoperability purposes, at least with socket outlets or vehicle connectors of Type 2. [29]
- High-power recharging points for motor vehicles that provide for DC charging shall be equipped at least with connectors of the combined charging system 'Combo 2'.[30]

As a result, the minimum requirement for public re-charging points requires Type 2 and Combo 2 type plugs to be present everywhere.

For charging at home or private business places, no such standardisation is available (yet).

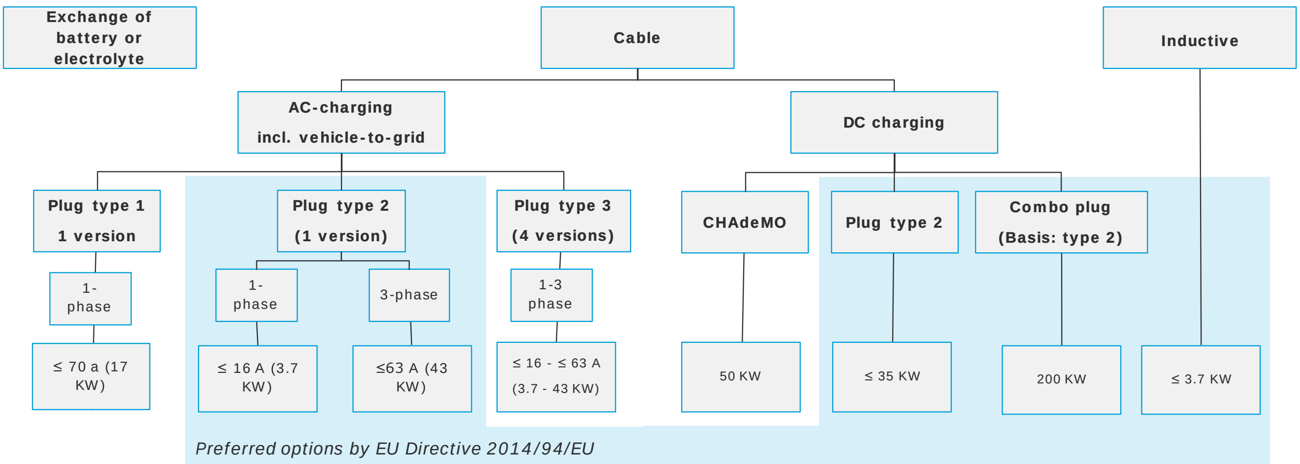


Figure 22: Options for charging infrastructure and the preferred option according to EU Directive 2014/94/EU

Source: Based on German Standardisation Roadmap E-Mobility, 2014[31]

29 As described in standard EN 62196-2

30 As described in standard EN 62196-3

31 Deutsche Normungs-Roadmap Elektromobilität – Version 3.0, 2014, p. 69

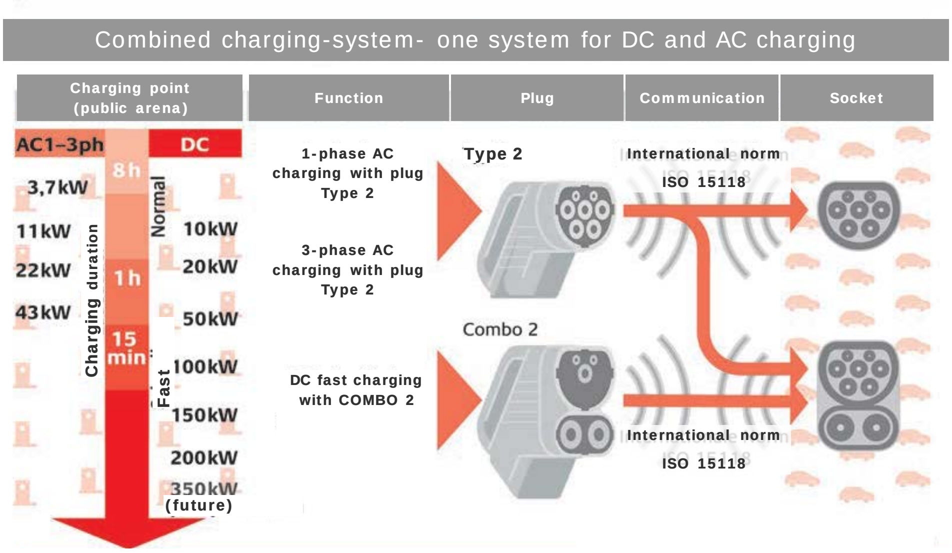


Figure 23: Combined Charging System (CCS) for Europe

Source: Based on Progress Report 2014 of the German National E-Mobility Platform [32]

3.3 Features of PEV Available Today

Batteries in PEV have various features that are relevant when studying the impact on the power system and network, including:

- Charging and discharging capacity while connected to the grid, in kW
- Battery size (capacity), in kWh

Figure 24 and Figure 25 below combine information on the charging type, battery size (kWh) and potential travel range of PEV vehicles currently available in the market. Presumably, information on PHEV combines REEV and PHEV (parallel PHEV) vehicles. For PHEV and REEV the NEDC[33] range refers solely to the battery capacity and not to the conventional fuel part.

For M1 type vehicles, it is no surprise, the battery capacity in BEV is larger than in PHEV, where it is limited to below 20 kWh. In addition, the following may be observed.

With regards the charging technology, most of the available models use Type 2 chargers and allow for slow or fast AC charging (up to 43 kW). This means Type 2 charging is the dominant charging infrastructure used. Fast charging with DC is, today, far less available for most of the cars, but in case it is available, CCS and Chademo are offered roughly in a similar number of cars.

32 Fortschrittsbericht 2014 –Bilanz der Marktvorbereitung; Nationale Plattform Elektromobilität; Fig.12

33 NEDC = Bew European Driving Cycle

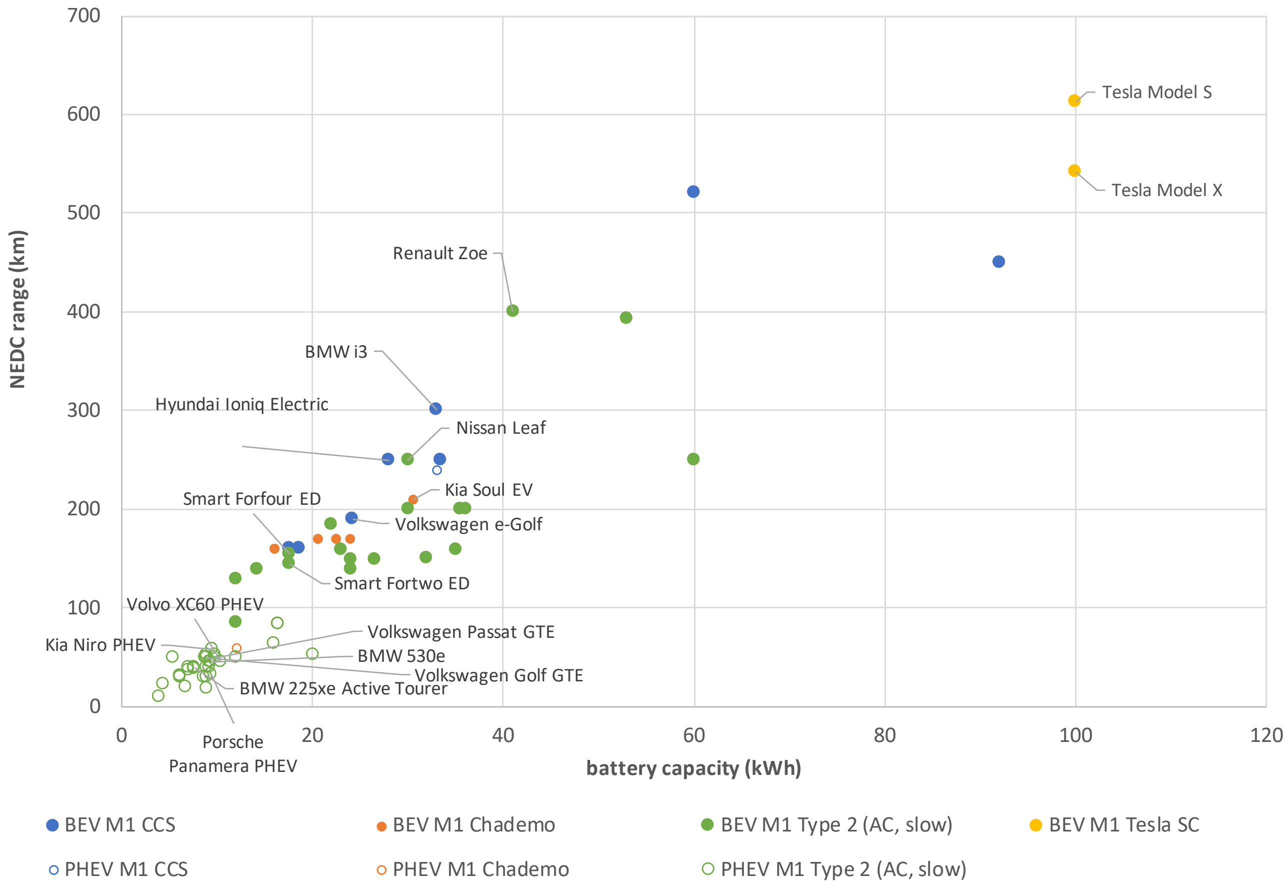


Figure 24: Battery size, NEDC range and (fast-) charging technology of currently available PEV M1 car models (passenger cars)

Source: DNV GL analysis, based on data from eafo

As an example, Figure 24 also cites 10 vehicles in the category of PHEV and BEV that are most sold in the market. Most of these cars use slow AC-based charging. In turn, some of the most successful cars offer fast charging (CCS or Tesla's specific charging type). The most popular cars apparently hardly offer (any more) Chademo.

In addition, it becomes evident that PEV that may be charged at higher power rates not necessarily provide for a larger battery, but charging power decreases the charging time required.

Many vehicles are limited to a battery size of 20 kWh, which often corresponds to a range of 150 km only. Moreover, most of the BEV have a battery capacity in the range of 20-40 kWh, only a few cars offer more. This corresponds to a range of 150-250 km. Hence, most of the cars offer a ratio of capacity size to NEDC range of about 15 kWh / 100 km, i.e. cars theoretically consume about 15 kWh when travelling a distance of 100 km. However, it is often reported and has been demonstrated that NEDC travel distances are more theoretic values and are hard to achieve in reality. This means, in practice, energy consumption per 100 km is higher and the range of the car is lower than NEDC figures shown in the graph.

Figure 25 below covers similar information for the N1 car segment as Figure 24 for M1. While the pattern of cars available to the market is less diverse than in the M1 segment, also here Type 2 AC charging dominates over fast charging (CCS and Chademo). In fact, the 6 most popular cars sold, making up more ca. 85% of the stock of cars sold, are BEV and use Type 2 AC charging.

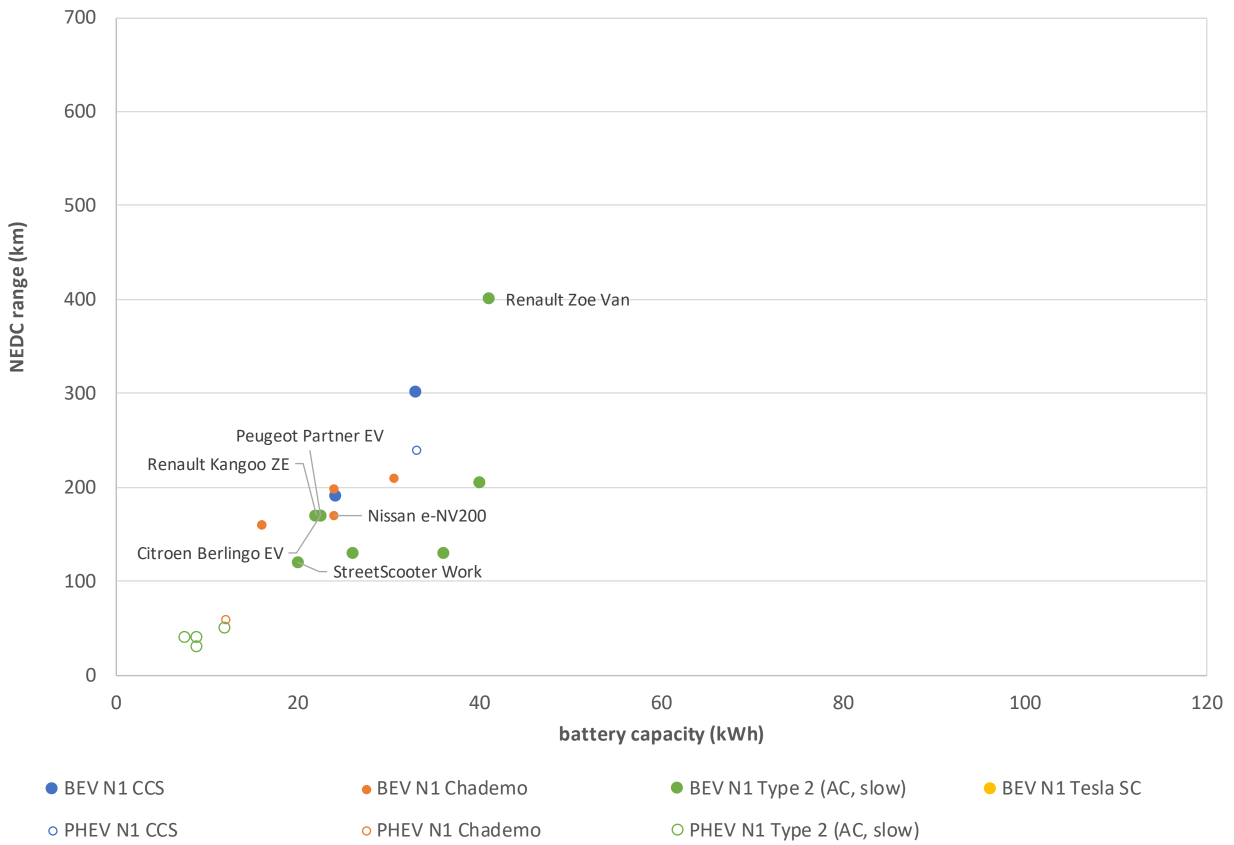


Figure 25: Battery size, NEDC range and (fast-) charging technology of available PEV N1 car models (light commercial vehicles)

Source: DNV GL analysis, based on data from eafo

3.4 Market Penetration of PEV

Figure 26 below exhibits the current fleet of PHEV and BEV in 28 European countries, as of end 2017, including passenger cars (M1) and light commercial vehicles (N1). According to that, the vehicles concentrate in a few Western and Northern European countries. The growth in total PEV numbers has focused on France, Germany, the Netherlands, the United Kingdom (UK) and Sweden, where the fleet size is in the range of 50,000-150,000 cars, including all categories, today. Yet, other countries with considerable PEV penetration are also Austria, Belgium Denmark, Italy and Spain, with total fleet size of 18,000 – 35,000. In all other geographies, the dissemination of PEV is still very limited and does not exceed 10,000 cars (Portugal as the mostly PEV 'populated' country).

Not surprisingly, passenger transportation vehicles dominate over light commercial vehicles almost everywhere.

However, the share of cars per category purchased varies by country. In France, BEV have by far seen the highest registration figures, while in all other countries PHEV have at least a share of about 40% (like in Italy, Spain, Germany) or provide for the majority (like in the Netherlands, Sweden, the UK, Belgium).

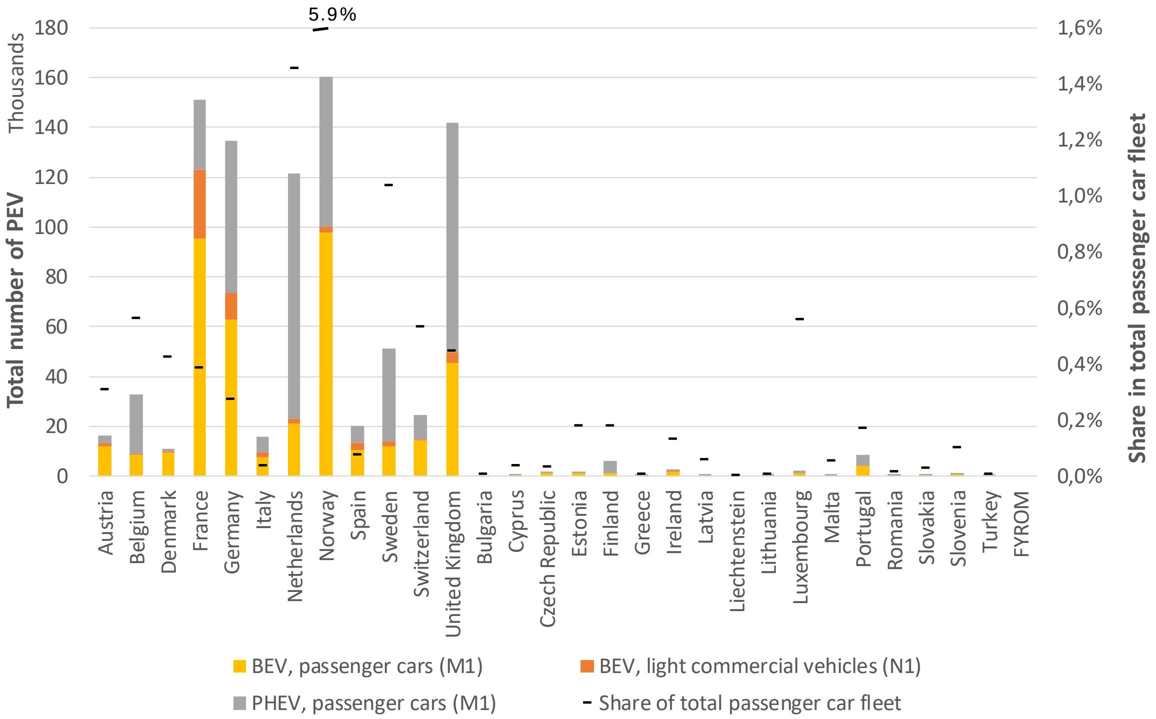


Figure 26: Total figures and relative portion of registered PEV by European country

Source: DNV GL analysis graph, based on eafo.eu and Eurostat data

When compared to the total passenger car fleet, the picture looks a bit different. Norway is the only country where PEV penetration may be considered noticeable, making up ca. 6% of all cars today. In the Netherlands and in Sweden, among the front runners in nominal PEV figures, the currently available PEV fleet makes up more than 1% of all passenger cars used in the country. In other countries, even front runners in nominal registration figures, the portion of PEV is still not more than around 0.3-0.6%. Luxemburg has already achieved a high share of EV (0.6%), compared to others.

The following graph shows for countries with a fast growing PEV sector (M1 only) registration figures for the last 3 years. While in France and in Norway EV grow faster than PHEV, in the Netherlands and the UK it is the opposite. In Germany, both segments have grown at comparable rates.

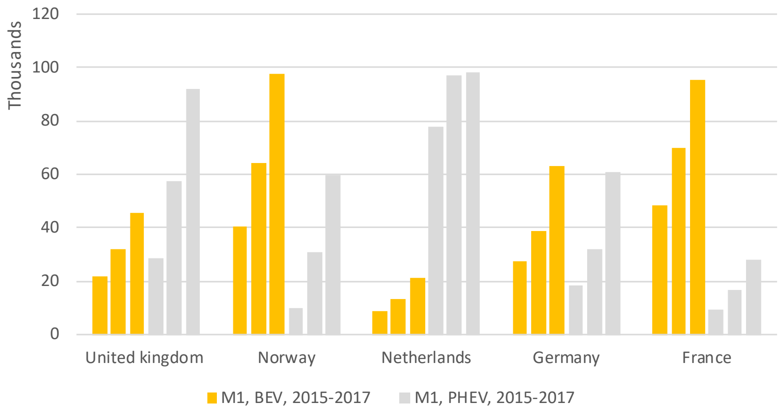


Figure 27: EV and PHEV (M1) year-end registration figures in selected numbers for 2015-2017

Source: DNV GL analysis, based on EAFO data

3.5 Available Public Charging Infrastructure

The following table compares the national public charging infrastructure targets of 2020, adopted in 2013, with the actual number of charging points installed by the end of 2017. It may be observed that various countries are lagging in achieving their targets and will probably achieve them.

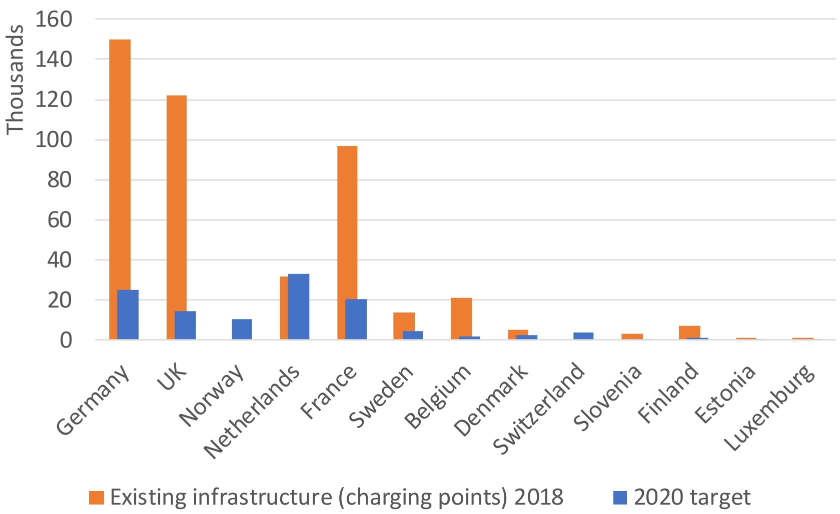


Figure 28: Achievement in installing public charging infrastructure for meeting 2020 targets in EU countries

Source: EUROPEAN COMMISSION, press release, Brussels, 24 January 2018

The following figure shows the recharging infrastructure that is currently available in the public arena in selected European countries (as of mid-2018). Except for Sweden and Finland, where fast charging points are at least equivalently available as slow AC charging, in all other countries slow AC charging dominates over other charging cable-based technologies.

Moreover, it becomes obvious that some countries have been more successful in developing also fast recharging points. While Germany, Luxemburg, the Netherlands and France are lagging, other countries like Slovenia, Norway, Estonia, Finland and the UK offer a higher portion of fast charging points.

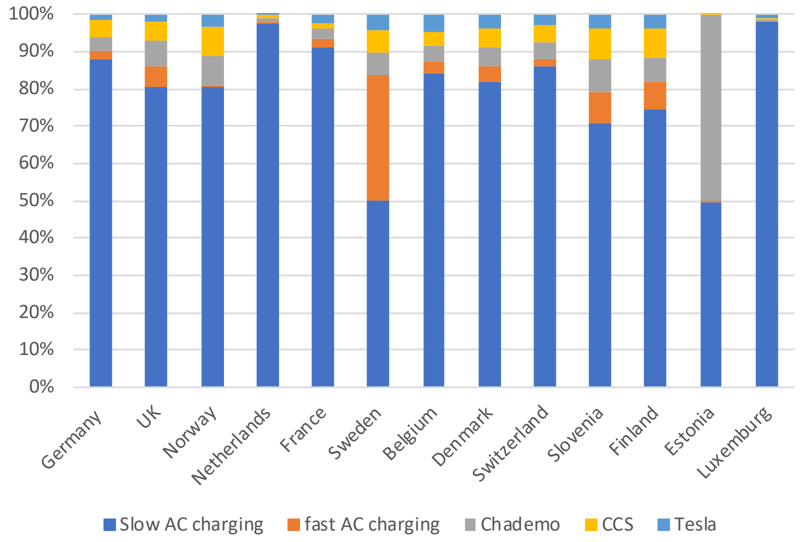


Figure 29: Re-charging infrastructure for PEV available in different European countries

Source: DNV GL analysis graph based on EAFO data

Figure 30 below depicts the average number of PEV per slow AC charging point (x-axis), fast charging point (y-axis) and all charging points in different countries (bubble size).

Most of the countries provide for ca. 5-10 cars per charging point, irrespective of the type of point. Belgium and Norway, in turn, provide for ca. 15 vehicles per charging point. Bearing in mind that these countries are among the countries with a very dynamic e-mobility growth, this means the pace of car development exceeds the infrastructure development (more than in other countries).

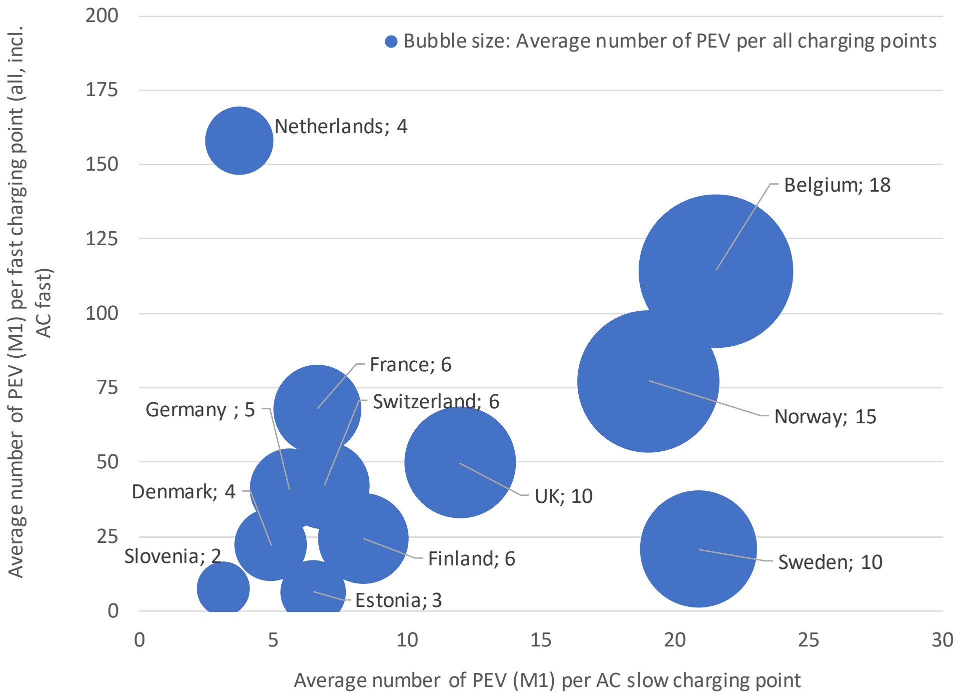


Figure 30: Average number of PEV per publicly available charging point in different countries
Source: DNV GL analysis graph based on EAFO data

3.6 Environmental Impacts of PEV

The key argument for an increasing use of PEV are the expectation of much lower carbon emissions and hence climate change impacts than conventional vehicles. Conversely, opponents of electric vehicles often argue that PEVs may even increase carbon emissions, due to a higher carbon intensity during manufacturing of the PEV itself and as a result of carbon emissions caused by electricity production.

