



Preparatory Study on Ecodesign and Energy Labelling of Batteries under FWC ENER/C3/2015-619-Lot 1

TASK 2

Markets – For Ecodesign and Energy Labelling

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2. Task 2: Markets

The objective of Task 2 is to present an economic and market analysis on batteries and battery components (particularly LIB) according to the definition presented in 1.2.1. The aims are:

- to provide basic economic information on batteries (according to the definition provided in 1.2.1) (subtask 2.1);
- to provide market size and cost inputs for the EU-wide environmental impact assessment of the product group (subtask 2.2);
- to provide insight into the latest market trends to help assess the impact of potential Ecodesign measures with regard to market structures and ongoing trends in product design (subtask 2.3, also relevant for the impact analyses in Task 3); and finally,
- to provide a practical data set of prices and rates to be used for Life Cycle Cost (LCC) calculations (subtask 2.4).

2.1. Definitions

In the following, several definitions and categories are used:

- Abbreviations for vehicles: combustion powered vehicles (ICE), vehicles utilizing a traction battery (xEV) full electric vehicles (BEV), plugin hybrid electric vehicles (PHEV), hybrid vehicles without option for external charging (HEV), hybrid vehicles making use of a fuel cell as range extender (FCEV).
- Abbreviations for battery markets: Traction batteries, also for auxiliary functions in industrial applications (motive); consumer, computing and communication applications (3C); stationary applications (ESS).
- Market, sales or other volumes in units of battery capacity (kWh, MWh or GWh) or in units of number of battery systems (thousand units: k#, million units: mio#).
- Sales or new installations: Volume (number of units) of battery systems or capacity (GWh) put into operation for the first time (e.g. new vehicles or new storage systems).
- Replacements: Replacement batteries (e.g. packs or cells) for systems already in use (GWh).

Decommissions: Decommissioned batteries (GWh) resulting either from decommissioned systems at their end of life (vehicles, stationary systems) or from broken and replaced batteries.

2.2. Generic economic data

In the MEErP, generic economic data refers to data that is available in official EU statistics (e.g. PRODCOM) and the aim is to identify and report the 'EU apparent consumption' which is defined as 'EU production + EU import – EU export'. Additionally, the average value of each product is verified. The information required for this subtask should be derived from official EU statistics so as to be coherent with official data used in EU industry and trade policy.

2.2.1. Approach to subtask 2

PRODCOM data is publicly available and is a direct source of market information. PRODCOM data does not give any direct information about the total number of installed batteries in use

in the EU28 member countries. The data might also not account for batteries imported to or exported from the EU as sub-unit of other products (e.g. batteries in cell phones).

2.2.1.1. Secondary batteries related PRODCOM categories

Several categories on batteries exist within the NACE2 classification (see [Table 1](#)), however there is no category for LIB cells, modules or packs. LIB based secondary batteries are included in the composite category 2702300 along with all other, not Pb-based secondary battery technologies.

27201100	Primary cells and primary batteries
27201200	Parts of primary cells and primary batteries (excluding battery carbons, for rechargeable batteries)
27202100	Lead-acid accumulators for starting piston engines
27202200	Lead-acid accumulators, excluding for starting piston engines
27202300	Nickel-cadmium, nickel metal hydride, lithium-ion, lithium polymer, nickel-iron and other electric accumulators
27202400	Parts of electric accumulators including separators

Table 1: PRODCOM categories related to batteries [1].

2.2.2. Results of the PRODCOM analysis

The PRODCOM category 27202300 Nickel-cadmium, nickel metal hydride, lithium-ion, lithium polymer, nickel-iron and other electric accumulators is analyzed in more detail for the years 1995, 2000, 2005, 2010, 2015 and 2017 based on Eurostat PRODCOM data obtained online in September 2018 [2].

[Figure 1](#) shows the development of production, import and export volumes in Euro for PRODCOM category 27202300 in the time from 1995 to 2017. The data shows an increase of market volume in all three categories. Since several battery technologies are aggregated in this PRODCOM category, values specific for LIB cannot be obtained from this data. Due to the development of the different battery technologies, it is likely that the market values in the 1990s and early 2000s can mainly be attributed to NiMH, NiCd and other technologies. The growth experienced since 2010 in all three market categories is likely to be a result of the development in the LIB market, which can be considered to be the dominant submarket under the battery technologies aggregated under 27202300 today (see and compare section 2.4.3 with a global analysis of different battery technologies).