To assess these impacts, Figure 31 presents selected results from a recent study by the European Environmental Agency (EEA). As the left chart shows, the carbon impact of BEV relative to internal combustion vehicles (ICE) is influenced by several factors:

- The initial carbon impact of BEV during the production phase is substantially higher than for ICE, mainly due to the carbon emissions caused by production of the battery.
- For similar reasons, the end-of-life impact of BEV is higher than for ICE but remains almost negligible in proportion to the overall lifetime impact.
- The overall carbon impact of BEVs finally strongly depends on the composition of the electricity mix. As illustrated by Figure 31 outperform diesel- as well as gasoline-fuelled vehicles when assuming the average European electricity fuel mix, whilst they would cause substantially higher carbon emissions if electricity was produced by coal-fired plants only.

Given the high share of inefficient coal- and lignite-fired plants in the Western Balkans, it seems far from certain that PEV would lead to decreasing carbon emissions in Macedonia. When assuming an increasing use of renewable energies and the gradual replacement of existing plants by modern (gas-fired) plants in the region, the carbon impact of future PEV will likely be less than that of ICE.

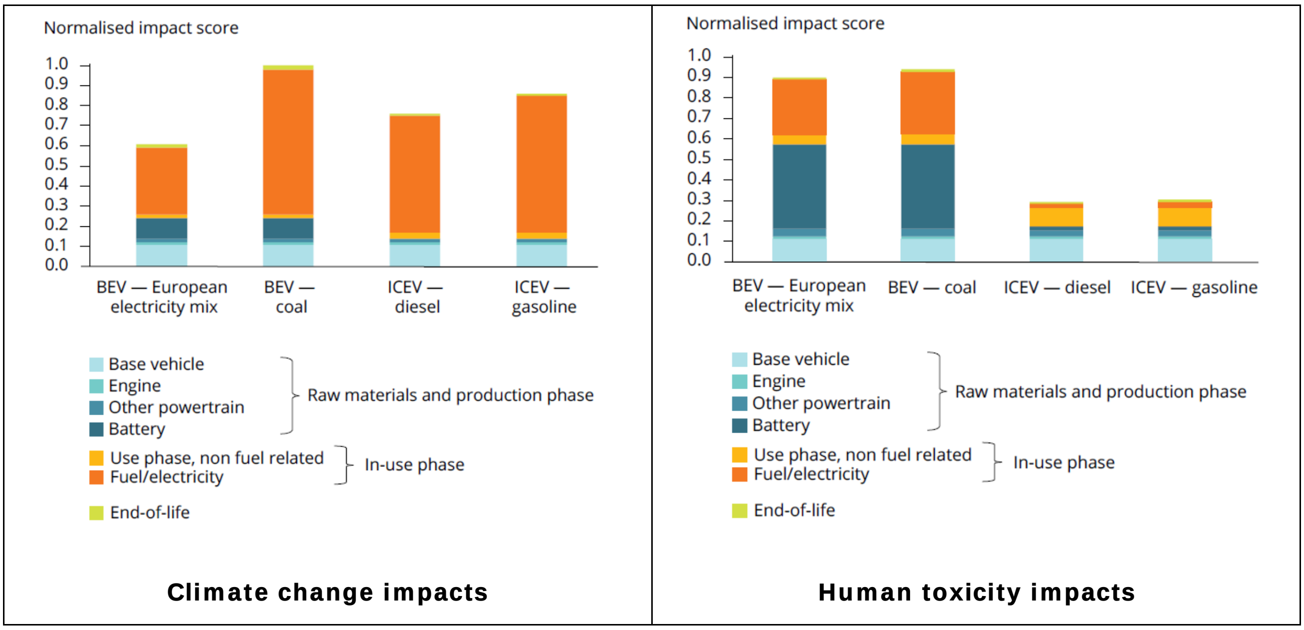


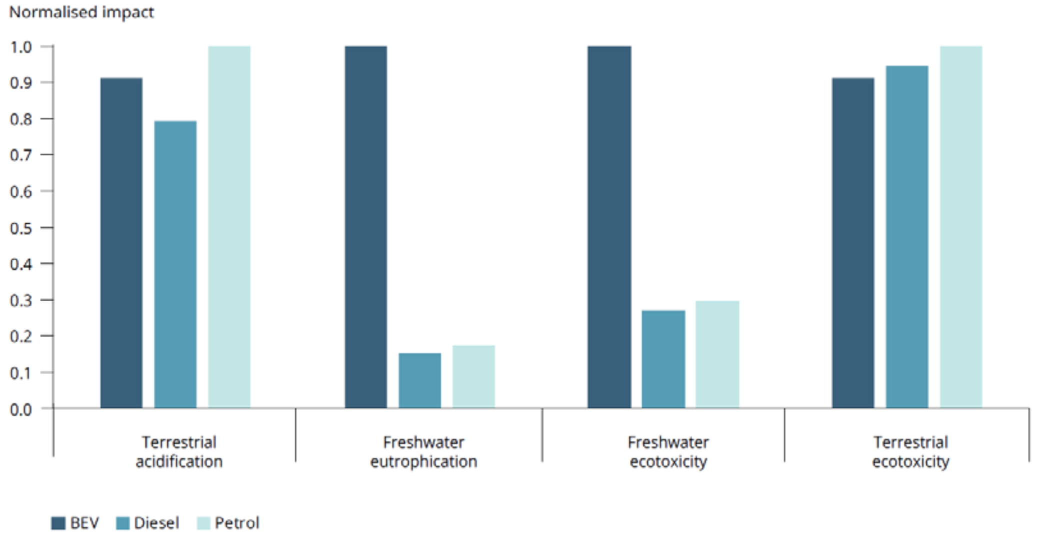
Figure 31: Climate change and human toxicity impacts of BEVs vs. ICEVs

Source: European Environment Agency. Electric vehicles from life cycle and circular economy perspectives, TERM 2018: Transport and Environment Reporting Mechanism (TERM) report. EEA Report No 13/2018. Copenhagen. 2018. pp. 57 - 58

The right side of Figure 31 complements these numbers as it also consider human toxicity impacts. In this case, BEV perform seriously worse than ICE both during the production and the use stage. For the production phase, the difference is again related to battery production. According to the EEA, however, BEV also cause higher fuel- resp. electricity-related toxic impacts during the use stage. As shown by Figure 32 these differences are mainly related to freshwater use and are thus again related mainly to the high share of thermal plants in Europe.

Finally, it is worth noting to comment also on the challenges of battery disposal. An increasing use of PEV will eventually need to a corresponding number of used batteries, which will have to be dealt with after their lifetime. Unless batteries were recycled, their disposal may have negative environmental consequences, although the EEA forecasts these to be limited, as indicated in Figure 31. Indeed, the main environmental impacts are related to manufacturing of new batteries, which seems particularly critical in terms of human toxicity impacts[34]. In the future, recycled of used PEV batteries will thus become increasingly important.

34 Moreover, lithium-ion batteries require finite raw materials, such as lithium or cobalt.



Note: Normalised impacts for each impact category are expressed as a proportion of the largest total impact. For BEVs, data for a LiNMC battery have been used. BEVs are assumed to be charged with the average EU electricity mix in 2013. See footnote 8 or source reference for further details.

Figure 32: Comparison of the environmental impacts resulting from the use stage of BEVs and diesel and petrol cars across four impact categories

Source: European Environment Agency. Electric vehicles from life cycle and circular economy perspectives, TERM 2018: Transport and Environment Reporting Mechanism (TERM) report. EEA Report No 13/2018. Copenhagen. 2018. p. 36

3.7 Impact of Financial and Non-Monetary Incentives

Figure 33 gives an overview of policy support mechanisms for PEV in selected countries in 2015, based on a recent IEA study. As the table shows, different countries use a fairly wide range of different instruments and incentive schemes. Overall, however, these can be roughly grouped into the following three resp. four categories:

- Financial incentives, which can be further differentiated for PEV purchase and use, respectively,
- Non-monetary incentives for PEV users, and
- Tailpipe emission standards.

The latter group principally applies to car manufacturers rather than vehicle owners and can thus be considered as less relevant for the purpose of this study. Conversely, the former two groups appear as clearly relevant.

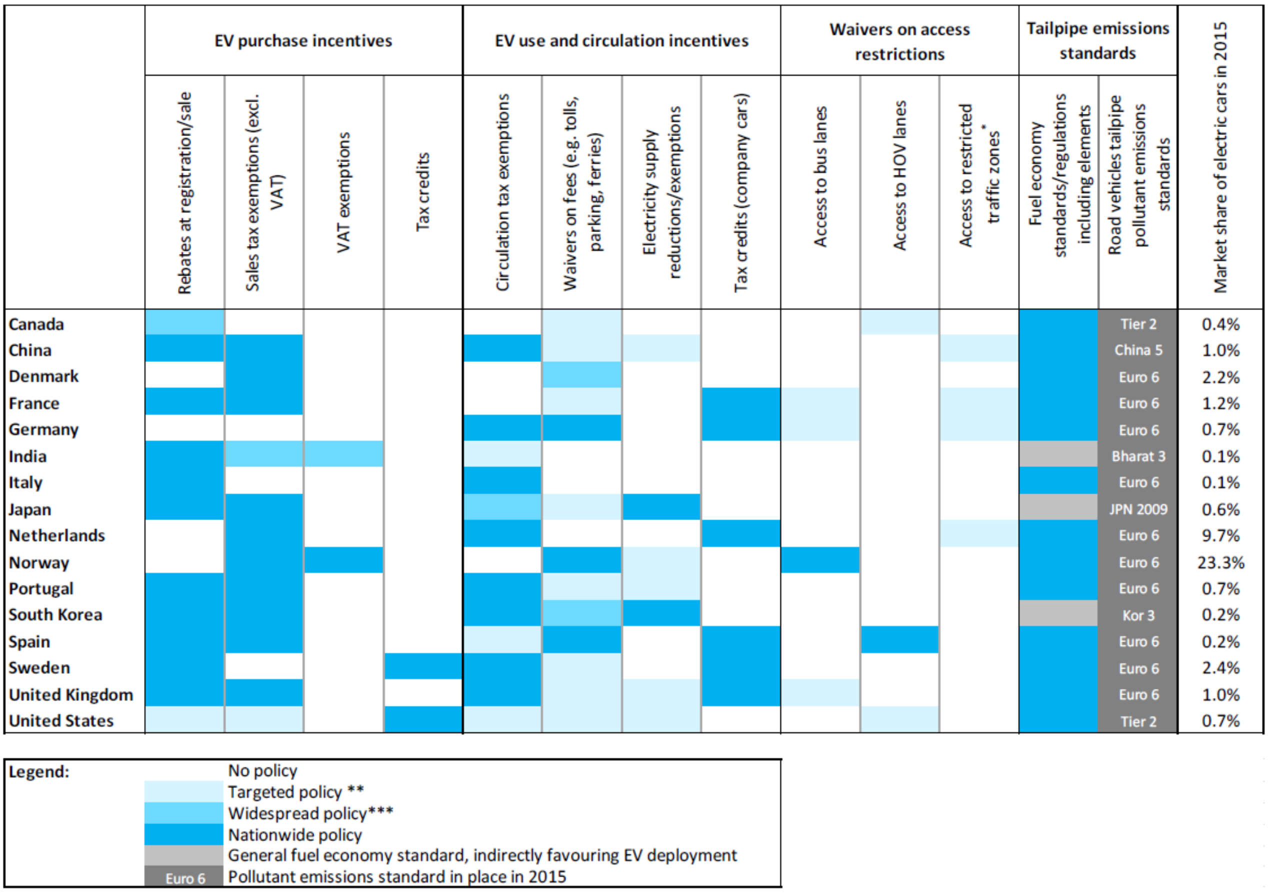


Figure 33: Policy support mechanisms for EV uptake in place in selected countries in 2015

Source: OECD/IEA, Global EV outlook 2016, p. 13

There is considerable anecdotal evidence about the importance of non-monetary incentives for the success of PEV in Norway, such as exemption from road tolls in the capitol Oslo and the privilege of being allowed to use the bus lanes. This seems to suggest that non-monetary incentives may play a major role for stimulating the use and roll-out of PEV. But when looking at Figure 34, this conclusion seems to be less obvious. More specifically, this chart indicates a clear (negative) correlation between the relative costs of electric vehicles and their share of new vehicle sales. In other words, Figure 34 arguably shows that the success of PEVs is strongly related to their costs relative to conventional vehicles, and that electric vehicles are generally more successful in countries where the costs of PEV are similar to, or even lower than, conventional ICE.

Conversely, it seems very difficult to identify a relation with the availability of charging infrastructure as shown in section 3.5 above. In contrast, one may even observe that the success of EVs in Norway has been quicker than the extension of the charging infrastructure, such that the latter can hardly be seen as a driver of growing PEV penetration.

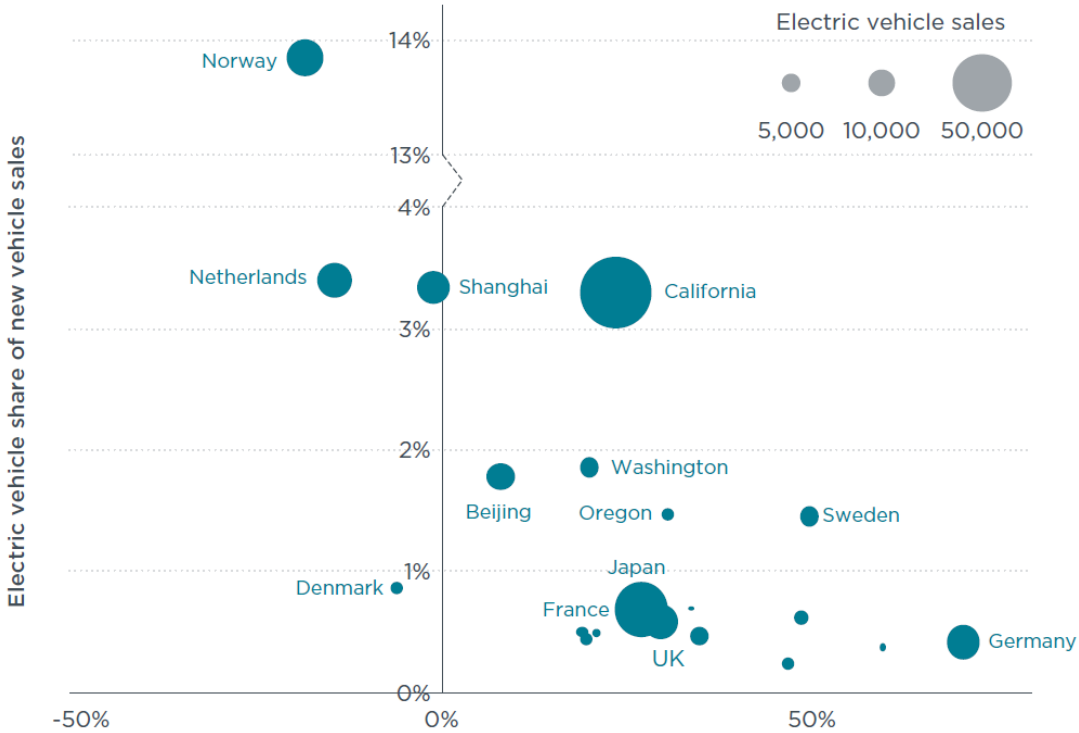


Figure 34: Electric vehicle share of new vehicle sales and average electric vehicle cost difference compared to conventional vehicles

Note: Electric vehicle cost compared to conventional vehicles (incl. retail price, incentives, taxes, fees)

Source: ICCT, International Council on Clean Transportation. PRINCIPLES FOR EFFECTIVE ELECTRIC VEHICLE INCENTIVE DESIGN. White Paper. June 2016, p. 27

Interestingly enough, these observations are also confirmed by additional information from Norway. Figure 35 provides a summary of the most important drivers for EV vehicles, based on a survey of Norwegian EV owners. The chart shows that the five most important incentives are all of a financial nature, whereas the availability of charging infrastructure was mentioned by less than 50% of the surveyed owners. Indeed, the survey found that more than 40% of PEV buyers were primarily interested in 'saving money'. Taking into account that this survey implicitly focused on early adopters, which are often willing to pay a premium, the importance of financial incentives can reasonably be expected to be even higher for a later 'mass market', and certainly also for buyers from less wealthy countries, such as North Macedonia.

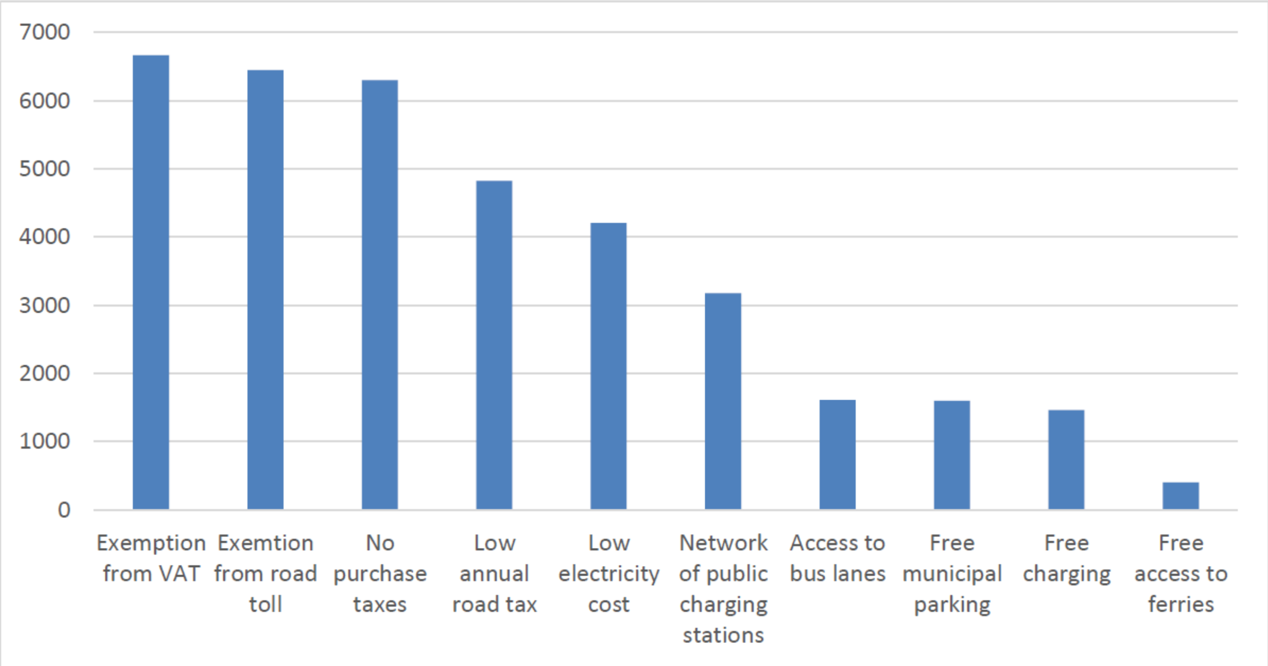


Figure 35: Most important EV incentives according to Norwegian EV owners

Source: Lorentzen, E., Haugneland, P., Bu, P. and E. Hauge. Charging infrastructure experiences in Norway - the worlds most advanced EV market. EVS30 Symposium Stuttgart, Germany, October 9 - 11, 2017. P. 9

3.8 Summary and Outlook

The future e-mobility sector will probably look different from today. The following aspects and observations give some outlook.

Charging infrastructure

- In many areas, especially urban, a ratio of about 10 PEV per charging point has been achieved. This is considered to meet the demand by drivers today to be able to recharge the vehicles almost instantaneously. As the deployment of PEV lags behind expectations, it may be concluded that other factors, like the cost, equipment and capability of PEVs as well as the cost for charging point access, are the true hurdles.

  Nonetheless, the extension of the public and / or private-company owned charging point infrastructure has focused on densely populated areas, while rural areas have been neglected. So, further efforts are needed there, too.

  At the same time, there are also urban areas where PEV deployment has been positive (due to direct financial support and indirect incentives, like high prices and taxes on conventional fuel), while the pace of adding public charging points is lagging, e.g. in Oslo.

- Latest surveys suggest that today's PEV drivers seek to retain their home as the prime charging point. Due to the limited scope for fast charging in ordinary houses and its cost, charging power will probably be limited there.

  Moreover, this suggests that, in particular, the regulation in the housing sector needs to be amended further to allow for more charging points, especially in multi-family dwellings. Otherwise, the adoption may stall or retard.

- The deployment of charging infrastructure in the private sector is enabled through the new EU Directive of 30 May 2018,[35] adopting several provisions on the installation of charging infrastructure in new and renovated buildings (residential and non-residential):
  - Non-residential buildings (new or undergoing major renovation)
    - with more than ten parking spaces: need to be equipped by
      - at least one recharging point, and
      - ducting infrastructure, namely conduits for electric cables, for at least one in every five parking spaces to enable the installation at a later stage of recharging points for electric vehicles.[36]
      - with more than twenty parking spaces: Member States need to lay down requirements for the installation of a minimum number of recharging points, by 1 January 2025
      - Buildings owned and occupied by small and medium-sized enterprises may be exempted
  - residential (new or undergoing major renovation): when more than ten parking spaces are available, ducting infrastructure, namely conduits for electric cables, needs to be installed for every parking space to enable the installation, at a later stage, of recharging points for electric vehicles.[37]
  - all (of the former) buildings:
    - specific categories of buildings may be exempted, e.g. cost of the recharging and ducting installations exceeds 7 % of the total cost of the major renovation of the building
    - Member States shall provide for measures in order to simplify the deployment of recharging points and address possible regulatory barriers, including permitting and approval procedures, without prejudice to the property and tenancy law of the Member States.

- In many regions, utilities, network operators and independent infrastructure operators consider the operation charging stations a promising business and make investments. Moreover, the concern of regional supply tariff differences that might affect a PEV driver when driving into different areas is mitigated by agreements on open access to charging stations and roaming

35 DIRECTIVE (EU) 2018/844 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL amending Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU on energy efficiency

36 The car park is either located inside or physically adjacent to the building. For major renovations, renovation measures include the car park or the electric infrastructure of the building

37 The car park is either located inside or physically adjacent to the building. For major renovations, renovation measures include the car park or the electric infrastructure of the building

agreements for financial settlement for the energy charged. However, it turns out that the business of charging stations is still a bet on the future as they do not pay off given the low PEV adoption levels and low trip ranges.

PEV deployment and technology

- It may be assumed that most of the countries will not meet their ambitious 2020 PEV penetration targets despite the implementation of economic support programmes. This may be explained by different reasons, e.g. the insufficient capability of PEV available today to meet technically the requirements of car drivers (range, charging time, etc), the limited or expensive access to public charging points, the purchase and lifetime cost of the cars, to name just a few.
- Technology-wise two trends are ongoing: First, research on batteries is aiming for extending both the vehicles' range (capacity) and the capability to charge at higher power rates. Secondly, more fast charging points will be implemented in the public arena, including appropriate points along the main transportation routes, to allow for fast charging during long-distance trips.

  Yet, fast charging capability in a well-meshed public charging grid and large PEV capacity is not required at the same time, however it might well the result, similar to conventionally-fuelled vehicles.
- From today's point of view, it is not clear which fuel / storage technology will be the dominant one in the future. It is quite probable that li-ion technology, the prevailing technology today, will be substituted by novel battery technologies at some point, either before or after 2030.

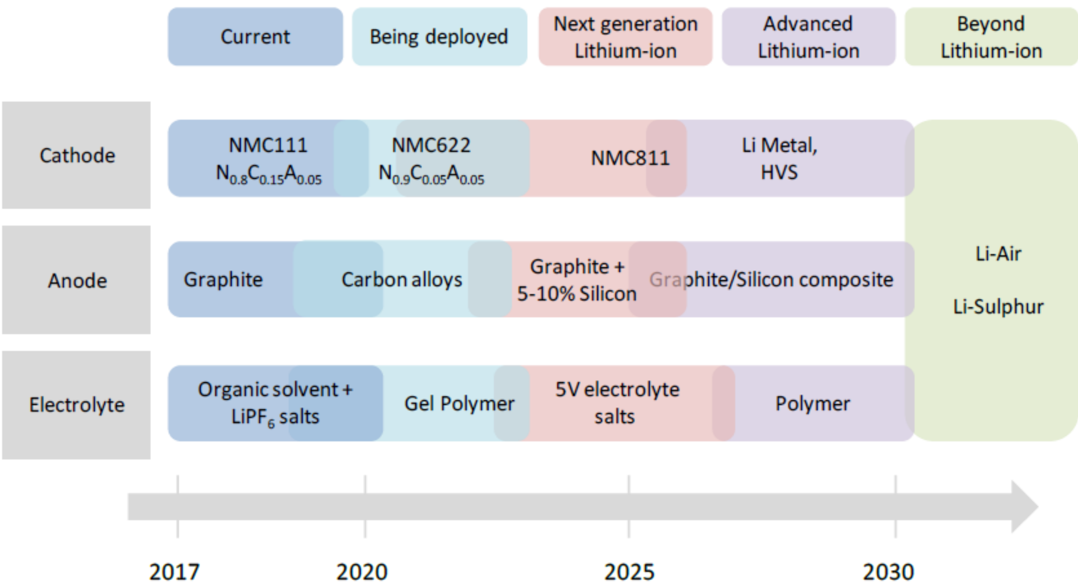


Figure 36: IEA's expectation on the battery technology commercialisation timeline

Source: IEA Global EV Outlook 2018

Moreover, battery-based drives may be complemented by other technologies, including

- Alternative fuels and technologies, like fuel cell and hydrogen, UC, etc.
- Hybrid system, combining batteries and other technologies
- Alternative charging technologies, like induction

For instance, it may be observed already today that cargo vehicles are equipped with alternative fuels / technologies or with hybrid systems. The latter combine the virtues of different technologies and compensate their disadvantages. Fuel, storage and recharge technology are selected and tailored to the specific use case and challenges of the transportation job, as well as to the local conditions (like mix of short and long-distance trips), the actual use and availability of road infrastructure, weight to be carried, etc.

- It may well be that differences in the charging standards used in different geographies (e.g. Asia) and preferences by car manufacturers persist. Moreover, there will probably be a mixed stock of cars (newer and older) that differ in the charging technology and the power rates they support. Public charging infrastructure, especially when serving a variety of car models, will therefore need to accommodate various charging approaches and plugs. EU regulation requires that at the least all public charging points support Type 2 / Combo 2 charging is supported. Nowadays, this hybrid approach is often the selected business model of charging infrastructure operators.

  Moreover, it is realistic to assume that different systems, including storage type, fuel type and charging technology, will probably co-exist, especially when considering cargo transportation, private and public passenger transportation, small commercial vehicles and private transport altogether.

4 ASSUMPTIONS FOR STUDYING THE IMPACT OF E-MOBILITY ON THE MACEDONIAN POWER SYSTEM

This part outlines the key assumptions and data sources used to derive an appropriate set of inputs on PEV that will be used in market modelling. The market model will be used and parameterised accordingly to calculate the impact of PEV on the North Macedonian power system and market in the long-run. The areas covered hereafter are:

- Scenarios for the development of PEV over the next 2 decades, including their regional distribution
- Assumptions on PEV, incl. usage patterns
- Allocation of regional statistical information to network nodes in the market model
- Charging strategy

4.1 Scenarios for E-Mobility Development in the Republic of North Macedonia

4.1.1 Development of PEV with a View until 2040

This study relies on two scenarios for the development of the penetration by PEV over the next 20 years:

- a conservative growth scenario, and
- an optimistic growth scenario.

For deriving the EV growth scenarios for Republic of North Macedonia, we consider existing scenarios for Republic of North Macedonia and assess them against the current and expected growth of e-mobility in other countries. We note we are not aware of a national PEV strategy or targets for the Republic of North Macedonia.

Figure 37 below depicts the current penetration by PEV in European countries as well as the national PEV fleet target by 2020, expressed in total number of EV per 1000 inhabitants. It may be observed that even ambitious countries tend to lag behind their 2020 targets. For instance, Germany has a target of 1 million EV by 2020. This translates into ca. 12 EV per 1000 inhabitants, starting from about 1.5 today.

Due to the delay in the EV growth it may be assumed that the national targets will often not be accomplished before 2025, or even later.

Various countries provide significant financial and other support to EV purchasers. In North Macedonia, the government currently refunds EUR 1,000 on a purchase of a PHEV vehicle, while for a BEV vehicle it refunds up to EUR 5000. Still, we assume that the development of EV in Republic of North Macedonia will lag behind more advanced countries, reflecting underlying economic differences between Republic of North Macedonia and economically stronger countries with regards GDP and household income. In turn, potential cost decline in battery technology and EVs will enable a stronger growth of EV, and EV in Republic of North Macedonia might grow faster at higher rates in the future than today.

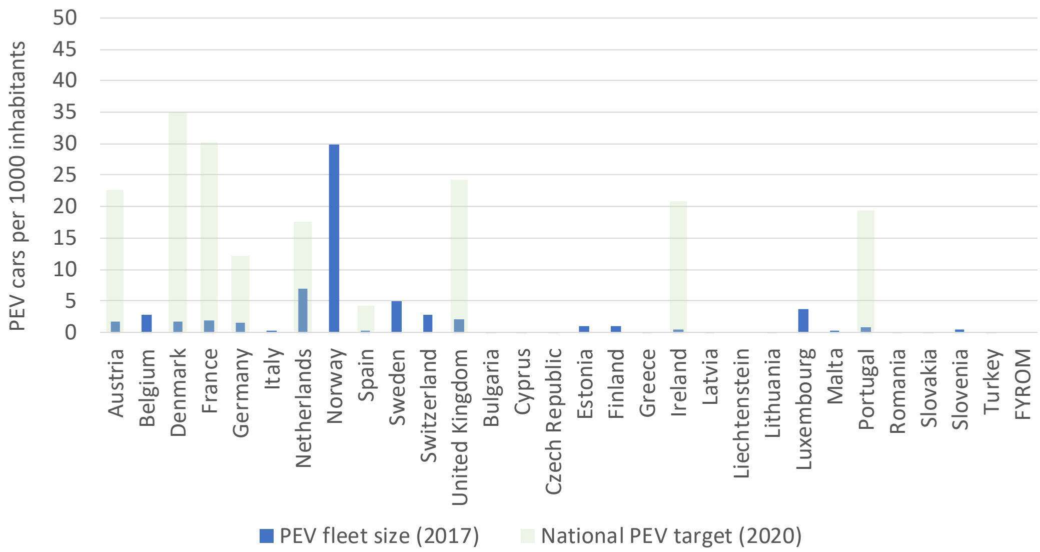


Figure 37: Penetration by EV in European countries as well as the national PEV fleet target by 2020 in vehicles per 1000 inhabitants

Source: DNV GL analysis, data from EFAO, Eurostat and IEA ("Global EV Outlook 2016")

Figure 38 shows different ENTSO-E scenarios for the EV development in Republic of North Macedonia until 2040.[38] The scenarios are: Best Estimate (BE), Sustainable Transition (ST), Global Climate Action (GCA), European Commission 2030 climate and energy targets (EUCO)[39], distributed generation (DG). Among all, two scenarios stand out.

- In the DG, the total number of EV grows to 70,000 cars by 2030 and to 170,000 cars by 2040; this corresponds to a very optimistic case
- In the ST scenario, EV grow moderately and at a constant rate to 50,000 vehicles in 2040.

38 See TYNDP

39 As agreed by the European Council in 2014

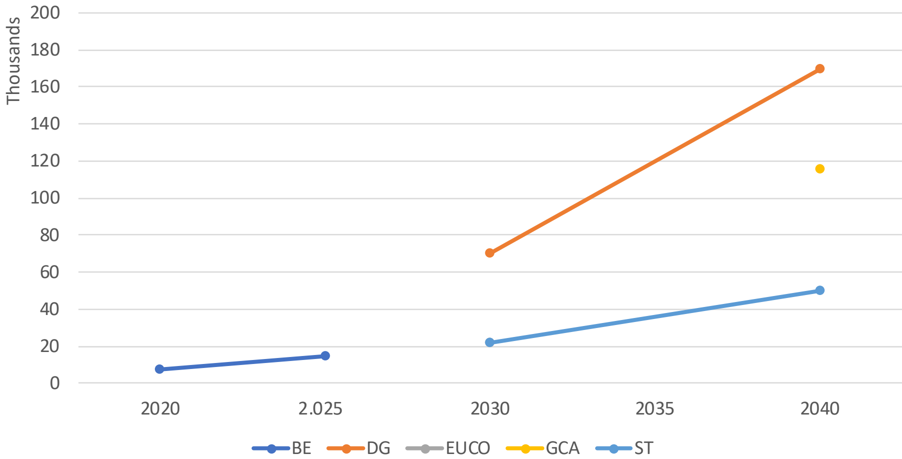


Figure 38: ENTSO-E projections for PEV in Republic of North Macedonia, in total number of vehicles

Source: ENTSO-E

The following graph illustrates the consequences of the different PEV growth scenarios, relating the total number of PEV assumed in 2030 and 2040 to the total fleet size (incl. conventional). The total number of PEV assumed to be available in 2030 and 2040 is divided by the total number of cars driving on the roads of Republic of North Macedonia in the future. While today the car per capita rate is nearly 20%, we assume it will be in the range of 20%-50% by 2030 and 2040. Moreover, we assume a constant population of 2 million.

ENTSO-E's DG scenario would mean every fourth to every second car will be a PEV by 2040, depending on whether the car per capita rate is 40% or 20%. The ENTSO-E ST scenario is much more conservative suggesting that among all cars about 7-13% will be PEV.

The ENTSO-E GCA scenario assumes every seventh to every fourth car will be a PEV.

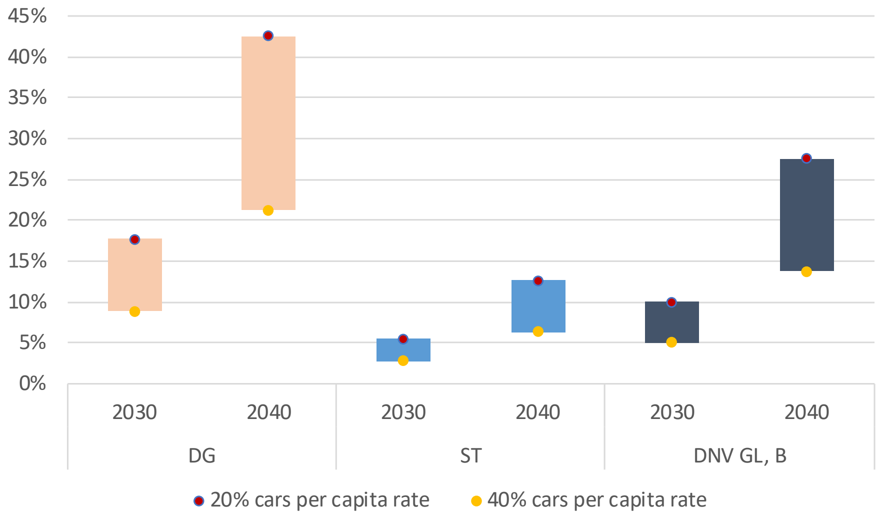


Figure 39: ENTSO-E and DNV GL projections for PEV in Republic of North Macedonia, as share of PEV relative to variable total car fleet size (conventional and alternative fuel)

Source: DNV GL analysis graph, ENTSO-E data

This said, we suggest considering in this study the PEV scenarios shown in Figure 40. The scenarios are defined as PEV per 1000 inhabitants. They are derived from assessing the ENTSO-E growth figures against the national growth targets by 2020/ 2025 in other European countries.

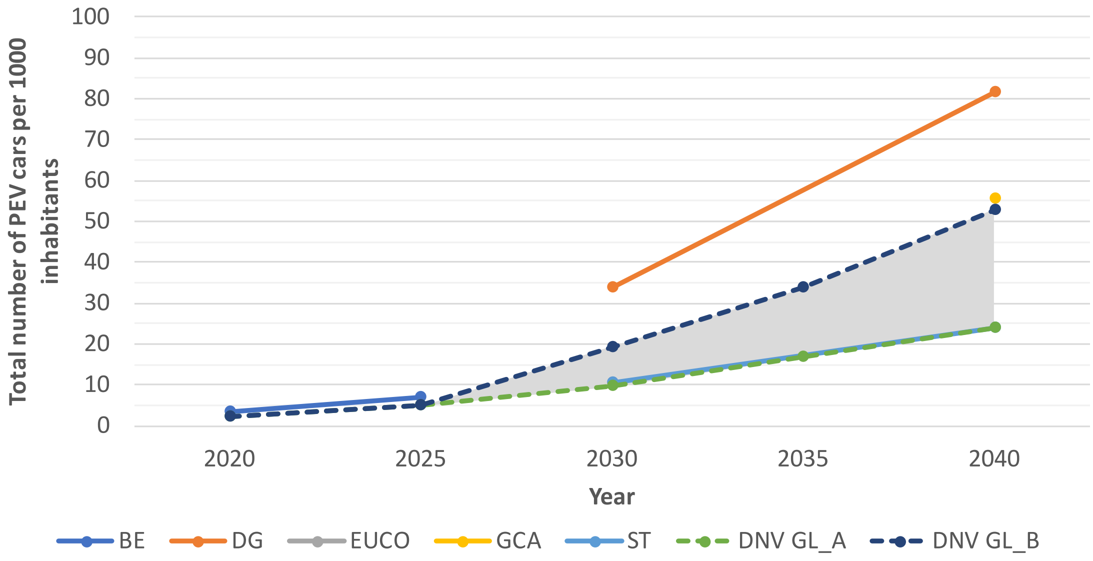


Figure 40: ENTSO-E and DNV GL projections for EV in Republic of North Macedonia, in PEV per 1000 inhabitants

Source: DNV GL analysis

Scenario A is roughly identical to ENTSO-E's ST scenario. It means that Republic of North Macedonia expects to have about 10 PEV per 1000 inhabitants by 2030, and 24 vehicles by 2040. In other words, Republic of North Macedonia would accomplish the 2020/ 2025 targets of Germany with a delay of de facto 5 years (by 2030) while it would have the same penetration in 2040 as more advanced countries are expected to have by 2025 (like Austria, France, the UK, Ireland and Portugal)

Scenario B is more progressive and assumes that one will see 35 PEV on the roads in Republic of North Macedonia in 2030, and about 53 in 2040. For 2040, it corresponds roughly to the ENTSO-E GCA outlook. This scenario literally assumes Republic of North Macedonia will have the same (high) penetration by 2035 as the very ambitious countries will achieve by 2020-2025. This means a time lag of about 10 years compared to very ambitious countries in terms of EV; Nonetheless, in this scenario Republic of North Macedonia would keep pace with many other countries with regards EV dissemination.

4.1.2 Spatial Development of PEV

In each scenario, total PEV numbers (per year) will be split by region in Republic of North Macedonia. To define the number of PEV by region, we look into the following parameters (see Annex I):

- Population
- BIP and Income
- Vehicles
- Tourism

These parameters are analysed to see whether they serve as indicator for the future split of PEV per region. We note this analysis is limited to a consistent set of statistical data for the period 2007-2016, while we are not aware of relevant studies that forecast one of these indicators for the next 1-2 decades.

The reason why tourism is looked at is the hypothesis some regions host a high number of tourists. This might suggest a noticeable increase of population by temporary visitors and adding (a considerable number of) new PEV apart from those considered for residential population.

Proposed Regional Split of PEV Development of PEV scenario

Table 8 below shows several potential regional splits of the assumed PEV growth according to 2016 values of population, GDP or cars per capita. It may be observed that the difference between Skopje region and the other regions is relatively high in terms of population and cars per capita, while the difference is less pronounced in terms of GDP and average net wage.

Table 8: Regional indicators for North Macedonia

	Population	GDP	Average monthly net wage	Cars per capita
Vardar Region	7%	15%	11%	6%
East Region	8%	13%	11%	8%
Southwest Region	11%	11%	13%	10%
Southeast Region	8%	16%	11%	7%

Pelagonia Region	11%	13%	13%	12%
Polog Region	15%	6%	14%	10%
Northeast Region	8%	8%	11%	7%
Skopje Region	30%	19%	17%	39%

Source: DNV GL analysis, based on data from State Statistical Office of the Republic of North Macedonia

As there is no clear picture of the historic and future drivers for the regional development of PEV, we use the population density of 2016 as a compromise. And in the absence of regional population projections, we assume today's regional split to remain constant. As shows, this means, for instance, the Skopje region will accommodate 30% of all PEV in any year whatever the scenario is.

Applying the current population split to the projected development of PEV gives the values shown in Table 9 below.

Table 9: Regional PEV growth reflecting current population split

	Scenario 1			Scenario 2		
	2025	2030	2040	2025	2030	2040
Vardar Region	736	1,471	3,679	1,471	2,207	7,357
East Region	850	1,700	4,250	1,700	2,550	8,500
Southwest Region	1,060	2,119	5,298	2,119	3,179	10,597
Southeast Region	837	1,674	4,184	1,674	2,511	8,369
Pelagonia Region	1,109	2,218	5,546	2,218	3,327	11,091
Polog Region	1,547	3,094	7,736	3,094	4,641	15,471
Northeast Region	850	1,699	4,248	1,699	2,549	8,495
Skopje Region	3,012	6,024	15,060	6,024	9,036	30,119

Source: DNV GL analysis, based on data from State Statistical Office of the Republic of North Macedonia.

Role of Tourism

Our review of the level of tourism compared to permanent population shows that in particular the regions of Skopje, Southwest and Southeast are visited by a considerable number of tourists (domestic and foreign) throughout the year. In fact, there is some potential for tourism triggered PEV use in Skopje for the high (total) number of visitors. In the other two regions, a considerable number of visitors compared to permanent population arrives and stays primarily in summer, suggesting a comparably high potential for PEV use for touristic purposes in summer season (presumably in the rental car sector).

If the touristic peak month was taken as an indicator for the additional number of PEV that might be put at the disposition of visitors, the number of PEV shown for the three regions in Table 9 would increase as follows (see Table 10). The additional power of the all additional PEV will be in the range of 1 to 160 MW, depending on the year, scenario, region and the assumed charging power.

Table 10: Tourism triggered need for PEV per year in three regions

	Scenario 1			Scenario 2		
	2025	2030	2040	2025	2030	2040
Southwest Region	317	634	1585	634	951	3170
Southeast Region	215	431	1077	431	646	2154
Skopje Region	142	284	710	284	426	1421
Sum	674	1349	3372	1349	2023	6745
Additional power of all cars						
- Assuming 3.7 KW / car						
o Southwest Region	1	2	6	2	4	12
o Southeast Region	1	2	4	2	2	8
o Skopje Region	1	1	3	1	2	5
- Assuming 50 KW / car						
o Southwest Region	16	32	79	32	48	158
o Southeast Region	11	22	54	22	32	108
o Skopje Region	7	14	36	14	21	71

Source: DNV GL analysis, based on data from State Statistical Office of the Republic of North Macedonia.

However, it should be noted that the numbers in Table 10 reflect an overly optimistic view on the impact of tourism on new PEV.

- First, it assumes one additional PEV per visitor visiting the region in touristic peak month. In reality, the ratio of rental cars per visitor will be much lower.
- Secondly, the figures in Table 10 do not differentiate between foreign and domestic visitors and assume each of them will equivalently seek a (rental) PEV. This is unrealistic as it is probably fair to assume that domestic tourists will likely not want / need to rent a PEV at their destination but would use their own car.
- Thirdly, additional high charging / discharging power from additional PEV is based on the assumption fast charging (e.g. at 50 kW) was available, as already being considered by the local DSO in North Macedonia.

However, assuming a far lower ratio of rental PEV per visitor reduces also the relevance of tourism for the total number of PEV to be assumed.

For instance, a rental PEV per visitor ratio of 10% would reduce the number of new PEV that is tourism triggered from ca. 30% to ca. 3% in the Southwest and Southeast region. This considerably lowers the impact the additional cars might have on the system, e.g. for provision of balancing reserves. As a result, we conclude that today's tourism figures do not justify increasing the number of prospective PEV and considering the tourist sector as an additional driver for PEV growth. This is only conceivable for 2040 s.t. very optimistic assumptions on the availability of fast charging and on the ratio of PEV per tourist.

4.2 Assumptions on PEV

4.2.1 PEV Technologies Considered

It may be expected all PEV technologies, incl. PHEV and REEV, will have their fair share in the growth of the e-mobility sector in Republic of North Macedonia. Yet, we propose to limit the analysis to BEV and neglect PHEV and REEV for the following reasons.

BEV tend to have a larger battery and are able to fully source the energy required for the travel distances assumed in this study from the battery only. Moreover, as the battery capacity and the discharge level (in kWh) tends to be higher in BEV the benefit and burden to the power system are more pronounced than with alternative vehicle types. The re-charging requires more electric energy, can take more time or may be stretched over a larger period, while the battery provides for more flexibility to provide balancing reserves.

Finally, reducing the number of technologies to be considered reduces complexity in the market model as aggregation becomes easier.

4.2.2 Technical Assumptions on PEV

Battery size

For the battery size in kWh, we rely on typical batteries used in vehicles that are currently available in the market. In the base case, we assume a size of 30 - 50 kWh.

In fact, there is no expectation in the sector a bigger battery will be needed in the future even to allow for long-distance travelling. Because a more densely meshed network of fast charging stations would allow also cars with relatively small batteries to make large distance trips.

Charging technology and power

By default, we assume slow (AC) charging at a rate of 3.7 kW for all PEV. A potential variation assumes a (small) portion of vehicles re-charging at higher power rates (e.g. 22 kW corresponding to medium speed).

There are various reasons for this conservative view on the prospective development of charging infrastructure. We assume there is or very limited scope for funding of fast charging infrastructure by public authorities or enterprises in Republic of North Macedonia. Hence, the bulk of the charging infrastructure is assumed to be purchase by individuals and be placed in private homes. However, the high price of charging infrastructure, households' limited income in Republic of North Macedonia and the limited power margins for charging available in private sector homes provide for considerable hurdles for fast charging.

One should bear in mind that the average daily travel distances combined with the energy consumption per 100 km lead to relatively low discharge levels, i.e. vehicles return to their base with a considerable amount of energy still stored in the battery. The differences in charging time between different levels of fast charging will, however, remain unnoticed by the market model as it operates on an hourly basis and fractions of an hour are not considered.

For simplicity, we do not consider efficiency losses for market simulations. Although this leads to a small loss of accuracy, this simplification appears justified against the background of the high efficiency (approx. 95%) of model Li-ion batteries.

Typical energy consumption

In this study, we assume, based on realistic values observed today, an energy consumption of 20 kWh / 100 km.

4.2.3 Driving Patterns of EV and PHEV

Due to the low penetration level by PEV and limited charging infrastructure available, little experience has been gained public on usage patterns of PEVs, including daily distances made, return time, charging habits, etc. Moreover, as PEVs grow in numbers and the right charging infrastructure becomes available, usage patterns will change.

In turn, there is more and long-term information on conventional car usage available from national surveys. Assuming certain efficiency of the electric drive train and similar usage patterns for conventional and PEVs, offers the possibility to use these surveys to derive assumptions on daily distances made, battery discharge level, etc. We are aware of the limitations of this approach, as, for instance, PEVs provide for a limited range in km only, compared to conventional fuel cars. Yet, we think some analogy for the two car technologies can be made and experience from conventional cars can be transferred to PEVs.

There are some studies on a national and European[40] level available that analyse the usage of cars in daily life. Hereafter, we depict the results from some of these studies, noting that the scope and results slightly differ. This and other data is used to derive appropriate assumptions for PEV in chapter 4.2. We focus on two key parameters:

- Time of car usage and return time
- Total daily travel distance

Time of usage and return time

An important parameter for this study is the time dimension in car usage. This means both the time when cars are driving and the time when they return to their home base or reach an intermediate destination with the possibility to connect to the grid. The difference between the two parameters

[40] E.g. “Driving and parking patterns of European car drivers --- a mobility survey”, JRC, 2012

practically means the driving period and the parking period, respectively. While parking, cars may be connected to the charging infrastructure.

The following figure depicts the hours during a typical working day (Monday to Friday), Saturday and Sunday when vehicles usually drive and return home. The majority of trips is made and finished between 9 am to 5 pm.

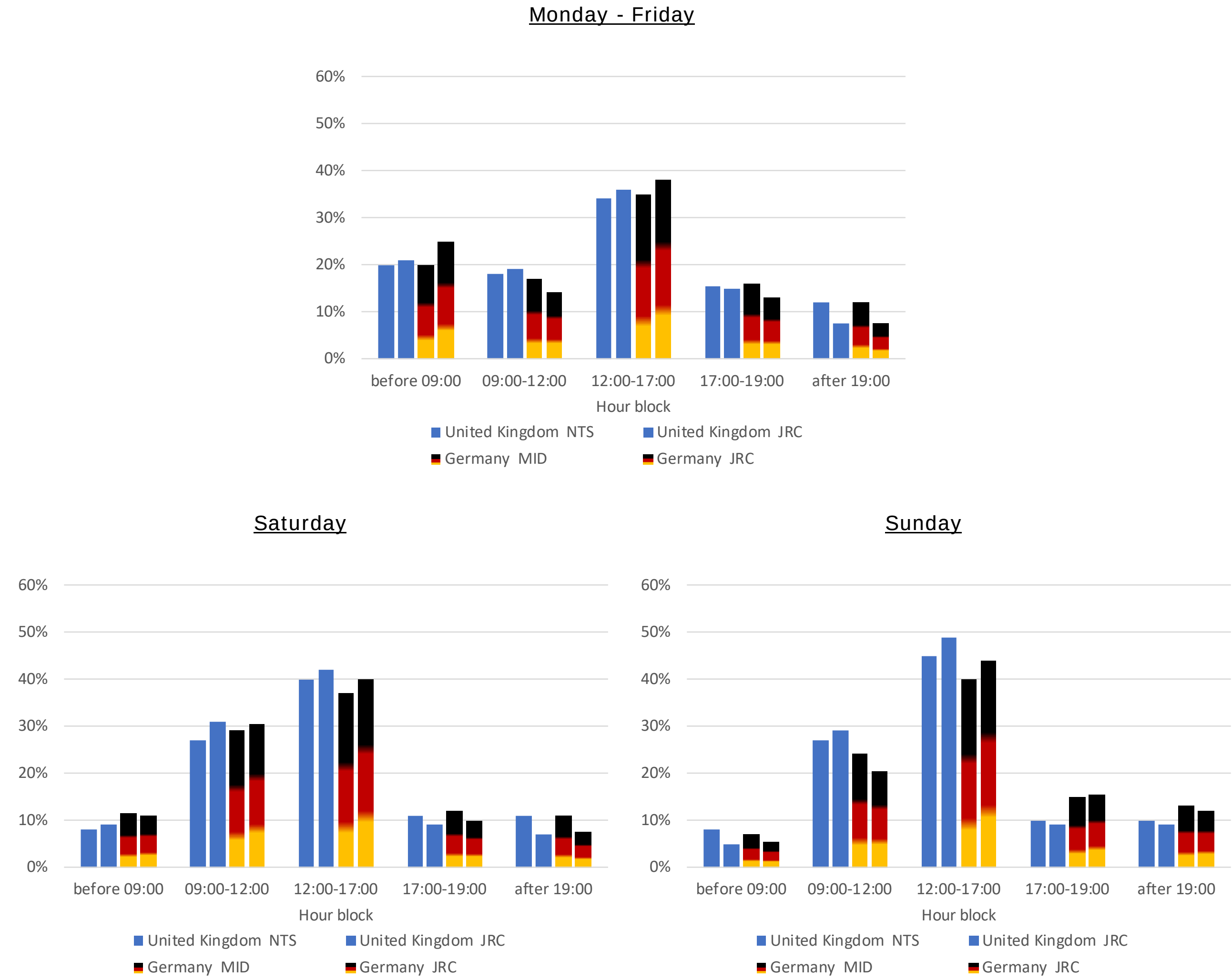


Figure 41: Comparison of distribution of car trips departure time in United Kingdom and Germany, according to JRC survey and national surveys (German MI, UK NTS).

Source: DNV GL analysis, based on “Driving and parking patterns of European car drivers --- a mobility survey”, JRC, 2012

To reflect in our model the fact that the return time is probabilistic, we derive 4 user types based on the JRC survey on the distribution of the travel and return time:

- “Morning driver”: leaving and returning on the same morning
- “Part-time” driver: leaving in the morning and return by early afternoon
- “Late return” driver: leaving in the morning and return late in the afternoon

- Charging throughout the day: variable leave, travel and return time

User types refer to probability density functions of their travel and return time. The density functions are assumed to be Gaussian distributed. Moreover, each user type has a different travel and return time pattern for working days, Saturdays and Sundays. For working days, the different user types are depicted in Figure 42.

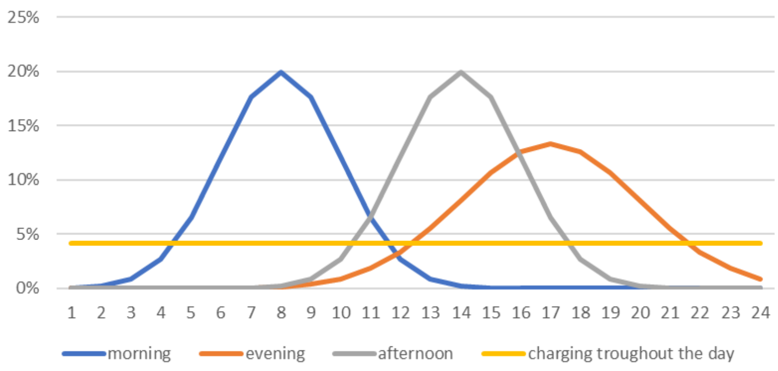


Figure 42: Hourly pattern of travel and return times for PEV users (Monday – Friday)

Source: DNV GL analysis

Combining the different user types with travel distance information (see below), one can calculate the mixed travel and return time profile combined with the discharge level of PEV and the corresponding need for charging need (in kWh). To do so, we add weights to each of the four user types that express their assumed probability, separate for working days, Saturdays and Sundays. For instance, for working days the following weights are used:

- “Morning driver”: 25%
- “Part-time” driver: 19.5%
- “Late return” driver: 55%
- Charging throughout the day: 0.5%

The mixed travel and return time profile (density function) is shown in Figure 43 (without travel distance information). As may be observed, it roughly reflects the empirical values shown in Figure 41 above.

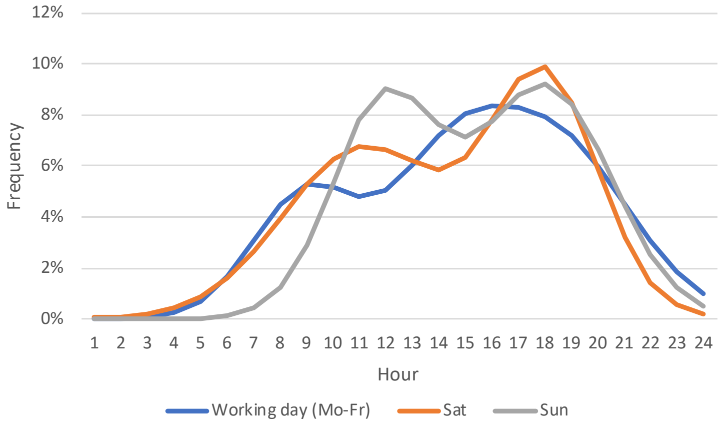


Figure 43: Aggregate PEV hourly usage patterns

Source: DNV GL analysis

Travel Distances

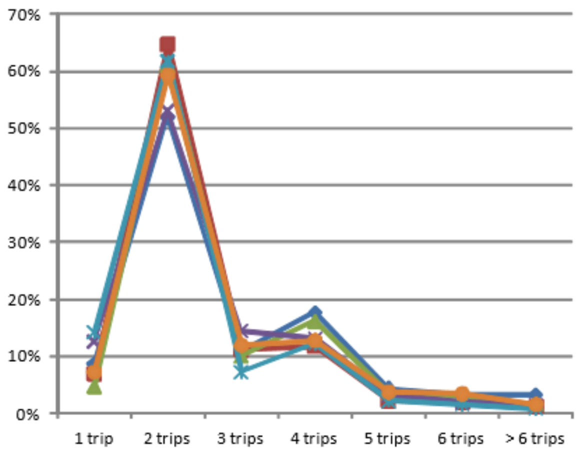
Statistically, there is little discrepancy between countries with regards the number of trips per day. Empirical evidence suggests[41], making 2 trips has a probability of 50-60% in all countries analysed, while 1 trip or more than 2 trips occur with a probability of 5-10%. In other words, half of the people use their car to go to one place only, presumably work, and return home.

From the actual number of trips the average number of trips is determined. In all countries analysed, the average number of trips per days is similar, i.e. 2-3 trips, with minor differences between weekdays. In most countries, Monday is the day when statistically less trips are made, while people make a slightly higher and similar number of trips on other days.

The figure to the right shows the total average daily driven distance in six countries. In Poland and Spain, the daily driven distance exceeds 70 km or even 80 km; in Germany, Italy and France it is in the range of 50-60 km and in the UK around 40 km; in all of the countries, the travel distances are similar on all days and there are no significant differences between working days and weekends.

[41] "Driving and parking patterns of European car drivers --- a mobility survey", JRC, 2012

Distribution of daily car trips by country



Average daily driven distance (km) by day and country

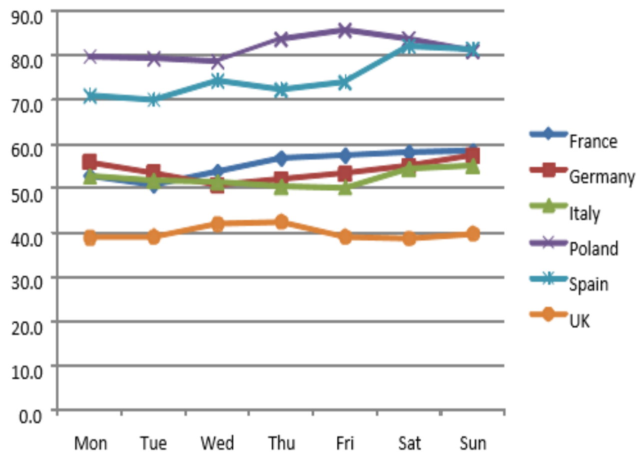


Figure 44: Distribution of daily car trips by country (left) and average daily driven distance (km) by day and country (right)

Source:

Moreover, not all car users drive the average distance, but there are individual differences in the distance made.

As empirical evidence shows total daily travel distances (incl. all trips per day) have a probabilistic density function similar to a Weibull distribution function [42], i.e. shorter travel distances are more frequent than longer journeys. This is because of a different number of trips and the length of each trip, e.g. distance to work. It is fair to assume that more trips per day lead to higher total distances travelled in one day.

For simplicity, we refrain from a probabilistic approach for daily travel distances but assume in our model the differences between user types as shown in Table 11. The travel distance assumed for the last 2 user types roughly corresponds to the average daily travel distance that has been empirically found. The travel distance assumed for the first two users reflects our expectation that a reduced travel time will lead, on average, to shorter travel distances.

To avoid over-estimating electricity consumption by EVs, and to account for the relatively small size of North Macedonian towns, we also consider a sensitivity with reduced average distances, as shown on the right side of Table 11.

[42] See e.g. https://www.forschungsinformationssystem.de/servlet/is/80865/

Table 11: Daily travel distance assumed per user type

User type	Daily travel distance assumed (km)	
	Base	Sensitivity
"Morning driver":	25 km	20 km
"Part-time" driver		
"Late return" driver	50 km	
Charging throughout the day		

Source: DNV GL analysis

The hourly PEV usage profile of each user (see above) is combined with assumption on the daily travel distance (see Table 11) to derive the mixed discharge level for each hour across all user types, as summarised in Table 12.

Table 12: Overview of assumptions for PEV

Parameter	Assumption
Battery used in PEV	
PEV technology	• Focus on BEV (neglect PHEV and REEV)
Size in kWh	• Base case: 30 kWh • Variation: 50 kWh
Charging technology and power	• Base case: 3.7 kW for all PEV, i.e. no fast charging • Potential variation: Share of fast charging at variable kW (e.g. 22 kW) • No efficiency losses assumed while charging • Fast charging case: 12.5 kW faster charging
Typical energy consumption	• 20 kWh / 100 km
Usage pattern of PEV	
Usage type, incl. probabilistic time of return and discharge level	• Differentiation between 3 different driving patterns (see study) defined by the return time (separate per weekday) • Complemented by a user type that has no a specific leave/ return pattern during daytime, including night driving times and provides for a uniform probability to charge for all 24 hours.
Typical driving distances	• 50 km per day for PEV returning in the late afternoon / evening, and PEV with no clear driving / parking pattern • 25 km for PEV returning between morning and early afternoon • Additional sensitivity with 20 km for all PEV

Source: DNV GL analysis

4.3 Assumption on Regional Structure used in the Market Model

The market model considers a regional split into 3 areas. Each of them combines various regions defined according to the State Statistical Office of the Republic of North Macedonia. Figure 45 illustrates the allocation of regions to market model areas.

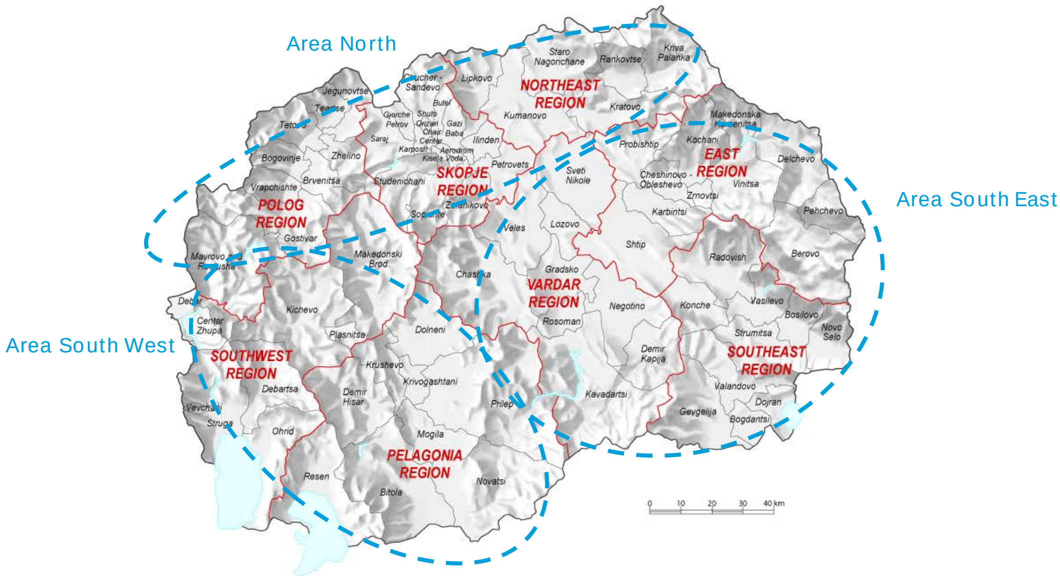


Figure 45: Allocation of Republic of North Macedonia regions to areas in the market model

Source: DNV GL analysis, map from State Statistical Office of the Republic of North Macedonia

Combining the allocation of Republic of North Macedonia regions to market model areas with the regional PEV growth assumed gives the following PEV figures per market model area, as shown in Table 13. It is expected that in future a higher part of the population will be located in the Skopje region, or in Northern North Macedonia. Furthermore, in July/August a 10% higher availability of cars – and therefore EVs - due to tourists visiting is assumed for each year.

Table 13: Assumptions on future evolution of PEV in North Macedonia

			Number of PEV					
			Scenario 1			Scenario 2		
	Population	%	2025	2030	2040	2025	2030	2040
North	1,125,391	54%	5,423	10,846	27,114	10,846	16,268	54,228
Southeast	501,270	24%	2,415	4,831	12,077	4,831	7,246	24,154
Southwest	448,640	22%	2,162	4,324	10,809	4,324	6,485	21,618
Sum	*2,075,301*	*100%*	*10,000*	*20,000*	*50,000*	*20,000*	*30,000*	*100,000*

Source: DNV GL analysis

4.4 Charging Strategies

The following sections outline firstly the charging strategies on the North Macedonian market and secondly the ability of the grid to handle the analysed EV charging strategies.

DNV GL has considered two different charging strategies for the two scenarios presented in Table 13 above. For each of these two charging strategies a faster charging rate of 11 kW per car and a slower charging rate of 3.7 kW per car was considered (in line with the rates outlined in Table 12), to reflect the possible technological development:

- EVs are pure **consumers**, or
- EVs provide vehicle-to-grid (**V2G**) services.

This means that in total 8 possible future charging possibilities, or cases, were explicitly considered:

1. Slow charging EVs as expected in scenario 1
2. Slow charging EVs as expected in scenario 2
3. Slow charging V2G enabled EVs as expected in scenario 1
4. Slow charging V2G enabled EVs as expected in scenario 2
5. Fast charging pure consumers as expected in scenario 1
6. Fast charging pure consumers as expected in scenario 2
7. Fast charging V2G enabled EVs as expected in scenario 1
8. Fast charging V2G enabled EVs as expected in scenario 2

As **consumers**, EVs can only withdraw power from the grid but not discharge. This represents a conservative assumption as EVs have limited flexibility as to when they draw from the system. Combining grid connection of the vehicles with the slow or fast charging rate of 3.7 or 11 kWh/h yields the following profiles when and how much one EV charges per hour.

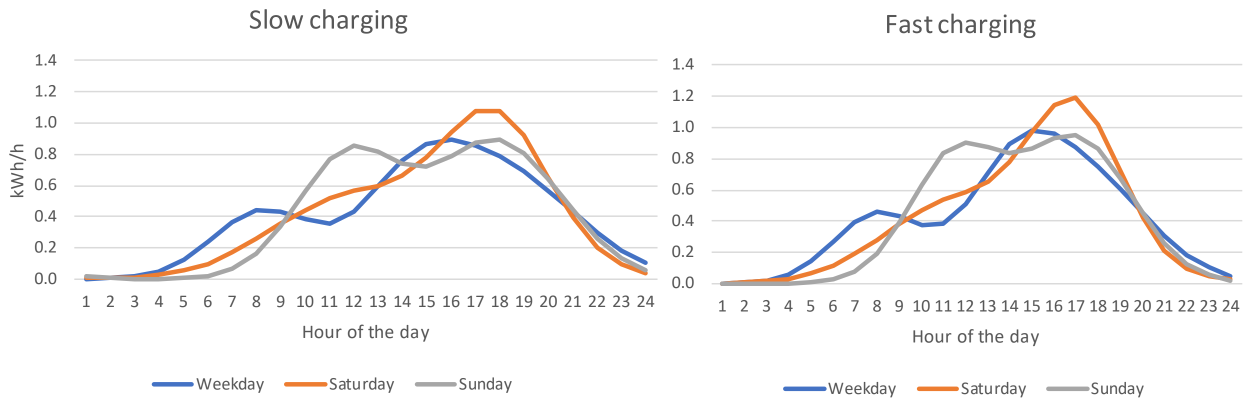


Figure 46: Probability profiles for slow (left) and fast charging (right) charging in kWh/h
Source: DNV GL analysis

The charging patterns are similar as the EVs recharge at identical times and can recharge at identical times, but in the slow charging case they have to charge over several hours, whereas for the fast charging case the EVs can fully recharge within one hour. As a result, the profile for slow charging EVs only reaches to a maximum of about 1.1 kWh/h per car, whereas for the faster charging vehicles the charging can be faster and higher, reaching 1.2 kWh/h per EV on Saturdays around 5pm, or 17:00 h.

Depending on the number of EVs assumed to be available in a scenario, the above number for one EV is the multiplied with the total number of EVs in North Macedonia to receive the total consumption of power from the grid per scenario.

If EVs can provide **V2G** services it is more important when an EV is connected to the grid, than when it has discharged and returns to the grid to charge. As a result, the following parameters play a role and when they are connected to the grid at any given time:

- the capacity attached to the grid (both charging and discharging)
- the volume/tank availability attached to the grid
- the EVs/power leaving the grid, or EVs currently away and/or driving
- the EVs/power returning to the grid (with some energy consumed by driving, or lost)
- the power required by an EV at any given time to be ready to drive

The EVs diving away or returning to the grid influence the capacity available to the system. The charging and discharging capacity therefore vary over time, as does the tank or volume availability. The charging resp. discharging capacity is assumed to follow the below weekly patterns for one EV that can charge slowly (at 3.7 kWh/h) or quickly (at 11 kWh/h) as shown in Figure 47.

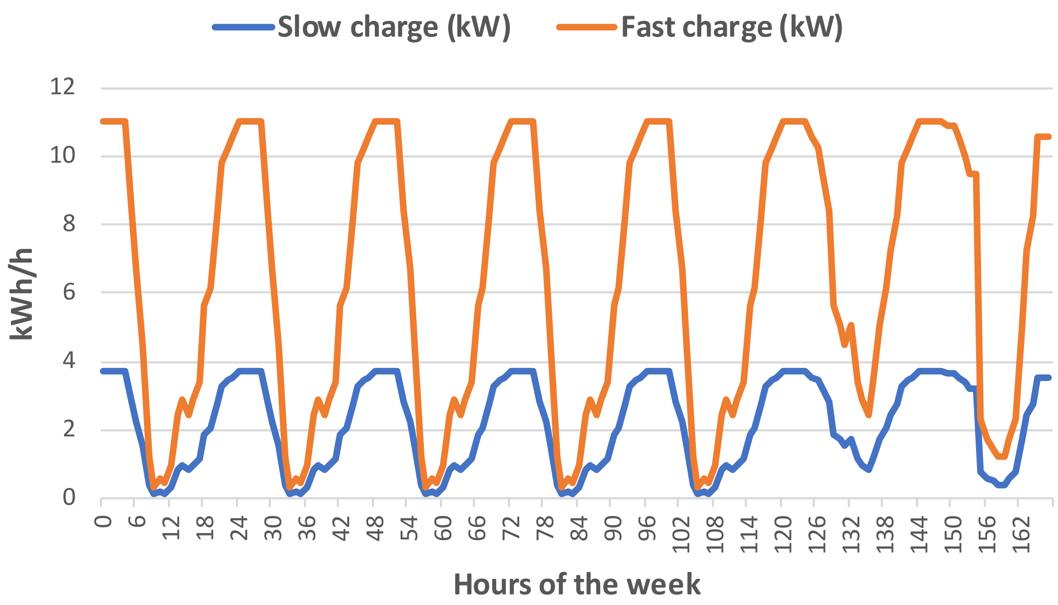


Figure 47: (Dis-) Charging capacity of single slow and fact charging PEV during the week
Source: DNV GL analysis

This capacity is then multiplied with the number of EVs assumed to be available in a given scenario to determine the overall capacity available to North Macedonia. As the capacity is divided over a number of EVs it is possible to charge and discharge simultaneously. This could be useful to allow constant availability of power to both EVs and the system.

Constraints are implemented on the EVs: First, it is assumed that vehicle owners would allow for a maximum rate-of-discharge of 80%, i.e. that a remaining charging level of 20% has to be maintained at all time, in order to avoid an excessive reduction of battery lifetime. Also, it is assumed that EVs must be completely charged in the morning day to accommodate travel needs of drivers. As a conservative assumption, all cars must be fully charged by 5am[43].

The tank volume the EVs are attached to follows the following pattern, combining what power is available with the constraints imposed defining what power level is required at a given time.

43 Clearly, both assumptions are at the extremes, i.e. there may drivers who would not accept such high discharge levels or could agree to partial battery load in the morning hours. In reality, vehicle owners or 'aggregators' being responsible for selling EV-based services into the market will likely use more sophisticated algorithms.

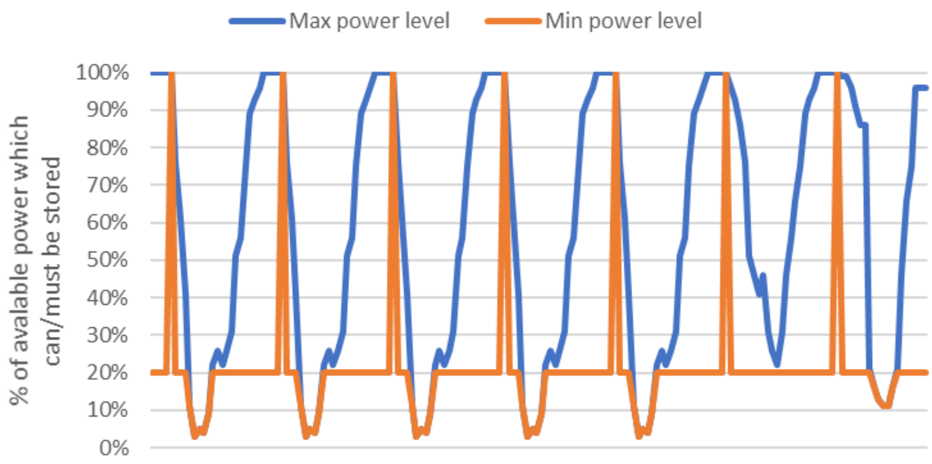


Figure 48 Minimum and maximum allowable volumes (or tank filling levels)

Source: DNV GL analysis

When cars are travelling during the course of the day, the volume dips as fewer EVs are assumed to be attached to the grid. The actual power available to the market has to be between the minimum and maximum level. This available power further changes based on EVs returning and driving away. The following patterns were assumed for this purpose.

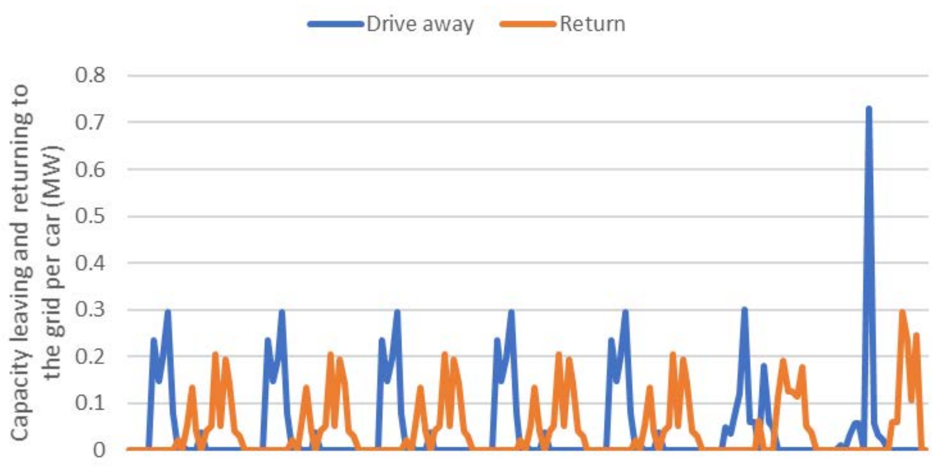


Figure 49 Capacity which leaves or returns to the grid over the course of a week (Monday – Sunday)

Source: DNV GL analysis

These patterns were derived from statistical data when cars are home (which is also when the EVs would be assumed to be attached to the grid) and when not. The above patterns indicate that during the morning cars leave and return around noon and during the late afternoon.

To summarize, two charging strategies were analysed for different numbers of EVs in the North Macedonian market: one strategy entailed the EVs acting as pure electricity consumers, another strategy considered EVs as V2G service providers that consume some power but could also store power for later release.

4.5 Summary

Table 14 summarises the assumptions on PEV penetration in North Macedonia in 2040 as developed in this chapter. As explained above, we assume that up to 100,000 PEVs may be used in 2040, corresponding to 50 PEV per 1,000 inhabitants. Besides the number of PEVs, Table 14 also shows the aggregate dis/charging capacity of all PEVs for the two scenarios considered, once using assumptions on slow charging (3.7 kW) and once with a mix of slow and fast charging (12.5 kW). Consequently, the total additional impact may reach up to 1,250 MW in the year 2040. Assuming an average travel distance of 50 resp. 20 km per day, these assumptions furthermore lead an additional electricity consumption of between 73 and 365 GWh/year.

Table 14: Summary of assumptions on PEV penetration in North Macedonia (2040)

Area	Share	# PEVs		Dis-/Charging capacity (MW)			
				Slow charging		Fast charging	
Scenario		A	B	A	B	A	B
North	54%	27,000	54,250	100	201	338	678
Southeast	24%	12,000	24,000	44	89	150	300
Southwest	22%	11,000	21,750	41	80	138	272
Total	100%	50,000	100,000	185	370	625	1,250

Source: DNV GL analysis

Table 15 summarises the key assumptions for further analysis under chapter 5.

Table 15: Key assumptions on PEV for further analysis

Parameter	Assumptions
PEV technology	• Focus on BEV (neglect PHEV and REEV)
Size in kWh	• Base case: 30 kWh • Variation: 50 kWh
Charging power	• Base case: 3.7 kW for all PEV, i.e. no fast charging • Potential variation: 12.5 kW faster charging
Typical energy consumption	• 20 kWh / 100 km
Driving patterns	• Differentiation between 3 different driving patterns (morning/evening, late return, permanent travel)
Typical driving distances	• 50 km per day for PEV • Additional sensitivity with 20 km for all PEV

Source: DNV GL analysis

5 TECHNICAL, ECONOMICAL AND REGULATORY ANALYSIS

5.1 Economic and System-Level Analysis

5.1.1 Market model results – overview

The economic analysis is based on market simulations carried out in the PLEXOS market model while neglecting national grid constraints. As Table 16 shows, we have used a regional model, which includes separate bidding zones for North Macedonia and other countries in South-Eastern Europe. Whilst other countries were represented with a limited degree of detail, the model considered all individual generating units within North Macedonia and key technical and commercial parameters. The model was used to carry out full hourly chronological simulations for all relevant years, i.e. 2025, 2030 and 2040.

PEV were modelled on an aggregate level in the form of energy storage, with one storage unit considered for each of the three regions within Macedonia. Besides maximum dis-/charging capacity and round-cycle efficiency, the 'PEV storages' were combined with 'enforced energy losses' representing the electricity consumption of PEV whilst driving. We varied available dis-/charging capacities, 'normal' and permitted storage levels on an hourly level, based on the typical hourly patterns for different type days (weekday, Saturday, Sunday) presented in section 4.4 above. These assumptions were furthermore varied between scenarios, reflecting different assumptions on the flexibility of PEV. Likewise, we differentiated between scenarios with 'native PEV consumption' (i.e. reflecting the original needs of the PEV), with modified charging patterns (responding to hourly market prices) and the option of providing additional services to the system, incl. discharging into the system ('vehicle-to-grid', or V2G).

Table 16: Key features of modelling approach for market modelling

Key features of modelling approach
• Based on regional market model (PLEXOS) • Hourly chronological simulations for set of photo years (2025/30/40) • PEVs represented as energy storage o Enforced energy 'losses' (PEV consumption) o Time-variable capacity o Options for flexibility, V2G
• Complementary analysis on impact on need and provision of ancillary services (at transmission)

Source: DNV GL

For the load analysis (see section 5.2.1), the incremental load and/or generation by PEV was distributed to individual grid nodes proportional to the nodal distribution of non-industrial consumption, i.e. we assumed that PEV load is distributed – within each region – in the same manner as non-industrial load. Likewise, the market model contained a simplified representation of reserves only. For further analysis (see section 5.1.3 below), the modelling results were complemented by additional assumptions and calculations to assess the potential impact and contribution of PEV on the need and provision of ancillary services.

Figure 50 shows how annual electricity prices are influenced by the two charging strategies. For comparison, the case that no EVs enter the market and create any kind of impact is also considered. The dark blue shows the base price for the case without EVs. Yellow to red bars indicate the EVs functioning as pure consumers, whilst green shaded bars show the cases where EVs are flexible and can discharge as well as charge.

Figure 50 indicates that prices vary little between different charging strategies, different number of EVs and different loading rates of these EVs. The charging rate of the EVs, whether fast or slow, has a negligible influence. Depending on the distances driven and the resulting power requirements, the charging capability of between 3.7 and 11 kWh/h per car is sufficient to “fill the tank” in one hour. This is supported by the minimal difference in charging profiles seen in Figure 46.

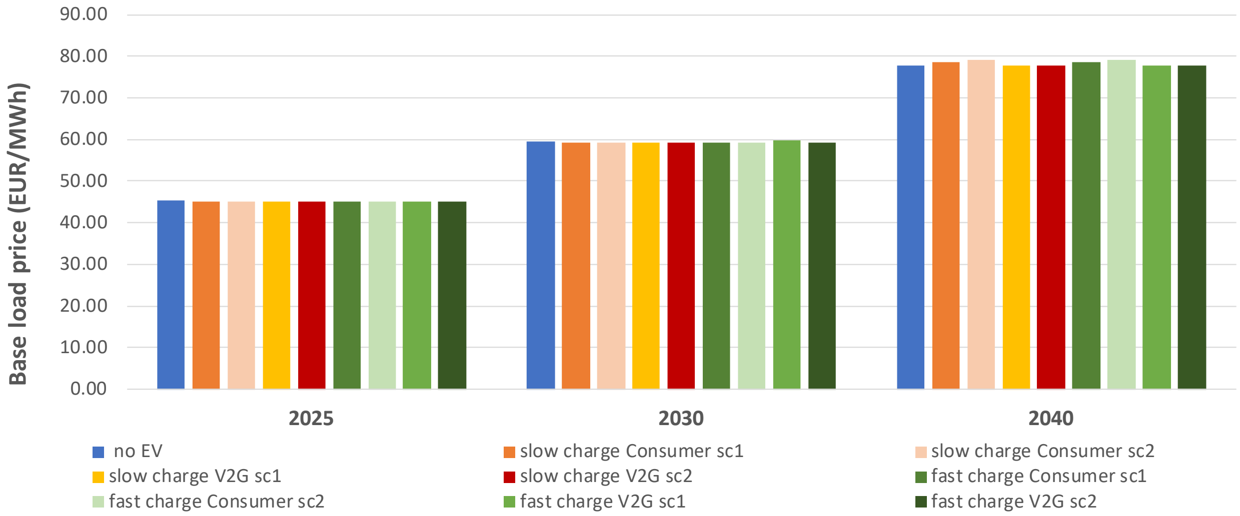


Figure 50: Effect of PEVs and charging strategies on base load electricity prices

Source: DNV GL analysis

A verification check where the model is altered to penalize high switching between generators[44] showed that **base prices are hardly influenced by the number of EVs** within the scenarios considered, at least as long as **EV exclusively act as consumers**. In 2025 and 2030, having more EVs as consumers (looking at the development from scenario 1 to scenario 2, or sc 1 to sc 2) hardly affects the base price, whereas in 2040 the price rises a little. This price increase is intuitive: prices increase as consumption increases. Therefore, more plants with higher operational costs have to be dispatched to meet the extra power required by the EVs acting as consumers.

Having **EVs with V2G capability,** on the other hand, lowers base prices after 2025. Two contravening effects are at work here:

1. First the base price increases compared to a situation with not EVs due to the increasing load of EVs.

[44] Fictional start costs were considered.

2. Then the base price is lowered due to the load shifting the V2G enabled EVs can do: The EVs load power in times where generation is cheaper and discharge when more expensive generators would otherwise need to start up.

Next, Figure 51 shows the volatility of hourly prices (measured as a standard deviation of hourly market prices). The graph indicates that the presence of EVs as additional consumers increases volatility. In contrast, V2G services reduce variability of price[45]. Again, these observations seem intuitive.

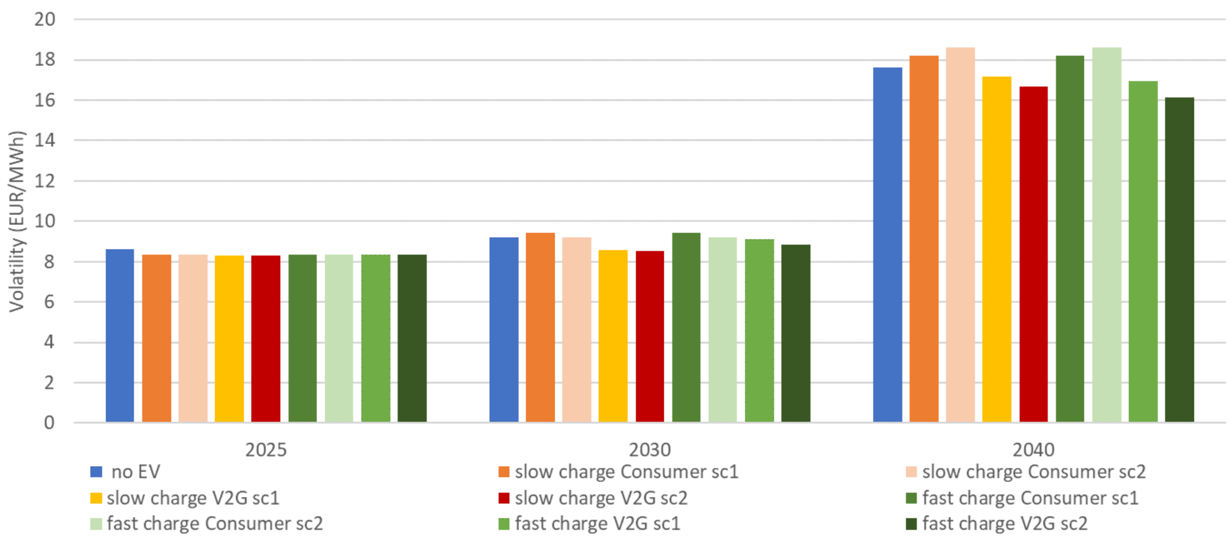


Figure 51: Effect of PEVs on annual price volatility

Source: DNV GL analysis

To summarize the effect of the expected developments of EVs shown here:

1. As the number of EVs grows, the load will grow and thereby raise prices.
2. The charging rate of the EVs is expected to have a negligible influence.
3. Having EVs capable of delivering V2G services potentially increases the base price initially due to increased load, but as more V2G capable cars become available, the load shifting has a price level and volatility lowering effect.
4. Having EVs as pure consumers increases the base price as well as the price volatility due to increased load.
5. Overall, EVs are expected to have a minimal influence on the system prices under the expected growth of EVs in North Macedonia at least until 2040 or until a comparatively high contribution can be made by EVs.

45 Figure 51 seems to indicate that having additional EVs as consumers in 2030 leads to decreasing volatility. However, this is a misleading observation caused by rounding errors. A closer look at the results confirmed that price volatility does indeed consistently increase.

5.1.2 Price and System Effect of PEVs – Examples from 2040 Scenario 1

As stated above, the influence of PEV on the North Macedonian power system and market seems to be very limited. To investigate these effects more closely, this section takes a closer look at selected results from scenario 1 in 2040, i.e. in a situation with a high penetration of PEV. The results shown below refer to all charging strategies. i.e. no EVs, EVs acting as pure consumers and EVs supplying V2G services.

Price and load duration curves

Figure 52 shows the annual price and load duration curves for North Macedonia for the case described above. The duration curves are shown for the case that no EVs are present (grey), EVs act as pure consumers (blue) or EVs can supply V2G services (orange).

It can be clearly seen that the duration curves for price differ minimally. In general, EVs acting as pure consumers lead to slightly increasing prices. This can be explained by the fact that EV consumption raises load at certain times, thereby requiring more expensive generators to run more. In contrast, EVs with V2G ability in the power system reduce high prices, while slightly raising otherwise lower prices. The reason for this is the behaviour of V2G enabled EVs: They charge and increase load in times that power is cheap and discharge power into the system at periods or higher prices, thereby reducing the generation of higher priced power.

These observations are supported by the load duration curves. In the presence of PEVs with V2G ability, peak load is reduced, whereas demand during low-load periods on the right is increased. If EVs are consumers only, overall load increases.

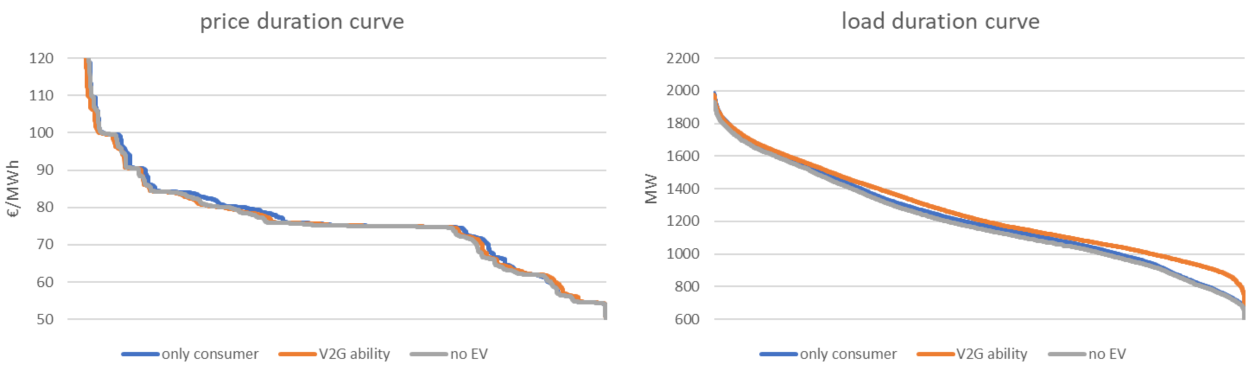


Figure 52: Price and load duration curves for 2040 scenario 1

Source: DNV GL analysis

PEV consumption and impact on generation dispatch and market prices

Figure 53 shows the dispatch of plants in North Macedonia during the first week on October as an example. This week and the associated dispatch are shown for three cases, i.e. without PEVs, with EVs acting as pure consumers and with EVs using V2G ability.

The green shaded areas show the demand, or generation, of EVs. If EVs are V2G enabled, they can generate to or draw from the grid with their full capacity, therefore the green shaded areas are more prominent in the top graph compared to the middle graph showing EVs as pure consumers. The behavior of V2G enabled cars shows a rising tendency to discharge in the evenings. Around midnight, i.e. when overall load decreases, EVs switch to charge their batteries in order to be full in the morning. Only some activity can be observed throughout the day, i.e. when these EVs are attached to the grid and their V2G capability made available to the grid. In summary, V2G enabled EVs allow for elimination of some price spikes as EVs can deliver power to the system but lead to higher prices during other periods.

The second graph shows that the 'native' load of PEVs, i.e. the electricity required for driving, remains marginal. Consequently, it is not surprising to see that the impact of PEVs on generation dispatch and market prices remains very limited as well. Nevertheless, additional (gas-fired) generation becomes necessary in some instances, for instance during the afternoon of the 1st day, leading to higher prices

In all three cases, the gap between demand (black line) and generation (i.e. the shaded areas) is filled by imports, and vice versa. This can be explained by the presence of cheaper generation in the region[46], whilst the interconnection capacity is large enough to accommodate the required import of power.

Nevertheless, the variations between the different charts indicate that PEV may be able to contribute to 'peak shaving', i.e. a reduction of daily peak load, at least during the (late) evening hours. In the particular case of North Macedonia, this may allow for a reduction of more expensive imports during these hours. Nevertheless, as also visible from Figure 53, this effect can be expected to be largely limited to the evening hours. In contrast, there is hardly any impact on peak load hours during the mid-afternoon, since a large share of the PEV fleet is still assumed to be disconnected from the grid at that time. In other words, whilst PEV may help to reduce (residual) demand during high-load hours in the evening, their ability to reduce actual peak load seems to be much more limited.

46 The coal-fired plant Oslomej (assumed to switch from lignite to hard coal in 2025) is not dispatched. This can be explained by relatively high fuel costs and since this plant is inflexible in regards to its dispatch (e.g. it has to run at least 10 hours and shut down for 2h). Instead gas is dispatched to run in some peak hours (red shaded areas).

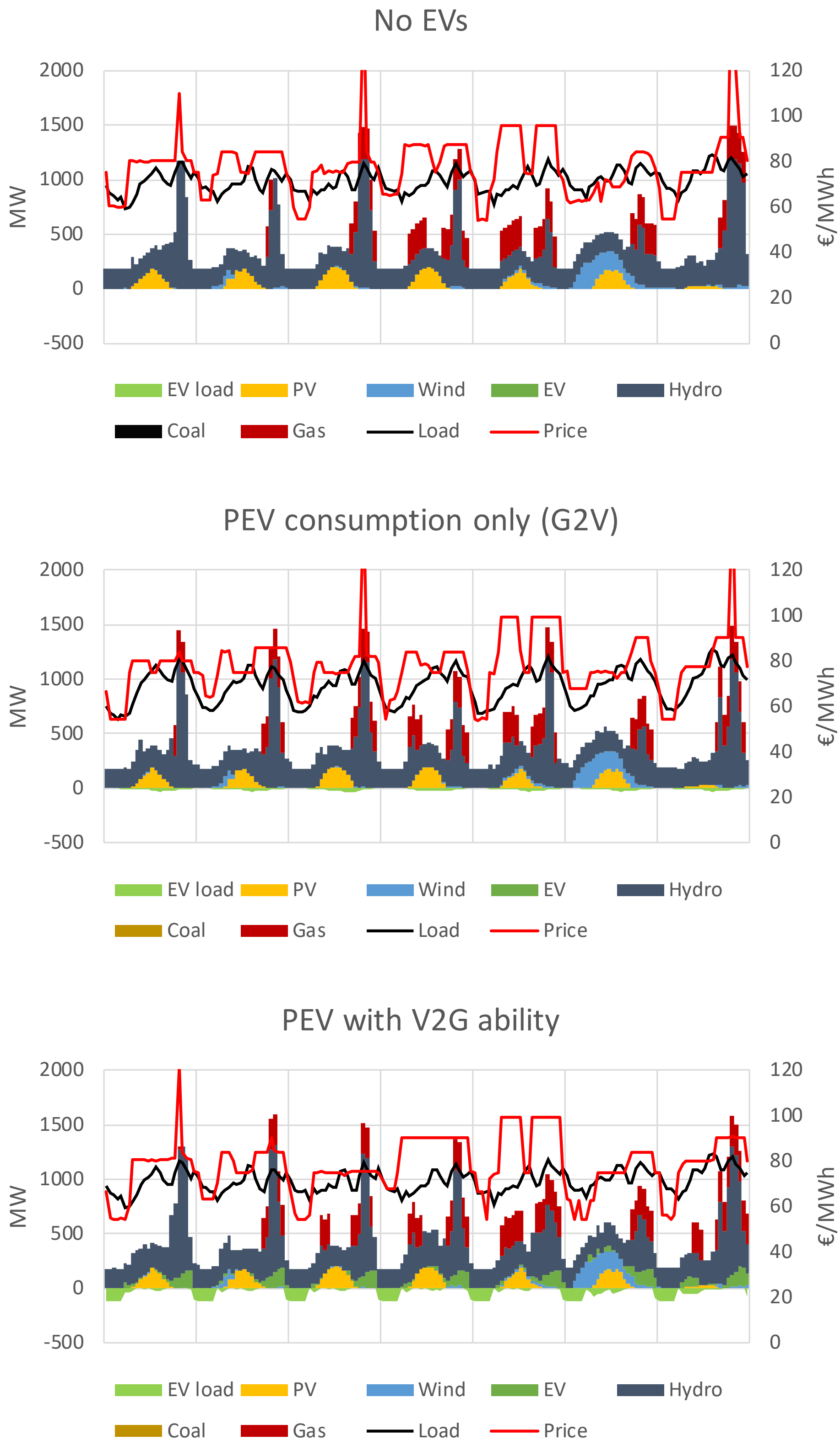


Figure 53: Sample dispatch results for 1st week of October (2040, scenario 1)

Note: Generation and load refer to primary y-axis (left), prices refer to secondary y-axis (right)

Source: DNV GL analysis

Reserve prices

In 2040, about 160 MW of reserves must be provided to the system, both for upwards and for downwards reserve. Figure 54 shows the resulting reserve prices for the base case (no PEV), once in chronological order (left) and once as a price duration curve right). The price that is estimated by the market model for the upwards (orange) and downwards reserve (blue) shows clear differences, indicating different generators being dispatched for these services.

On first sight, prices for upward reserves seem to be higher than those for downwards reserves. The duration curves, however, reveal that upwards can largely be provided at no additional costs to the system. This can probably be explained by the fact that upwards reserves can be delivered by (undispatched) hydropower plants, which can ramp up quickly but which are typically used at less than full capacity only due to energy constraints. Conversely, higher prices usually occur when cheap generation (e.g. hydropower) has to be reduced in order to provide reserves.

Conversely, downwards reserves are more varied in prices. About half of the year the prices are also around 0 €/MWh, whilst prices range between 0 and 40 €/MWh for the other half of the year. Again, this effect seems plausible as the provision of downward reserves requires a minimum level of generation above minimum stable level. Figure 53 furthermore suggests that this may often require hydropower to be operated above its technical minimum even during periods of low prices, which requires more expensive sources of generation to be used during peak periods.

With regards to the provision of reserves and balancing energy by PEV, Figure 53 indicates a limited economic potential already. This is further discussed in section 5.1.3

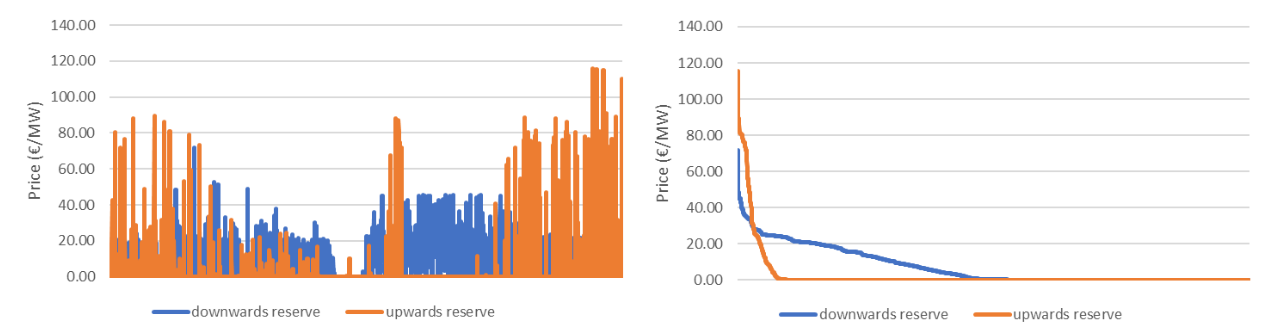


Figure 54: Reserve prices in 2040 (€/MW/h)

Note: Left chart in chronological order, right chart as duration curves

Source: DNV GL analysis

Avoiding RES curtailment

The results of this study **do not** indicate that the EVs avoid curtailment of renewable generation. This can be explained by the small amounts of PV and wind (renewables or RES) expected to enter the North Macedonian power market compared to the overall load, i.e. the renewable generation fraction of total generation. Furthermore, sufficient flexibility is being provided by hydro plants[47] and transmission lines within North Macedonia or with neighbouring regions.

Occurrence of system bottlenecks in the transmission network

As agreed with MEPSO, the North Macedonian power system has been represented by 3 nodes (North, South-East, South-West) in the market model; compare Figure 45. These three nodes are connected between each other, and neighbouring countries, by means of fictive NTC lines. Strictly speaking, the 'flows' across these lines represent bilateral (commercial) exchanges but must not be misunderstood as physical flows. Nevertheless, an analysis of the changes between different assumptions on PEV still provides certain insights.

Figure 55 shows the duration curves of the exchanges between the three North Macedonian nodes considered in the market model. Again, the duration curves are shown for scenario 1 in the year 2040, assuming that no EVs are present (grey), EVs act as pure consumers (blue) or that EVs can supply V2G services (orange). The three charts indicate that the commercial exchanges are hardly influenced by the assumptions on the presence and use of EVs. Given that physical flows depend on the regional distribution of generation and load, it thus seems fair to assume that the same observation also holds for actual load flows on the transmission grid.

Overall, Figure 55 thus indicates that PEVs would not lead to any relevant congestion at the transmission level. For a more detailed analysis, please refer to the network analysis in section 5.2.

47 The use of hydro plants to provide balancing services to the system assumes that sufficient water and water flow to hydro plants is available for power generation.

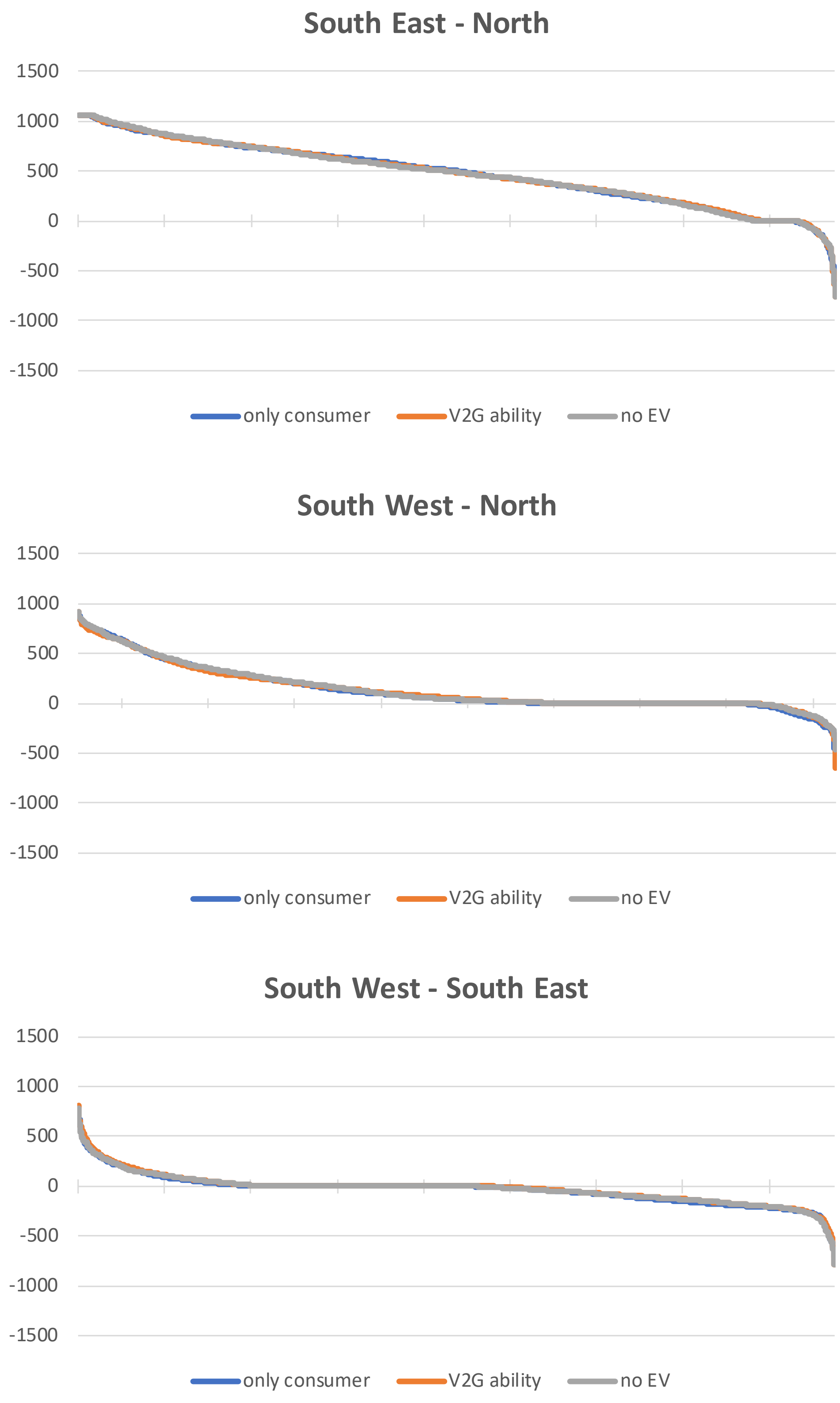


Figure 55: Flow duration curves for inter-North Macedonian connections (in MW)

Source: DNV GL analysis

5.1.3 Contribution of PEVs to Provision of Ancillary Services (Operating Reserves) and Back-up Capacity

In this section, we examine the potential of PEV to provide balancing reserves, peak shaving and back-up capacity. We refer to 'technical potential' as the volumes of capacity and energy (i.e. MW and MWh, respectively), which can theoretically be used for balancing purposes.

To start with, the theoretical potential depends on the corresponding characteristics of PEV (and their charging points). For illustration, Table 14 summarizes the maximum theoretical values, based on the assumptions on PEV penetration listed in Table 12 and Table 13 above. We emphasise that these figures do not account for any relevant technical or operational constraints as further discussed below but simply reflect installed (dis-) charging and storage capacity. Even under these highly optimistic assumptions, available flexibility basically remains below 100 MW / 1,000 MWh at least until 2030. Moreover, actual storage use is even lower, with no more than 180 MWh being daily used by PEV on average until 2030, and a maximum of 600 MWh even in the most extreme 2040 scenario. These numbers already indicate that the potential contribution of PEV for ancillary services and back-up capacity will remain limited at least over the next decade, but likely even until 2040.

Table 17: Theoretical potential of flexibility available from PEV in North Macedonia

	Scenario 1			Scenario 2		
	2025	2030	2040	2025	2030	2040
Number of PEV	*10,000*	*20,000*	*50,000*	*20,000*	*30,000*	*100,000*
Max. (dis-) charging capacity (MW)	*37*	*74*	*185*	*74*	*111*	*370*
Max. storage capacity (MWh)	300	600	1,500	600	900	3,000
Average daily storage use (MWh)	60	120	300	120	180	600

Based on an average (dis-) charging capacity of 3.7 kWh and a storage capacity of 30 kWh.
Source: DNV GL analysis

In practice, the real flexibility available to the system will be substantially lower, for various reasons. Amongst others, it is necessary to consider a number of other parameters, such as the driving and charging patterns of different drivers, the willingness to make PEV flexibility available to the market or power system, and the technical means of optimisation and control:

- As a matter of principle, PEV may only provide ancillary services as long as they are parked and connected to a charging point. As a starting point, available PEV capacity van thus be assumed to show the 'inverse profile' of the daily driving patterns as introduced in section 4.2.3 above.
- Similarly, the ability to provide ancillary services of PEV's connected to the grid depends on their state-of-charge (SOC) and current (dis-) charging pattern:
    - o PEVs may principally provide upward regulating power if they are able to withdraw additional power from the grid. This is possible only as long as their batteries are not fully charged and whilst they do not yet charge at max. power. Conversely, PEVs that are fully loaded and/or which already use their max. charging capacity cannot contribute to the provision of upward regulation.

- For downward reserves, the opposite is true. In this case, PEVs may provide balancing power as long as they can either reduce their current rate of charging or, potentially, inject (additional) power into the grid. In the latter case, they must still have spare battery capacity available, i.e. their SOC must be (well) above a lower limit of for instance 20%.
- In the second case, the provision of ancillary services will usually be further limited by the aim of ensuring fully loaded batteries before the vehicle's owner may use it again for driving. Consequently, downward reserves can only be provided as long as it is still possible to load the battery to its target SOC before the PEV has to be ready for use again.
- Unless PEV owners are willing to deliberately limit the SOC of their vehicles, the ability of the PEV fleet to provide upward balancing power can thus be assumed to be highest in the late afternoon and (early) evening, i.e. when the bulk of the PEV fleet returns home and has been discharged by driving during the day. A second peak can be expected during (mid-) morning, i.e. when people have arrived for work or business, depending on the availability of (public) charging stations at work and/or business facilities.
- The same considerations principally hold for the provision of downward reserves by PEVs that are operated as 'consumers' only. These PEVS may only act as providers of downward balancing power whilst charging.
- Additional downward regulating power may be provided by drivers, which have agreed to operate their vehicle in the 'vehicle to grid' mode, i.e. for injecting from the battery back into the grid. In this case, the substantially flexibility can principally be provided to the grid, provided that it is still possible to make up for such uses and increase the battery's SOC to a desired target level. As a result, the flexibility available from this group will be mainly limited in the early morning, i.e. before people start leaving home, but will otherwise follow the daily pattern of vehicles connected to the grid, as stated above.

The implications of these considerations are two-fold: First, they imply that the real flexibility available from PEV will be much smaller than the values shown in Table 14 and will furthermore vary significantly over time. And secondly, the provision of ancillary services by PEV critically depends on each user's willingness to make the corresponding flexibility available to the system, in particular with regards to V2G services.

Table 18: Assumptions on max. reserve capacity available from PEV (in MW)

Limit for reserve provision (MW)	Scenario 1			Scenario 2		
	2025	2030	2040	2025	2030	2040
Capacity-related limit[(a)]	*19*	*37*	*93*	*37*	*56*	*185*
Energy-related limit[(b)]	*38*	*75*	*188*	*75*	*113*	*375*
Max. potential	*19*	*37*	*93*	*37*	*56*	*185*

Notes: [(a)] – Assumed as 50% of max. (dis-) charging capacity; [(b)] – Based on 25% of storage capacity and continued utilisation of 2 hours.
Source: DNV GL analysis

Based on the numbers provided in Table 17, Table 18 presents a set of assumptions on the maximum volume of reserves, which may be available from PEV at any time of the day. Please note that these estimates do not account for limitations at different times of the day. A comparison with Table 19, however, reveals that the resulting volumes represent limited share of total reserve needs only, at least until 2030 or in scenario with moderate assumptions on the future penetration of PEV. Furthermore, as explained above, available volumes will be substantially smaller during most of the day, including in particular during most of the daytime hours.

Table 19: Assumed reserve requirements for North Macedonia (in MW)

Reserve	2020	2025	2030	2040
FCR (primary)	*8*	*8*	*8*	*8*
aFRR (secondary)	*41*	*41*	*41*	*41*
mFRR (fast tertiary)	*111*	*113*	*116*	*146*
Total	*160*	*162*	*165*	*195*

Source: MEPSO

Consequently, it seems fair to conclude that the potential for the provision of ancillary services from PEV is likely to remain very limited at least for the next 10 – 15 years. In addition, the market modelling results in section 5.1.3 have also shown that the (opportunity) costs of operating reserves appear to be fairly low during a large part of the year, which strongly limits the potential value of reserve provision.

Nevertheless, we also note that the volumes available may be sufficient to cover at least a large part of the need for frequency containment reserves (FCR) and automatic frequency restoration reserves (aFRR), i.e. primary and secondary frequency control. Moreover, both services must be provided by spinning reserves, whereas fast tertiary reserves can also be provided by idle hydropower plants, subject to sufficient water being available in (daily) reservoirs. Furthermore, we have argued in section 5.1.3 that the provision of (spinning) operating reserves may be especially difficult during low load hours, such as night hours. Interestingly enough, these periods broadly coincide with the time when most PEVs will be connected to the power system and may potentially provide ancillary services, at least in the first few hours of the day or, if owners accepted an only partially filled battery at the beginning of the working day, until the early morning.

As reserves are represented in aggregate in the market model only, it is difficult to derive more accurate estimates on the expected quantitative impacts of PEV on the costs of reserve provision. Yet, these considerations imply that PEV may primarily help to reduce variable costs of reserve provision, both for upward and downward regulating capability. In contrast, it seems questionable whether they would allow for a tangible reduction of fixed costs, i.e. in the form of a reduction of installed capacity. Amongst others, we note that peak load in the North Macedonian seems to occur during mid-afternoon already, i.e. at a time when a large proportion of the EV fleet can still be assumed to be offline. Consequently, the North Macedonian power system will still require sufficient sources of flexible capacity.

For similar reasons, our analysis does not suggest that PEV will be able to provide a significant contribution to the provision of back-up power. In this context, we furthermore note that back-up capacity may have to be provided over several hours, such that the energy-related limits in Table 18 above would have to be further derated.

Finally, we have also investigated to which extent PEV may be able to satisfy MEPSO's needs for ancillary services in the future. The results of this analysis are presented in Figure 56. The blue columns indicate the total reserve capacity that may be made available by PEV in different years. For this purpose, we have assumed that PEV can make up to 50% of their dis-/charging and storage capacity available during all hours of the day, reflecting the absence of cars from charging stations, the travel-related use of the storage capacity and the expectation that vehicle owners will not agree to an extreme use, which may seriously shorten battery lifetime and/or constrain their driving ability on the next day[48]. Finally, we assume slow charging for scenario 1 but a mix of slow and fast charging for scenario 2.

With regards to reserve requirements, we differentiate between capacity- and energy-related needs. This differentiation reflects the fact that for instance FCR mainly represents a capacity-service but will not normally entail a substantial provision of energy. Conversely, manual FRR (tertiary reserves) may have to be provided without interruption for a longer time and hence require significant volumes of energy[49]. For these reasons, the energy-related needs are almost twice as high as the capacity-related ones, which are equivalent to those shown in Table 19.

As Figure 56 shows the available reserve potential from PEV is (much) smaller than MEPSO's requirements for all years and scenarios. IF MEPSO wanted to exclusively on PEV for reserve provision, the following number of PEVs would be required:

- 170,000 – 210,000 in case of slow charging, but
- 150,000 – 180,000 in case of fast charging.

Please note that these numbers are likely <u>under</u>-estimated as we have used optimistic assumptions on the availability of reserves from PEV and neglected additional reserve needs, which may result from a larger PEV penetration. The latter aspect would need to be managed by suitable restrictions and/or incentives for dis-/charging by PEV owners. At the same, we also note that PEV may play a more important role for provision of FCR and aFRR, which require less capacity and, equally important, put a lower requirement on the availability of energy.

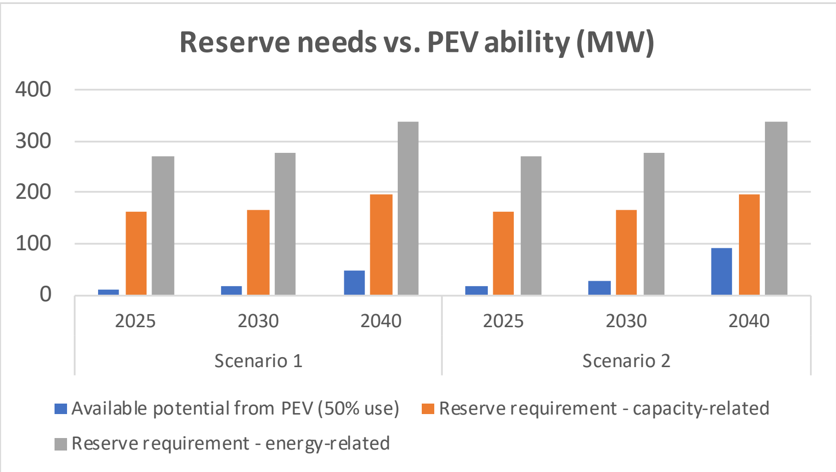


Figure 56: Reserve needs vs. theoretical potential available from PEV

Source: DNV GL analysis

48 These assumptions can still be regarded as very optimistic.

49 For our analysis, we have assume an uninterrupted use for up to ½ h for FCR, 1 h for aFRR and 2 h for mFRR.

5.2 Network Analysis

5.2.1 Load-Flow Calculations

The load-flow calculations (steady-state) were carried out for the transmission (400 kV and 110 kV) network. This is necessary to check the steady-state performance of the system for minimum and maximum demand conditions and to identify potential branch overloads and voltage violations in the mentioned voltage levels after the integration of PEVs.

For network simulations, MEPSO made available future grid models in PSS/E for the “green” generation / consumption scenario “A” pattern for the years 2025, 2030 and 2040 (incl. forecasted load, production and new topology). DNV GL extended the information in the network model by adding load from PEV as well as the possible regulation that may be provided by PEVs either by additional charging or by feeding back into the grid. Information on import and export of energy as well as nodal demand was considered based on the market simulation (see Table 20).

In addition, the following assumptions and settings were used:

- All load flow calculations were carried out for the normal switching state.
- The tap changers of all transformers were deactivated for the n-0 calculations and considered for n-1 analysis only. In addition
- The ratings for the overhead lines and transformers were set according to rating A.
- All loads are connected to 110 kV busses.
- Loading was checked for 110 kV overhead lines and 400/x kV transformers.
- Voltage operating ranges were checked according to ENTSO-E COMMISSION REGULATION (EU) 2016/1388 of 17 August 2016 and according to the MEPSO Grid Code of 6 November 2014.
- The voltage level at busbar BITOLA 2 400 kV was set to 1 pu (1.02 for scenarios 8 & 10).

The scenarios considered are presented in Table 20. More detailed assumptions on generation, load and the contributions by PEV are presented in Annex II.

Table 20: Scenarios for load flow calculations

Target years	2030		2040		
	Winter max.	Summer max.	Winter max.	Summer max.	Summer min.
Grid-to-vehicle (G2V)	7	8	1	2	3
Vehicle-to-grid (V2G)	9	10	4	5	6

Source: DNV GL analysis

The normal operating voltage ranges for 300 – 400 kV and 110 – 300 kV according to ENTSO-E guidelines and according to the MEPSO Grid Code are presented in Table 21 and Table 22, respectively.

Table 21: Operating voltage ranges for 300 - 400 kV

Nominal voltage (kV)	Voltage range (pu)	Time period for operation
300 – 400	0.90 – 1.05	Unlimited
	1.05 – 1.10	To be specified by each TSO but not less than 20 minutes and not more than 60 minutes
110 - 300	0.90 – 1.118	Unlimited
	1.118 – 1.15	To be specified by each TSO but not less than 20 minutes and not more than 60 minutes

Source: ENTSO-E

As shown in Table 22, quasi-stationary operation shall be possible in the entire frequency range from 47.5 Hz to 51.5 Hz and for voltages in the range of 0.9 to 1.05 or 1.115 pu (effective values of the chained voltage).

Table 22: Operating voltage ranges according to MEPSO Grid Code

Voltage level	Voltage intervals under normal conditions [kV]		Short interval with exceptionally low voltages in regimes with disturbances [kV]		Short interval with exceptionally high voltages in regimes with disturbances [kV]	
	Unlimited		30 minutes	60 minutes	60 minutes	60 minutes
110	99	122.65	88 – 93.5	93.5 - 99	122.65–126.5	
400	360	420	320 - 340	340 - 360	420 – 435	435-440

Observations and conclusions

Table 23 summarises results of the load flow analysis; more details results are presented in Annex II. This overview shows that most scenarios do not lead to any violations of ratings or voltage limits. Moreover, no issues were observed for 2030.

Table 23 also shows that some potential issues were identified in three 2040 scenarios, incl. one scenario with PEV operating in the G2V mode (2040 summer max, sc. 2) and two scenarios with PEV operating in the V2G mode (2040 winter and summer max, sc. 4 and 5). As further discussed in Annex II, these problems are mainly limited to the Skopje region, which is characterised by a well-meshed grid and offers various options for topological measures. After discussions with MEPSO, it was therefore assumed that all issues in or caused by the Skopje area can be adjusted by changing switching states. This assumption is also supported by the observation that overloads caused by transformer outages generally coincided with a highly uneven use of parallel transformers in the (n-0) state.

Overall, our analysis does, therefore, not reveal any serious concerns on the impact of the PEV penetrations considered on the secure and stable operation of the transmission grid.

Table 23: Summary results of load flow calculations

Target years	2030		2040		
	Winter max.	Summer max.	Winter max.	Summer max.	Summer min.
Grid-to-vehicle (G2V)	7	8	1	2	3
Vehicle-to-grid (V2G)	9	10	4	5	6

Green shaded cells indicate no issues, yellow shaded cells indicate the presence of limited issues, which are likely related to the switching state in the Skopje area.
Source: DNV GL analysis

5.2.2 Dynamic Issues

The characteristics of charging stations as consumers (grid-to vehicle or G2V) or producers (vehicle to grid or V2G) are basically not different from those of other consumers or generating units with converters. The charging stations do not bring any specific problems.

Charging stations in consumer mode are not able to support the grid. From charging stations in the generation mode, the dynamic network support can be realized. All generators that enable fast load flow, voltage, and frequency control are useful for maintaining grid stability during or after a short-circuit.

Dynamic grid support means that generation plants remain connected to the grid during short voltage drops. If generation plants were to be disconnected from the grid during low voltage drops, this would lead to a power deficit, which would result in further destabilization of the grid. In terms of system security, therefore, the breaking capacity of generating units must be kept as low as possible in the event of voltage drops.

As a contribution to system security, sufficient robustness of the generating units against voltage and frequency changes is required. The injection of short-circuit and reactive power into the transmission grid will decrease as a result of the expansion of renewable energies. With storage based on PEVs, support for the transport network can only be achieved to a limited extent due to their integration into subordinate voltage levels.

The grid connection rules are designed to avoid the shutdowns of the generators when a fault in the transmission network is clarified according to the concept. Voltage support by generating units can essentially only affect the grid area and the voltage level in which the installations are connected.

The generating units contribute to the voltage support if the voltage deviates more than ± 10% from the nominal value. Thus, this voltage regulation is active only in case of short-circuit.

Restricted network support (eLVRT or Zero Power Mode) means that generation plants cannot disconnect from the grid in case of short-circuit and quickly re-inject active power.

The full dynamic network support means that generating unit would additionally actively feed reactive and / or active current during the fault. During the voltage dip, the active current can be forced back by the reactive current. Inverters with dynamic network support functions provide support within milliseconds, thus helping to prevent network disturbance from spreading.

In concrete terms, other studies show that effects of short-circuits in the transmission network can be significantly reduced with reactive power supply of renewable energy plants in medium and high voltage networks. For example, studies by the German industry bdy FNN[50] found that a simulated loss of around 1,400 MW of power can be reduced by 50 percent if power generation plants have restricted dynamic network support.

In the transmission system planning, TSO use the following criteria for dynamic stability:

- Transient stability - any 3-phase short circuit, successfully cleared by the primary protection system in service, shall not result in the loss of the rotor angle stability and the disconnection of the generation unit unless the protection scheme requires the disconnection of a generation unit from the grid, and
- Static stability - possible phase swinging and power oscillations, triggered by switching operation or bulk power transits, in the transmission grid shall not result in poorly damped or even undamped power oscillations.

For the investigated situation, multiple charging station with bidirectional power flow (P2V and V2G) should be considered as generating plants. The requirements for power park modules are listed in the MEPSO Grid Code (XVII.3.1 – 3.5).

In general, the following behaviour regarding the voltage support in case of disturbances (according to chapter XVII.3.5 in MEPSO Grid Code) was found:

- better voltage support with increasing k-factor,
- at short-circuit in HV grid -> less effective voltage support by PEVs in the MV network,
- at short-circuit in MV grid -> only slight voltage changes in the HV network.

For PEVs in the MV of HV network:

- k > 0: good voltage supporting effect; Specifications of the static voltage support in case of fault, however, can have influence for the voltage supporting effect of the fed-in reactive current, which must be taken into account (k-factor describes provision of the additional reactive current); moreover, effects on existing network protection technology,
- eLVRT: limited dynamic voltage support, but better behaviour than k = 0,
- k = 0: not recommended, as not voltage supporting,

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The transient states (starting time of the short-circuit and return of the voltage) are not the subject of the study. The raising of the k-factor can lead to overshoot or undershoot of voltage level, and thus possibly instabilities.

If the automatic reclosing is applied in the HV grid, under certain conditions, the fault can be fed for short-time by the PEVs after the overhead line was disconnected from the grid. The disconnection of the PEVs connected at MV level via the voltage protection $U_{<<}$ occurs only after the disconnection of the line in the substation.

The grid disconnection of the PEVs is guaranteed in the case of HV short-range faults or MV faults near the substation due to the voltage protection (for example $U_{<<}$ = 0.45 pu). If the short-circuit is far away in the HV or MV grids, the required separation from the grid can only be ensured with eLVRT and k = 0. The voltage drop may be insufficient for the stage $U_{<}$ (for example $U_{<}$ = 0.8 pu).

Conclusion

Each plant (connection point for PEVs, multiple charging station) requires a separate study with dynamic models supplied by the manufacturer.

It can be expected that the same standards will apply in future in North Macedonia as in other countries of the European Union. One example is the EU Regulation 2016/631, which is used as the basis for the harmonization of European standards and technical connection rules.

5.2.3 Power Quality Issues

In contrast to the load flow calculations, we will analyse the impact of PEVs on dynamic stability and power quality mainly in a qualitative way.

In distribution networks, the flow of harmonics reduces power quality and consequently causes several problems:

- overloads on distribution networks due to the increase in the RMS current
- overloads on neutral conductors due to the summing of third-order harmonics
- overloads, vibrations and premature ageing of generators, transformers, motors, etc., increase transformer noise
- overloading and premature ageing of capacitors in VAR compensation equipment
- distortion of the supply voltage, capable of disturbing sensitive loads
- disturbances on communication networks and telephone lines
- increase electric losses

The characteristics of charging stations as consumers (grid-to vehicle or G2V) or producers (vehicle to grid or V2G) are basically not different from those of other consumers or generating units with converters. The charging stations do not bring any specific problems.

Potential sources of harmonics are for example – frequency converters, wind and solar generation systems with inverters, all equipment with built-in switching devices or with internal loads with non-linear voltage/current characteristics, etc.

So that the network operator can assess possible power quality, the planner or the installer provides the required information about the connected electric systems. This depends on the technical connection conditions of the local grid operator. For example – assessment and approval of the grid operator are required for e-mobility charging stations rated > 4.6 kVA (grid operator Bayernwerk AG in Germany).

The assessment of power quality at the grid connection point is relevant and mandatory for all voltage levels. The differentiation according to voltage levels is not possible. Corresponding chapters are available in grid codes and connection guidelines for LV, MV and HV networks.

The difference is only in which form it is represented (simplified or completely at larger charging station) and who performs the assessment (only the grid operator or grid operator with a certification authority).

Technical criteria for evaluation of suitable grid connection point are:

- utilization of existing assets
- increase of short-circuit current
- static voltage rise
- voltage fluctuations
- flicker
- harmonics

For the investigated situation, multiple charging station with bidirectional power flow should be considered as generating plants. The requirements for power park modules are listed in the MEPSO Grid Code (III.4; XVII Appendix 8; XX Appendix 11).

Following requirements regarding power quality are already available in MEPSO Grid Code:

- flickers
- harmonics
- phase unbalance

Following requirements regarding power quality are <u>not</u> available in MEPSO Grid Code (in comparison with German guidelines):

- admissible voltage changes (magnitude of the voltage changes caused by all generating plants with a point of connection to a network; voltage changes at the junction point attributable to the connection and disconnection of generators or generating units; voltage change at every point in the network in the event of disconnection of one generating plant or of several plants simultaneously at one network connection point)
- inter-harmonics
- audio-frequency centralized ripple-control (if applicable in North Macedonia; apart from the limitation of the level reduction, it is not allowed to generate inadmissible interference voltages)
- commutation notches (only for line-commutated inverters)

It can be recommended to use filters (if applicable - active filters) in multiple charging stations to reduce the harmonic level in the network.

Conclusion

Each plant (multiple charging station) requires a separate study or rating regarding power quality. It can be recommended to use the manufacturer-supplied type certificate with all available data for each generator unit (harmonic, flicker etc.).

For example, according to the German guideline FGW TR8. According to the German grid code studies regarding valuation of the grid connection (incl. power quality) are necessary for generating plants ≥ 135 kW.

It can be expected that the same standards will apply in future in North Macedonia as in other countries of the European Union. One example is the EU Regulation 2016/631, which is used as the basis for the harmonization of European standards and technical connection rules.

5.3 Economic and Regulatory Framework

To support an increasing penetration of PEV and their successful grid and market integration, several measures should be considered or may even be required. As shown in Table 24 we differentiate between incentives, enabling conditions and obligations on PEV owners and operators.

Table 24: Examples of needs and incentives to promote PEV penetration and integration

Area	Examples
Incentives	– Financial incentives (e.g. subsidies, exemptions etc.) – Non-monetary (e.g. priviledged access)
Enabling conditions	– Charging infrastructure – Metering and communication infrastructure – Market access for ‘aggregators’
Obligations	– Exposure to hourly / real-time prices – Strict connection and operating rules

Source: DNV GL

Incentives

To promote an increasing penetration of PEVs, a range of different incentives may be used. As already discussed in section 3.7 above, this includes financial as well as non-monetary incentives. Please refer to these discussion above for further details.

Enabling conditions

As already mentioned in section 3.5, the availability of sufficient and standardized charging infrastructure is an essential precondition at least for enabling long-distance travel, but also for facilitating the everyday use of PEVs for driving to work etc.

Besides physical charging infrastructure, this will also require a comprehensive roll-out of necessary metering and communication infrastructure. At a minimum, this will be required for all public charging stations, i.e. where vehicle owners may charge their vehicles away from home, i.e. as a precondition for metering and billing. But in principle, the same also applies for private charging at home, in order to facilitate or even enable 'intelligent' charging or the provision of ancillary services to system and network operators, i.e. in the form of controlled charging (G2V) or discharging (V2G). Especially the latter will furthermore require functioning communications, indicating that connectivity will become key for the ability to successfully to control large portfolios of PEV.

The latter aspect is closely related to the necessary commercial arrangements. In line with first developments and experiences in other European countries and the ongoing revision of the European directives, we do not believe that PEV will be centrally controlled by the TSO and/or DSOs in the future. In contrast, we envisage that this function will be increasingly carried out by so-called 'aggregators', i.e. independent (market) parties, which specialise on creating large portfolios of PEV on a contractual basis, in order to aggregate and intelligently manage the flexibility of the PEVs in the portfolio. These aggregated capabilities may then be used either for optimising the charging pattern and reduce the costs of charging energy or to provide ancillary services to system operators.

As the rapid development of so-called aggregators or 'virtual power plants' in some European countries (e.g. Germany, UK) shows, it seems reasonable to assume that these parties will themselves engage into developing the necessary contractual structures, algorithms and control system. Nevertheless, such services can only be provided if aggregators are allowed to engage into corresponding services and assume a key role in future energy markets (compare Figure 57). Assuming that this may not yet possible under Macedonian legislation and regulations, this signals a clear need for future development of the applicable market rules.

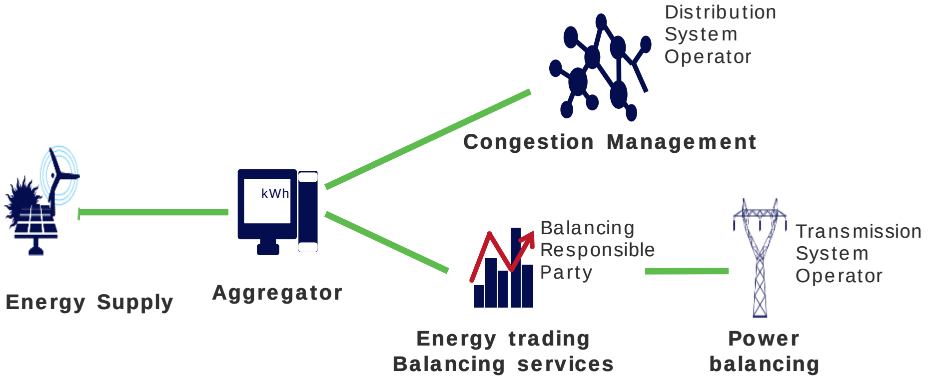


Figure 57: Central role of aggregators in flexibility market design

Obligations

Besides incentives and enabling conditions, PEV will also need to be subject to certain obligations. Amongst others, the market simulations have shown that PEV may lead to 'extreme' usage patterns, such that certain restrictions may be required to avoid critical situations and, more generally, ensure incentives for an efficient and market-/system-supportive behaviour.

As Figure 58 shows, we generally differentiate between grid- and market-related obligations. On the grid side, there will be an obvious need for clear connection rules and processes. Similarly, it be necessary to ensure strict operating rules and allow for controlling interventions by system operators in case of critical situations or emergencies. From the perspective of network operators, they will furthermore have to be able to recover the costs of additional investments into charging and related infrastructure, which is not financed on a private / independent basis. Strictly speaking, this issue is not directly related to obligations on vehicle owners and may also be considered as part of incentives, but there may be a need to adjust current network charges accordingly.

On the market side, we basically see two key requirements. First and foremost, it will be paramount to expose PEV owners and/or operators to hourly or even real-time prices. This will be key for incentivising and efficient response to current system or market needs or costs.

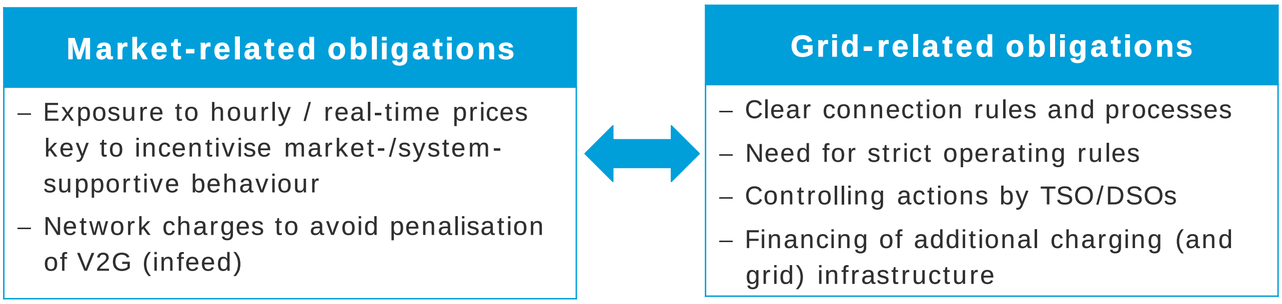


Figure 58: Market and grid-related obligations for grid and market integration of PEV

Source: DNV GL

6 KEY CONCLUSIONS AND RECOMMENDATIONS

Figure 65 summarises the key conclusions and recommendations of this study.

To start with, the analysis in the report has shown that North Macedonia will be able to safely integrate up to 100,000 PEV into the wholesale market the transmission system (compare chapter 5). We furthermore note that this result did not require any strong assumptions on ‘intelligent’ charging patterns etc., such that it seems reasonable to expect that it would be possible to integrate even larger numbers of PEV. Nevertheless, we also emphasise that our analysis was limited to the transmission level only, i.e. we did not consider potential issues at the distribution level.

At the same time, it is also important to note that this penetration may not be achieved without dedicated support. Clearly, the key driver should be continued cost reductions, which will hopefully result from an increasing use of PEV globally. Still, at least in an initial stage, dedicated financial support for instance by the government may be required to promote the purchasing and use of PEV.

Similarly, implementation and availability of sufficient and standardised charging infrastructure, incl. metering and communication facilities, can be considered as a fundamental precondition. Without easy access to (public) charging facilities, PEV owners would otherwise be strongly limited in their driving options. Consequently, the relevant infrastructure will have to be gradually developed, in line with the (expected) growth of PEVs.

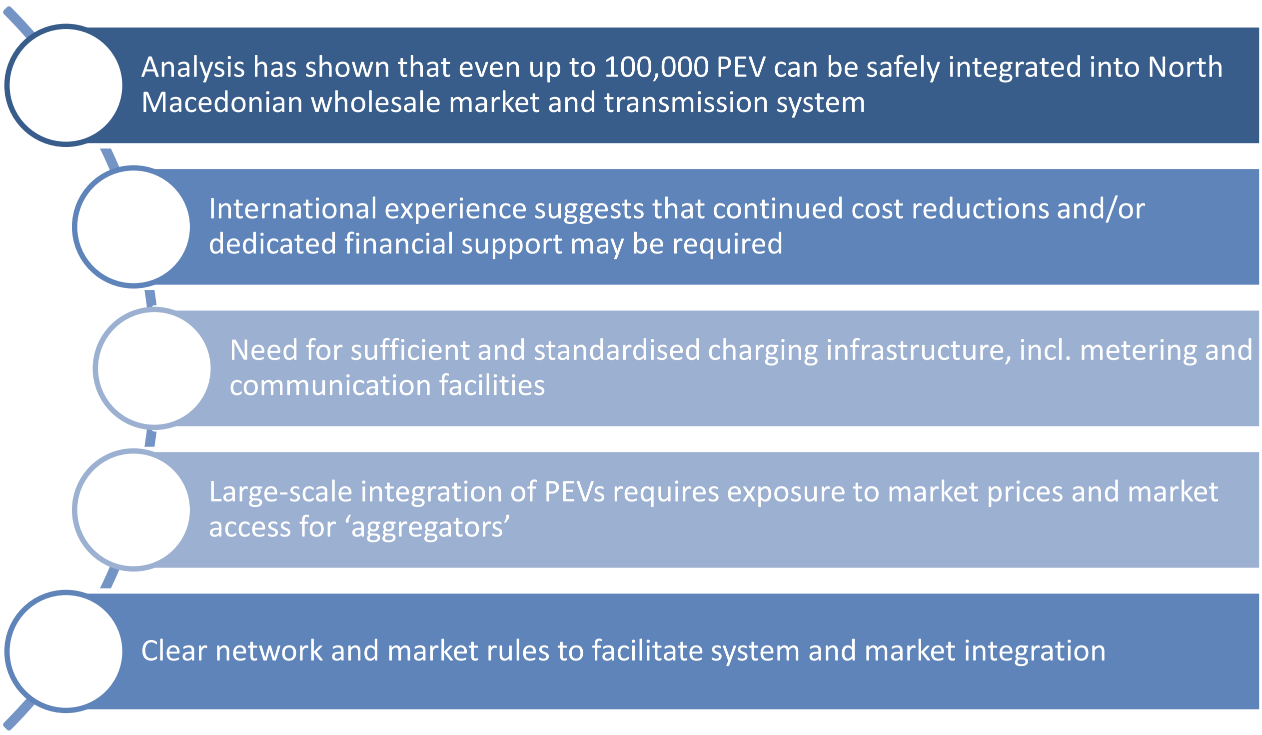


Figure 59: Summary of conclusions and recommendations

Despite the overall positive assessment, successful system and market integration of PEV will depend an efficient dis-/charging behaviour or PEVs. As highlighted in section 5.3, exposure of PEV owners and operators to market prices and market access for so-called ‘aggregators’ can thus be considered as key conditions for large-scale integration of PEVs.

The latter will finally require clear rules to facilitate system and market integration. This again implies that it will become necessary to further develop and adjust existing network and market rules. Corresponding efforts have already bene undertaken in some European countries and will be mandated under the updated European legal framework for the electricity sector. As the penetration of PEVs grows, corresponding changes will also have to be implemented in North Macedonia.

Annex I: Analysis of Indicators for the Regional Split of PEV Development

In each scenario, total PEV numbers (per year) will be split by region in Republic of North Macedonia. To define the number of PEV by region, we look into the following parameters:

1. Population
2. BIP and Income
3. Vehicles
4. Tourism

These parameters are analysed to see whether they serve as indicator for the future split of PEV per region. We note this analysis is limited to a consistent set of statistical data for the period 2007-2016, while we are not aware of relevant studies that forecast one of these indicators for the next 1-2 decades.

The reason why tourism is looked at is the observation some regions host a high number of touristic visitors and the hypothesis this might suggest a noticeable increase of population by temporary visitors and adding (a considerable number of) new PEV apart from those considered for residential population.

Population

Figure 60 below shows the regional split of population in Republic of North Macedonia. The Skopje region accounts for about 30% of the total population, whereas the residual population spreads more or less equally over all other 7 regions, i.e. about 10% per region.

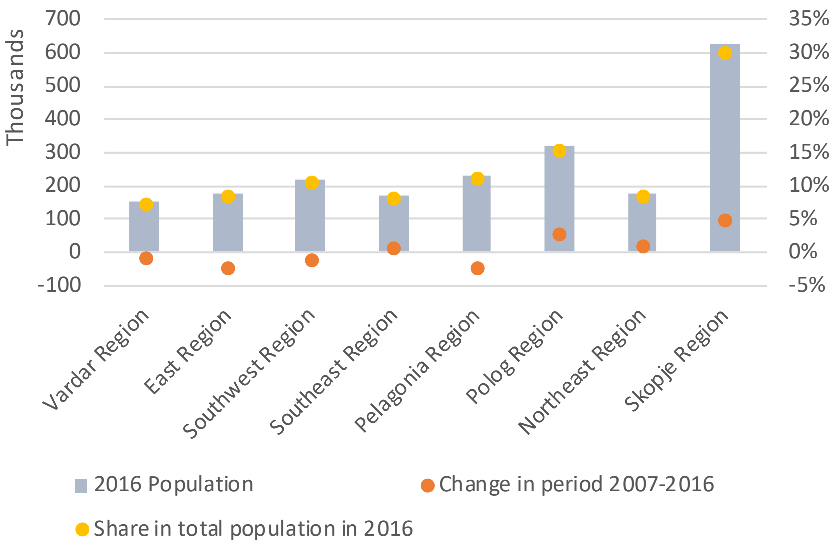


Figure 60: Regional population split

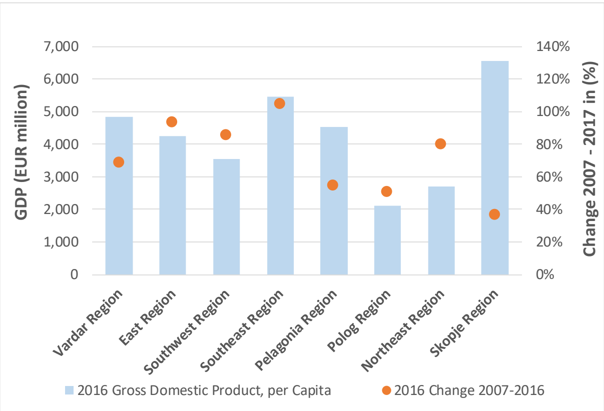
Source: DNV GL analysis, based on data from State Statistical Office of the Republic of North Macedonia (www.makstat.stat.gov.mk)

GDP and income

The Skopje region has a GDP per capita of about EUR 60,000 (MKD 400,000), as the left part of Figure 61 shows. Several other regions in the East and West of the country have a GDP in the range of EUR 40,000 to 50,000, while GDP per capita in the regions of Southwest, Polog and Northeast is as low as EUR 15,000 to 30,000.

All regions have increased their GDP over the decade from 2007- 2016 and several poorer regions in Republic of North Macedonia have been able to partially decrease the regional differences in GDP compared to richer regions. For example, whilst the region of Skopje provides for the lowest increase (ca. 37%), various regions have achieved a growth by up to 100% in a decade. As a result, many poorer regions have been able to reduce the gap to wealthier regions. This is also illustrated by the right part of Figure 61, showing the regional GDP compared to the national average and its change in the period 2007-2016. Nevertheless, the Skopje region still enjoys a much higher GDP per capita than the other regions. Moreover, the GDP per capita of Polog and Northeast still is far below the national average, and Polog grew even less than the average rate in the period 2007-2016. Consequently, it seems difficult to assume a guaranteed convergence of relative GDP in the foreseeable future.

GDP per capita



GDP in % of national average

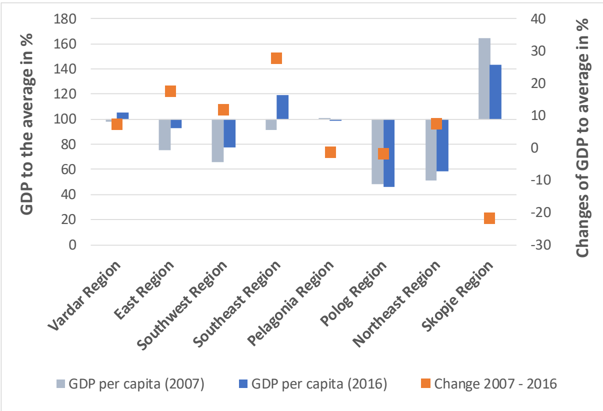


Figure 61: GDP per region

Source: DNV GL analysis, based on data from State Statistical Office of the Republic of North Macedonia (www.makstat.stat.gov.mk)

The following graph depicts the average monthly net wage in Euro per employee. It indicates a considerable difference between regions, especially between Skopje and the other regions.

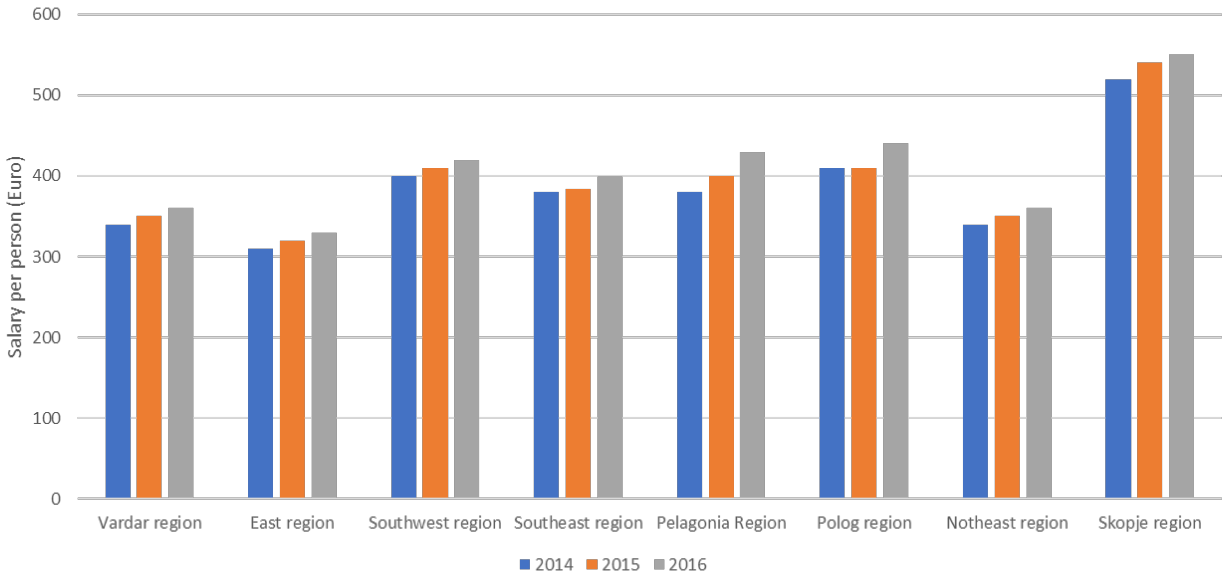


Figure 62: Relative salary levels by regions of North Macedonia

Source: DNV GL analysis, based on data from State Statistical Office of the Republic of North Macedonia (www.makstat.stat.gov.mk)

Vehicles

Figure 63 indicates the use of passenger and small commercial vehicles in Republic of North Macedonia. The distribution of the total car fleet roughly corresponds to the regional population split shown in Figure 60. In addition, it may be observed that the share of goods vehicles is small compared to passenger cars and similar in all regions. Moreover, Figure 63 shows that the increase of GDP apparently has allowed the total car fleet to grow, in the last decade, by more than 45% in all regions, in the Polog region by 110%.

Bearing in mind that Polog has a relatively low GDP compared to other regions, this result suggests that the growth in GDP has allowed people to buy a car (for the first time), while in other regions, e.g. Skopje there is already a higher penetration of cars. Due to its relative wealth compared to the national average (according to the GDP), the Skopje region enjoys a substantially higher penetration of cars than the other regions.

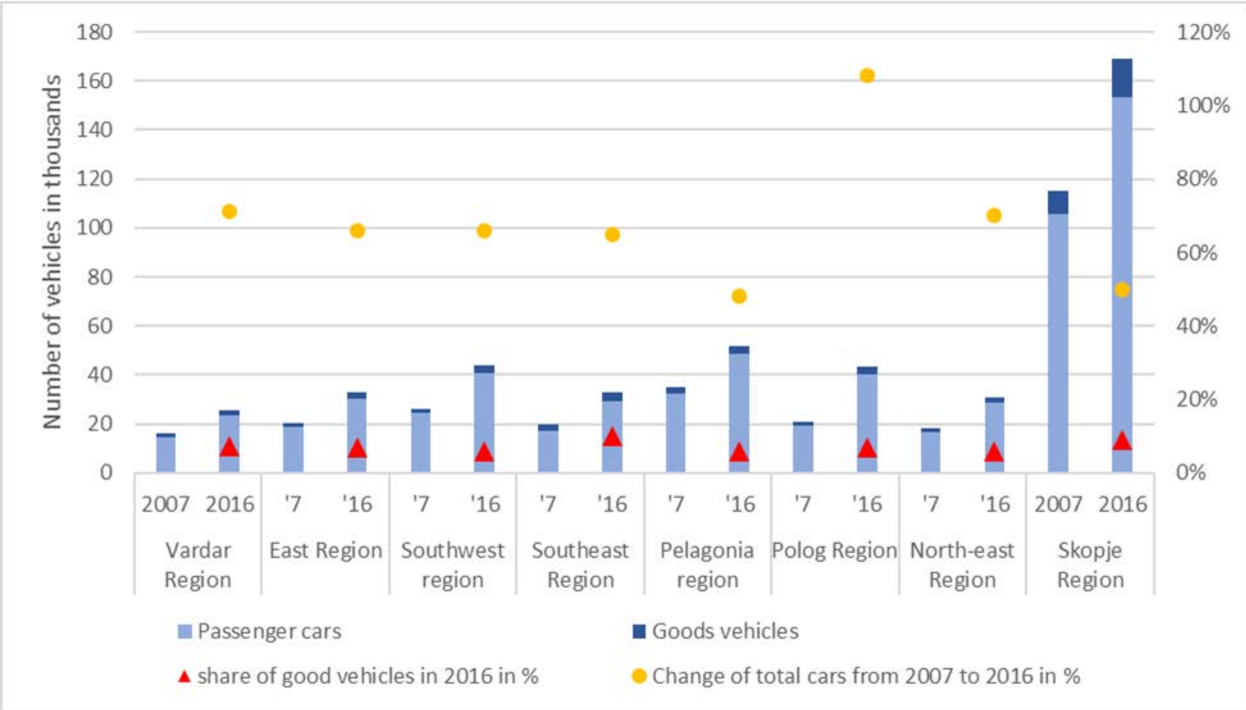


Figure 63: Penetration of passenger and light-duty vehicles by region

Source: DNV GL analysis, based on data from State Statistical Office of the Republic of North Macedonia (www.makstat.stat.gov.mk)

Tourism

Figure 64 below depicts the population and the total number of tourists per year for all regions. It suggests that a few regions, incl. Skopje, Southeast and Southwest, are the key travel destinations, in total and relative numbers, including domestic and foreign visitors. For instance, total annual number of visitors in the Southwest region correspond to about 150% of permanent population. In the Southeast and the Skopje region all visitors correspond to 80% and, respectively, 45% of population. Some other regions host, in the course of one year, visitors to the extent of 20-25% compared to their permanent population.

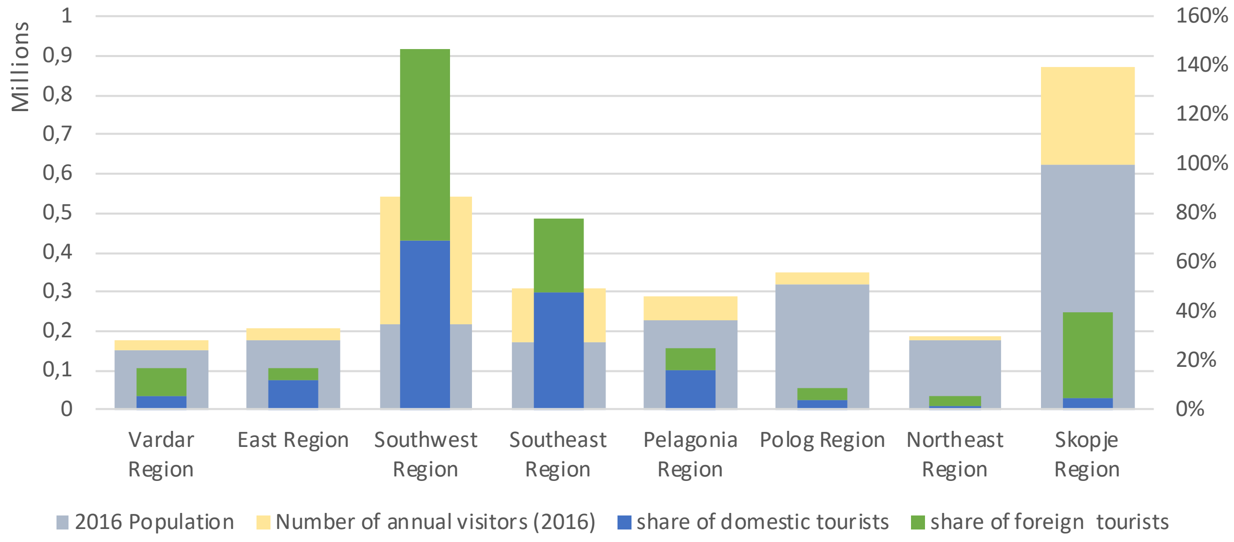


Figure 64: Population and visitors by region

Source: DNV GL analysis, based on data from State Statistical Office of the Republic of North Macedonia (www.makstat.stat.gov.mk)

Figure 65 depicts the impact of visitors on a monthly basis. It may be observed for all regions that visitors tend to come in summer, however, for the Skopje region and others (not shown) the peak touristic month corresponds to a limited increase of population incl. permanent and temporary. Contrary to that, in the Southwest and Southeast region the level of tourism is high compared to the number of residents and the number of visitors during touristic peak month corresponds to 25-30% of permanent population and visitors (primarily in summer).

As a result, there is some potential for tourism triggered PEV use in Skopje for the high (total) number of visitors. In the other two regions, a considerable number of visitors arrives and stays primarily in summer, suggesting a comparably high potential for PEV use for touristic purposes in summer.

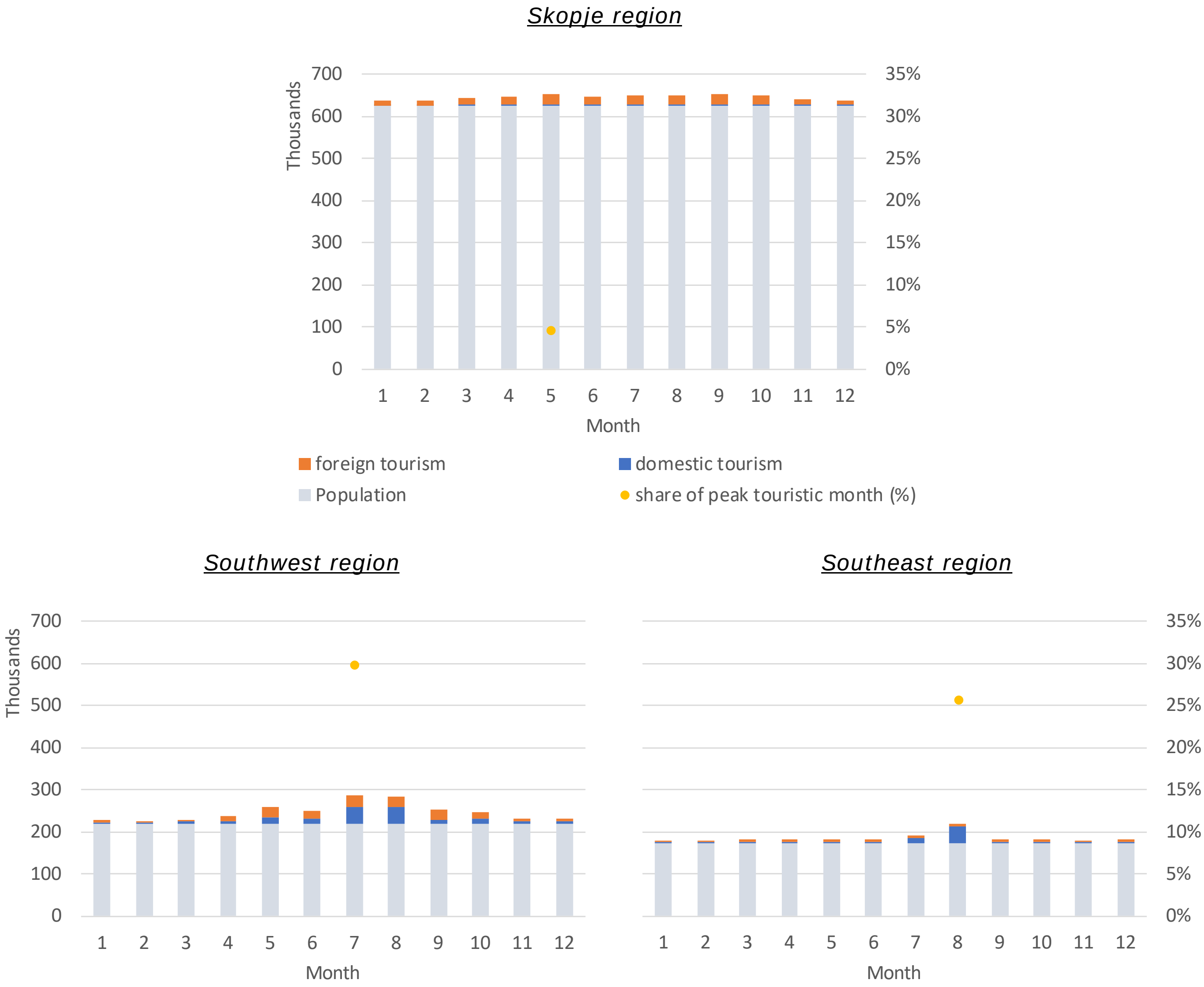


Figure 65: Impact of visitors on effective population

Source: DNV GL analysis, based on data from State Statistical Office of the Republic of North Macedonia (www.makstat.stat.gov.mk)

Annex II: Detailed Assumptions and Results of Load-Flow Analysis

Table 25: Generation and load in calculated scenarios (in MW)

Scenario				Load		Import	Generation		Overloads
				Native	EV		Normal	EV	
1	*2040*	*Winter max*	*G2V*	1406	1172	2292	286	-	-
2	*2040*	*Summer max*	*G2V*	950	1316	1862	404	-	1 overhead line
3	*2040*	*Summer min*	*G2V*	629	-	391	238	-	-
4	*2040*	*Winter max*	*V2G*	1935	106	1392	649	-	1 overhead line, 1 transformer
5	*2040*	*Summer max*	*V2G*	1490	108	1117	480	-	1 overhead line, 1 transformer
6	*2040*	*Summer min*	*V2G*	599	30	339	290	-	-
7	*2030*	*Winter max*	*G2V*	1611	440	1556	494	-	-
8	*2030*	*Summer max*	*G2V*	1477	-	580	567	330	-
9	*2030*	*Winter max*	*V2G*	1842	37	1185	694	-	-
10	*2030*	*Summer max*	*V2G*	1477	12	854	635	-	-

Source: DNV GL analysis

Target year 2030 with PEVs as load (G2V)

Table 26: Highest and lowest line voltages in target year 2030 (G2V)

Bus Number	Bus Name	Voltage (pu)	
		Scenario 7	Scenario 8
26004	BITOLA 2	1.0349	1.0508
26902	T-SPOJ2	1.0348	1.0507
26072	SUVODOL-1	1.0345	1.0502
26035	ILOVICA	0.9543	0.9500

Source: DNV GL analysis

Table 27: Highest line loadings in target year 2030 (G2V)

Line	Loading (%)	
	Scenario 7	Scenario 8
26076 TIKVES - 26079 FENI 110 kV	61.5	39.9
26104 TETO-EC - 26999 SK 1-B 110 kV	47.9	60.5
26104 TETO-EC - 26998 SK 4-B 110 kV	27.6	56.1
26066 SPILJE - 26115 B.MOST 110 kV	39.2	55.1

Source: DNV GL analysis

Table 28: Loading of the transformers target year 2030 (G2V)

N	Transformer	Power [MVA]	Voltage [kV]	Loading [%]	
				Scenario 7	Scenario 8
1	BITOLA	300	400/110/35	34.30	31.90
2	BITOLA	300	400/110/35	35.10	31.20
3	DUBROVO	300	400/110/35	33.10	36.30
4	DUBROVO	300	400/110/35	33.90	37.20
5	SKOPJE 4	300	400/110/35	66.20	54.50
6	SKOPJE 4	300	400/110/35	27.70	9.30
7	SKOPJE 5	300	400/110/35	4.80	14.70
8	SKOPJE 5	300	400/110/35	67.50	54.70
9	STIP	300	400/110/10	46.90	40.70
10	OHRID	300	400/110/10	30.90	38.40
11	KUMANOVO	300	400/110/10	31.00	20.60

Source: DNV GL analysis

Conclusion

From the network model no overloads of overhead lines or transformers are visible in the normal switching state. All voltage ranges are met.

Target year 2030 with PEVs as generator (V2G)

Table 29: Highest and lowest line voltages in target year 2030 (G2V)

Bus Number	Bus Name	Voltage (pu)	
		Scenario 9	Scenario 10
26120	OHRID	0.9961	1.0511
26004	BITOLA 2	1.0347	1.0509
26902	T-SPOJ2	1.0346	1.0508
26072	SUVODOL-1	1.0343	1.0503
26084	B.GNEOTINO	1.0336	1.0487
26122	OHRID 4	1.0256	1.0469
26125	OHRID 3	1.031	1.0464
26047	OHRID 2	1.0252	1.0461
26056	RESEN	1.0257	1.0453
26006	BITOLA 3	1.025	1.0432
26007	BITOLA 4	1.0235	1.0417
1011	XEL_BI12	1	0.955
26073	SUSICA	0.9716	0.9549
26035	ILOVICA	0.9651	0.952

Source: DNV GL analysis

Table 30: Highest line loadings in target year 2030 (G2V)

Line	Loading (%)	
	Scenario 9	Scenario 10
26062 SK 3 - 26063 SK 4-A 110 kV	66.8	35.3
26022 DUBROVO - 30102 XTH_DU11 400 kV	37.8	65.6
26104 TETO-EC - 26999 SK 1-B 110 kV	56.4	61.8
26129 BUNARGIK - 26998 SK 4-B 110 kV	9.1	59.0
26104 TETO-EC - 26998 SK 4-B 110 kV	32.0	55.8
26105 Z.RID - 26999 SK 1-B 110 kV	54.8	24.9
26003 BITOLA 1 - 26004 BITOLA 2 110 kV	53.4	46.2
26003 BITOLA 1 - 26004 BITOLA 2 110 kV	53.4	38.1
26021 DUBROVO - 26030 KAVADARCI 110 kV	53.2	26.3
26066 SPILJE - 26115 B.MOST 110 kV	41.8	52.0

Source: DNV GL analysis

Table 31: Loading of the transformers target year 2030 (V2G)

N	Transformer	Power [MVA]	Voltage [kV]	Loading [%]	
				Scenario 9	Scenario 10
1	BITOLA	300	400/110/35	39.60	27.00
2	BITOLA	300	400/110/35	40.60	26.40
3	DUBROVO	300	400/110/35	47.20	34.80
4	DUBROVO	300	400/110/35	48.40	35.60
5	SKOPJE 4	300	400/110/35	85.80	37.80
6	SKOPJE 4	300	400/110/35	20.30	11.40
7	SKOPJE 5	300	400/110/35	16.90	23.30
8	SKOPJE 5	300	400/110/35	96.40	37.80
9	STIP	300	400/110/10	61.60	24.40
10	OHRID	300	400/110/10	34.50	29.90
11	KUMANOVO	300	400/110/10	52.20	13.60

Conclusion

From the network model no overloads of overhead lines or transformers are visible in the normal switching state. All voltage ranges are met.

In addition, the n-1 security rule was checked for scenario 9, which showed the highest line loadings. Any elements already overloaded in the n-0 stated were not considered for n-1 calculations. Moreover, this study does not assess possible actions to remove violations, as this would require detailed studies to be carried out to develop the contingency plans.

The results of the contingency analysis are presented below in Table 32. Some outages of 110 kV overhead line lead to insignificant overloads in the Skopje area. Similarly, a failure of 400 kV transformers at Skopje 4 or Skopje 5 may lead to overloads in other branches.

We note that all the overloads are either located in the Skopje area and/or caused by contingencies in that area. DNV GL was informed by MEPSO that this area is characterised by a meshed network, which allows for various topological actions, such that any overloads can be considered less critical, i.e. that they can usually be managed by topological measures.

Table 32: Contingency analysis for scenario 9

Monitored element Type: 1 - Transformer 2 - Overhead line							Rating A	FLOW	Loading	Contingency element
Start node		kV	End node		kV	Type	MVA	MVA	%	
26059	SK 1-A	110	3WNDTR	SKOPJE 5	WND 2	1	300	300.7	100.2	Overhead line 26003-26065
26111	SK 1	400	3WNDTR	SKOPJE 5	WND 1	1	300	308.8	102.9	Overhead line 26003-26065
26111	SK 1	400	3WNDTR	SKOPJE 5	WND 1	1	300	303.2	101.1	Overhead line 26013-26115
26111	SK 1	400	3WNDTR	SKOPJE 5	WND 1	1	300	305.1	101.7	Overhead line 26017-26066
26059	SK 1-A	110	3WNDTR	SKOPJE 5	WND 2	1	300	300.1	100	Overhead line 26032-26065
26111	SK 1	400	3WNDTR	SKOPJE 5	WND 1	1	300	308.2	102.7	Overhead line 26032-26065
26059	SK 1-A	110	3WNDTR	SKOPJE 5	WND 2	1	300	301.1	100.4	Overhead line 26059-26063
26111	SK 1	400	3WNDTR	SKOPJE 5	WND 1	1	300	309.7	103.2	Overhead line 26059-26063
26059	SK 1-A	110	3WNDTR	SKOPJE 5	WND 2	1	300	304.2	101.4	Overhead line 26062-26063
26111	SK 1	400	3WNDTR	SKOPJE 5	WND 1	1	300	313.1	104.4	Overhead line 26062-26063
26059	SK 1-A	110	3WNDTR	SKOPJE 5	WND 2	1	300	308.5	102.8	Overhead line 26066-26115
26111	SK 1	400	3WNDTR	SKOPJE 5	WND 1	1	300	316.9	105.6	Overhead line 26066-26115
26111	SK 1	400	3WNDTR	SKOPJE 5	WND 1	1	300	303.7	101.2	Overhead line 26069-26125
26105	Z.RID	110	26603	TETO-ZR-GT	15	1	100	101.7	101.7	Overhead line 26105-26604
26059	SK 1-A	110	26063	SK 4-A	110	2	123	190.8	171.3	400/110/35 kV Transf. Skopje 5
26062	SK 3	110	26063	SK 4-A	110	2	123	140.2	123.1	400/110/35 kV Transf. Skopje 5
26063	SK 4-A	110	3WNDTR	SKOPJE 4	WND 2	1	300	478.5	159.5	400/110/35 kV Transf. Skopje 5
26064	SK 4	400	3WNDTR	SKOPJE 4	WND 1	1	300	510.5	170.2	400/110/35 kV Transf. Skopje 5
26059	SK 1-A	110	26063	SK 4-A	110	2	123	119.9	105.3	400/110/35 kV Transf. Skopje 4
26059	SK 1-A	110	3WNDTR	SKOPJE 5	WND 2	1	300	484.8	161.6	400/110/35 kV Transf. Skopje 4
26105	Z.RID	110	26603	TETO-ZR-GT	15	1	100	100.2	100.2	400/110/35 kV Transf. Skopje 4
26111	SK 1	400	3WNDTR	SKOPJE 5	WND 1	1	300	513.5	171.2	400/110/35 kV Transf. Skopje 4
26105	Z.RID	110	26603	TETO-ZR-GT	15	1	100	100.8	100.8	400/110/10 kV Transf. Kumanovo
26111	SK 1	400	3WNDTR	SKOPJE 5	WND 1	1	300	306.9	102.3	400/110/10 kV Transformer Ohrid

Target year 2040 with PEVs as load (G2V)

Table 33: Highest and lowest voltages in target year 2040 (G2V)

Bus Number	Bus Name	Voltage (pu)		
		Scenario 1	Scenario 2	Scenario 3
26017	GLOBOCICA	1.0369	0.9886	1.0076
26004	BITOLA 2	1.0335	1.0353	1
26902	T-SPOJ2	1.0335	1.0352	0.9981
26066	SPILJE	1.0349	0.9789	1.0078
26072	SUVODOL-1	1.0332	1.0347	0.9981
26120	OHRID	0.9997	1.0344	1.005

26085	DEBAR	1.0339	0.978	1.0077
26021	DUBROVO	1.0196	1.0337	1.0164
26042	TPP NEGOTINO	1.0197	1.0337	1.0033
26084	B.GNEOTINO	1.0324	1.0331	0.9981
26043	NEGOTINO	1.0185	1.0322	1.0032
26125	OHRID 3	1.0321	1.0284	1.004
26005	BITOLA 2	1	1.03	0.9981
26064	SK 4	0.9769	0.97	1.0182
26045	OSLOMEJ	1.0015	0.9696	1.0067
26074	TETOVO 1	0.9788	0.9547	1.0052
26117	GOSTIVAR 2	0.9951	0.9546	1.005
26049	POLOG	0.9916	0.9527	1.005
26075	TETOVO 2	0.979	0.953	1.0049
26018	GOSTIVAR	0.9929	0.9549	1.0048
26029	JUGOHROM	0.9735	0.9657	1.0033
26113	TEARCE	0.9734	0.9629	1.0032
26132	ZELINO	0.9755	0.956	1.0031
26059	SK 1 - A	0.9834	0.9633	1
26014	VRUTOK	1	0.9559	1
26035	ILOVICA	0.9654	0.9691	0.9681

Source: DNV GL analysis

Table 34: Highest line loadings in target year 2040 (G2V)

Line	Loading (%)		
	Scenario 1	Scenario 2	Scenario 3
26062 SK 3 - 26063 SK 4-A 110 kV	47.7	100.1	27.5
26059 SK 1-A - 26063 SK 4-A 110 kV	49.7	72.8	18.6
26013 VRUTOK - 26049 POLOG 110 kV	68.2	23.3	6.6
26066 SPILJE - 26115 B.MOST 110 kV	66.8	27.2	6.9
26069 STRUGA - 26125 OHRID 3 110 kV	6.6	60.8	13.0
26030 KAVADARCI - 26076 TIKVES 110 kV	59.7	20.4	12.0
26013 VRUTOK - 26117 GOSTIVAR 2 110 kV	59.2	5.8	2.4
26009 VALANDOVO - 26164 GRADEC 110 kV	58.8	43.3	27.1
26024 ZAPAD - 26062 SK 3 110 kV	58.2	43.8	8.5
26076 TIKVES - 26079 FENI 110 kV	58.1	21.9	17.0
26035 ILOVICA - 26073 SUSICA 110 kV	41.3	51.2	37.1

Source: DNV GL analysis

Table 35: Loading of transformers in target year 2040 with PEVs (G2V)

N	Transformer	Power [MVA]	Voltage [kV]	Loading [%]		
				Scenario 1	Scenario 2	Scenario 3
1	BITOLA	300	400/110/35	34.60	35.60	13.80
2	BITOLA	300	400/110/35	35.50	34.70	14.80
3	DUBROVO	300	400/110/35	28.70	15.50	18.70
4	DUBROVO	300	400/110/35	29.40	48.80	19.20
5	SKOPJE 4	300	400/110/35	49.10	43.50	17.30
6	SKOPJE 4	300	400/110/35	61.20	72.40	22.90
7	SKOPJE 5	300	400/110/35	23.20	4.50	11.70
8	SKOPJE 5	300	400/110/35	81.70	94.10	29.40
9	STIP	300	400/110/10	55.20	37.20	21.00
10	OHRID	300	400/110/10	29.50	45.70	6.80
11	KUMANOVO	300	400/110/10	58.20	45.60	12.40

Conclusion

One overhead line is loaded by 100% in the scenario 2:

- 26062 SK3 - 26063 SK4 110 kV: 100.1%
  This element is located in the Skopje area. DNV GL was informed by MEPSO that this area is characterised by a meshed network, which allows for various topological actions, such that any overloads can be considered less critical, i.e. that they can usually be managed by topological measures.

The n-1 security rule was checked for scenario 2, which showed the highest line loadings. Any elements already overloaded in the n-0 stated were not considered for n-1 calculations. Moreover, this study does not assess possible actions to remove violations, as this would require detailed studies to be carried out to develop the contingency plans.

The results of the contingency analysis are presented in Table 36 and Table 37.

The analysis shows that violations generally occur in the Skopje area only. These appear less critical, assuming that they can be managed by topological measures. In addition, we observe a slight overloading between Struga and Ohrid. But this flow is caused by a transformer outage at Skopje as well, such that the same considerations regarding the potential use of topological measures apply. In particular, we note that the parallel transformer was loaded less than 5% in the (n-0) case.

Table 36: Violations resulting from contingency analysis for scenario 2

Monitored element Type: 1 - Transformer 2 - Overhead line							Rating A	FLOW	Loading	Contingency element
Start node		kV	End node		kV	Type	MVA	MVA	%	
26064	SK 4	400	3WNDTR	SKOPJE 4	WND 1	1	300	532.8	177.6	400/110/35 kV Transformer Skopje 5
26111	SK 1	400	3WNDTR	SKOPJE 5	WND 1	1	300	484.8	161.6	400/110/35 kV Transformer Skopje 5
26063	SK 4	110	3WNDTR	SKOPJE 4	WND 2	1	300	461.6	153.9	400/110/35 kV Transformer Skopje 5
26059	SK 1	110	3WNDTR	SKOPJE 5	WND 2	1	300	435.9	145.3	400/110/35 kV Transformer Skopje 5
26111	SK 1	400	3WNDTR	SKOPJE 5	WND 1	1	300	331.9	110.6	Overhead line 26059-26063
26111	SK 1	400	3WNDTR	SKOPJE 5	WND 1	1	300	326.4	108.8	Overhead line 26062-26063
26111	SK 1	400	3WNDTR	SKOPJE 5	WND 1	1	300	320.2	106.7	Overhead line 26069-26125
26059	SK 1	110	3WNDTR	SKOPJE 5	WND 2	1	300	314	104.7	Overhead line 26059-26063
26111	SK 1	400	3WNDTR	SKOPJE 5	WND 1	1	300	309.3	103.1	400/110/10 kV Transformer Ohrid
26111	SK 1	400	3WNDTR	SKOPJE 5	WND 1	1	300	309.4	103.1	Overhead line 26003-26065
26059	SK 1	110	3WNDTR	SKOPJE 5	WND 2	1	300	306.2	102.1	Overhead line 26062-26063
26111	SK 1	400	3WNDTR	SKOPJE 5	WND 1	1	300	304.6	101.5	Overhead line 26032-26065
26111	SK 1	400	3WNDTR	SKOPJE 5	WND 1	1	300	302.5	100.8	Overhead line 26017-26066
26059	SK 1	110	3WNDTR	SKOPJE 5	WND 2	1	300	301.4	100.5	Overhead line 26069-26125
26111	SK 1	400	3WNDTR	SKOPJE 5	WND 1	1	300	301	100.3	Overhead line 26017-26069
26059	SK 1	110	26063	SK 4	110	2	123	232.3	235.8	400/110/35 kV Transformer Skopje 5
26069	STRUGA	110	26125	OHRID	110	2	123	119.3	101.5	400/110/35 kV Transformer Skopje 5

Table 37: Monitored voltage changes for scenario 2

Node		kV	V-INIT	V-CONT	Contingency element	
26062	SK 3	110	0.990	0.899	26063-26064-26264	400/110/35 kV Transformer Skopje 4
26024	ZAPAD	110	0.989	0.898	26063-26064-26264	400/110/35 kV Transformer Skopje 4
26033	KOZLE	110	0.988	0.897	26063-26064-26264	400/110/35 kV Transformer Skopje 4
26029	JUGOHROM	110	0.967	0.894	26063-26064-26264	400/110/35 kV Transformer Skopje 4
26113	TEARCE	110	0.964	0.892	26063-26064-26264	400/110/35 kV Transformer Skopje 4
26013	VRUTOK	110	0.957	0.889	26063-26064-26264	400/110/35 kV Transformer Skopje 4
26018	GOSTIVAR	110	0.956	0.888	26063-26064-26264	400/110/35 kV Transformer Skopje 4
26117	GOSTIVAR 2	110	0.956	0.888	26063-26064-26264	400/110/35 kV Transformer Skopje 4
26132	ZELINO	110	0.957	0.887	26063-26064-26264	400/110/35 kV Transformer Skopje 4
26074	TETOVO 1	110	0.956	0.887	26063-26064-26264	400/110/35 kV Transformer Skopje 4
26049	POLOG	110	0.954	0.886	26063-26064-26264	400/110/35 kV Transformer Skopje 4
26075	TETOVO 2	110	0.954	0.885	26063-26064-26264	400/110/35 kV Transformer Skopje 4
26017	GLOBOCICA	110	0.989	0.886	26059-26111-26258	400/110/35 kV Transformer Skopje 5
26066	SPILJE	110	0.980	0.857	26059-26111-26258	400/110/35 kV Transformer Skopje 5
26085	DEBAR	110	0.979	0.856	26059-26111-26258	400/110/35 kV Transformer Skopje 5
26032	KICEVO	110	0.972	0.849	26059-26111-26258	400/110/35 kV Transformer Skopje 5
26115	B.MOST	110	0.974	0.835	26059-26111-26258	400/110/35 kV Transformer Skopje 5
26062	SK 3	110	0.990	0.832	26059-26111-26258	400/110/35 kV Transformer Skopje 5

Node		kV	V-INIT	V-CONT	Contingency element	
26121	SV.PETKA	110	0.987	0.832	26059-26111-26258	400/110/35 kV Transformer Skopje 5
26106	KOZJAK	110	0.986	0.832	26059-26111-26258	400/110/35 kV Transformer Skopje 5
26024	ZAPAD	110	0.989	0.831	26059-26111-26258	400/110/35 kV Transformer Skopje 5
26057	SAMOKOV	110	0.977	0.830	26059-26111-26258	400/110/35 kV Transformer Skopje 5
26033	KOZLE	110	0.988	0.830	26059-26111-26258	400/110/35 kV Transformer Skopje 5
26045	OSLOMEJ	110	0.971	0.830	26059-26111-26258	400/110/35 kV Transformer Skopje 5
26023	G.PETROV	110	0.997	0.808	26059-26111-26258	400/110/35 kV Transformer Skopje 5
26199	MILADINOVCI	110	1.006	0.801	26059-26111-26258	400/110/35 kV Transformer Skopje 5
26059	SK 1	110	1.006	0.801	26059-26111-26258	400/110/35 kV Transformer Skopje 5
26025	ZLZ-SVR	110	1.005	0.800	26059-26111-26258	400/110/35 kV Transformer Skopje 5
26080	ZLZ-JUG	110	1.005	0.800	26059-26111-26258	400/110/35 kV Transformer Skopje 5
26105	Z.RID	110	1.005	0.800	26059-26111-26258	400/110/35 kV Transformer Skopje 5
26010	V.GLAVINOV	110	1.005	0.800	26059-26111-26258(	400/110/35 kV Transformer Skopje 5
26110	SARAJ	110	1.005	0.799	26059-26111-26258	400/110/35 kV Transformer Skopje 5
26015	G.BABA	110	1.002	0.796	26059-26111-26258	400/110/35 kV Transformer Skopje 5
26018	GOSTIVAR	110	0.956	0.784	26059-26111-26258	400/110/35 kV Transformer Skopje 5
26117	GOSTIVAR 2	110	0.956	0.783	26059-26111-26258	400/110/35 kV Transformer Skopje 5
26013	VRUTOK	110	0.957	0.783	26059-26111-26258	400/110/35 kV Transformer Skopje 5
26029	JUGOHROM	110	0.967	0.782	26059-26111-26258	400/110/35 kV Transformer Skopje 5
26113	TEARCE	110	0.964	0.779	26059-26111-26258	400/110/35 kV Transformer Skopje 5
26049	POLOG	110	0.954	0.775	26059-26111-26258	400/110/35 kV Transformer Skopje 5
26132	ZELINO	110	0.957	0.771	26059-26111-26258	400/110/35 kV Transformer Skopje 5
26074	TETOVO 1	110	0.956	0.770	26059-26111-26258	400/110/35 kV Transformer Skopje 5
26075	TETOVO 2	110	0.954	0.769	26059-26111-26258	400/110/35 kV Transformer Skopje 5
26066	SPILJE	110	0.980	0.897	26069-26125	110 kV Overheadline Struga - Ohrid
26085	DEBAR	110	0.979	0.896	26069-26125	110 kV Overheadline Struga - Ohrid
26017	GLOBOCICA	110	0.989	0.888	26069-26125	110 kV Overheadline Struga - Ohrid
26069	STRUGA	110	1.010	0.864	26069-26125	110 kV Overheadline Struga - Ohrid

Target year 2040 with PEVs as generator (V2G)

Table 38: Highest and lowest voltages in target year 2040 (V2G)

Bus Number	Bus Name	Voltage (pu)		
		Scenario 1	Scenario 2	Scenario 3
26004	BITOLA 2	1.0327	1.0122	0.9981
26072	SUVODOL-1	1.0327	1.0122	0.9981
26902	T-SPOJ2	1.0327	1.0122	0.9981
26125	OHRID 3	1.0324	1.0165	1.0092
26084	B.GNEOTINO	1.0317	1.0101	0.9982
26020	DELCEVO	0.9473	0.9731	0.9904
26035	ILOVICA	0.9472	0.9713	0.9684
26041	M.KAMENICA	0.9459	0.9717	0.995

Source: DNV GL analysis

Table 39: Highest line loadings in target year 2040 (V2G)

Line	Loading (%)		
	Scenario 1	Scenario 2	Scenario 3
26062 SK 3 - 26063 SK 4-A 110 kV	104.2	112.0	27.6
26069 STRUGA - 26125 OHRID 3 110 kV	61.1	97.9	15.4
26059 SK 1-A - 26063 SK 4-A 110 kV	93.2	92.5	17.1
26034 KOCANI - 26067 STIP 1 110 kV	70.1	59.8	13.8
26003 BITOLA 1 - 26004 BITOLA 2 110 kV	68.8	67.5	18.5
26003 BITOLA 1 - 26004 BITOLA 2 110 kV	68.8	65.8	18.5
26021 DUBROVO - 26030 KAVADARCI 110 kV	68.8	62.0	13.9
26032 KICEVO - 26065 SOPOTNICA 110 kV	57.3	67.0	13.2
26003 BITOLA 1 - 26065 SOPOTNICA 110 kV	58.2	65.8	17.3
26104 TETO-EC - 26999 SK 1-B 110 kV	64.6	57.1	9.0
26009 VALANDOVO - 26164 GRADEC 110 kV	63.5	55.7	17.1

Source: DNV GL analysis

Table 40: Loading of transformers in target year 2040 with PEVs (V2G)

N	Transformer	Power [MVA]	Voltage [kV]	Loading [%]		
				Scenario 4	Scenario 5	Scenario 6
1	BITOLA	300	400/110/35	49.50	45.60	11.60
2	BITOLA	300	400/110/35	50.70	44.50	11.30
3	DUBROVO	300	400/110/35	55.20	39.70	22.70
4	DUBROVO	300	400/110/35	56.60	57.40	23.30
5	SKOPJE 4	300	400/110/35	63.80	77.10	12.10
6	SKOPJE 4	300	400/110/35	95.90	96.40	22.80
7	SKOPJE 5	300	400/110/35	24.50	37.80	6.60
8	SKOPJE 5	300	400/110/35	141.40	148.10	30.00
9	STIP	300	400/110/10	85.00	57.70	26.40
10	OHRID	300	400/110/10	54.60	66.50	11.30
11	KUMANOVO	300	400/110/10	91.80	53.70	24.50

Conclusions

The load flow analysis reveals the following overloads in the (n-0) case already:

One overhead line is in the scenario 5 overloaded (over 100 %):

- Overhead line 26062 SK 3 - 26063 SK 4-A 110 kV
  Overloaded at 104.2 % for scenario 4 / 112 % for scenario 5
- Transformer SKOPJE 5:
  Overloaded at 141 % for scenario 4 / 148 % for scenario 5

In addition, we observe very high loadings at two other overhead lines:

- 26069 STRUGA - 26125 OHRID 3 110 kV
- 26059 SK 1-A - 26063 SK 4-A 110 kV

All voltage ranges are met.

The overloads in the (n-0) state, again mainly in the Skopje area, indicate potential issues with the switching state and/or the detailed nodal allocation of the additional (EV) load, which would require a more detailed analysis and fine-tuning of the grid model. For these reasons, no contingency analysis was carried out for these scenarios.

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