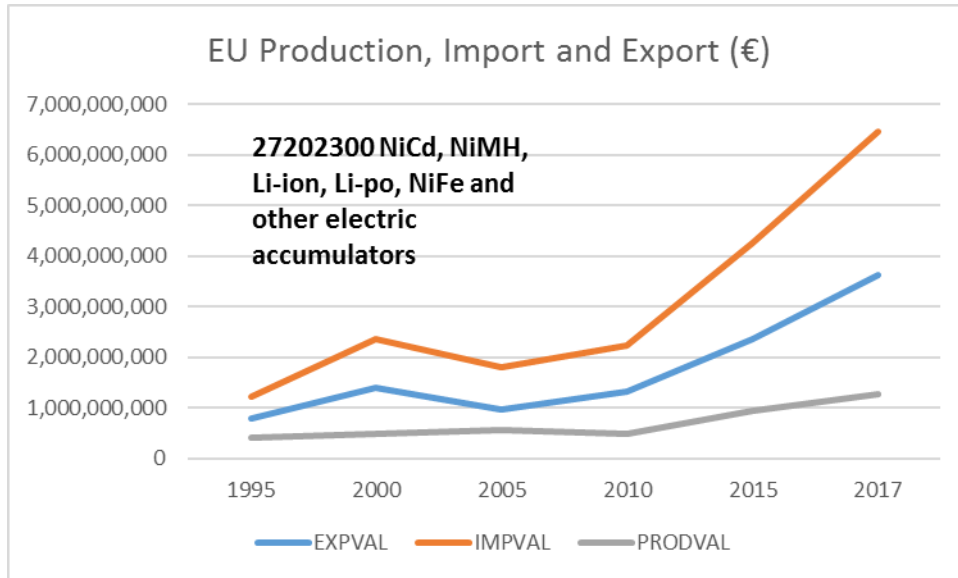


Figure 1: EU production, import and export summarized in PRODCOM category 27202300: Nickel-cadmium, nickel metal hydride, lithium-ion, lithium polymer, nickel-iron and other electric accumulators [2].

Note that no production volumes in terms of units or kWh are available from Eurostat.

The value of batteries integrated into applications or sold as end products in Europe can be assessed by considering the EU consumption value (EU sales and trade), which results from the sum of production and import minus export values (see Figure 2). After a plateau like market behavior between 2000 and 2010, a steep increase of the EU consumption value can be observed. The 2017 value adds up to about 4 billion Euro. Assuming that the majority share of this value can be attributed to LIB with a market price of 300 to 500 €/kWh (assumed mix of higher priced consumer cells and lower priced automotive cells), the value corresponds to a capacity of 8 to 13 GWh. In consideration of its estimated character, this number is in accordance with the data presented in section 2.3.5 (based on a bottom up estimation of the capacity demand by passenger electric vehicles (xEV) and home storage ESS (energy storage systems) markets; 3C (consumer, computing, communication) markets are not considered).

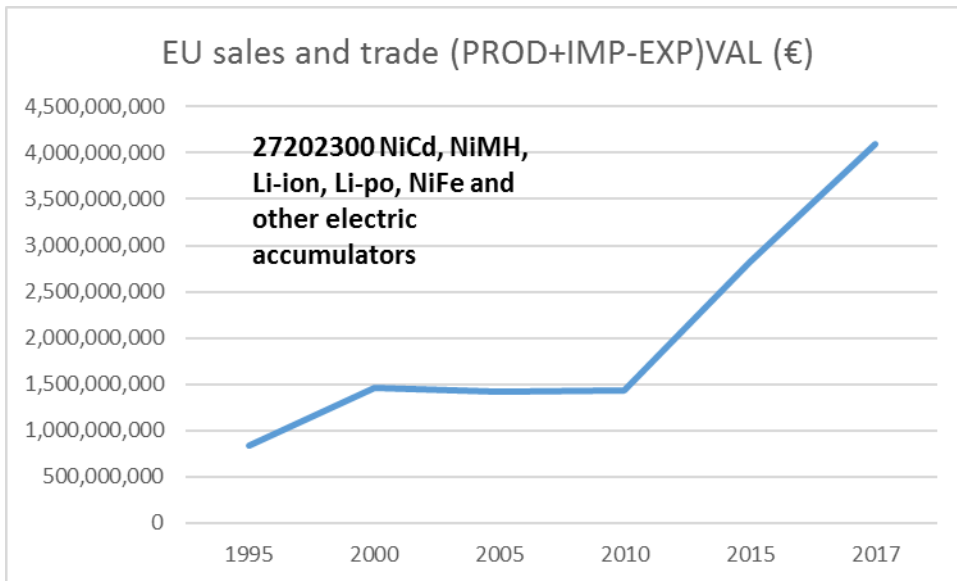


Figure 2: EU sales and trade (PROD+IMP-EXP) summarized in PRODCOM category 27202300 Nickel-cadmium, nickel metal hydride, lithium-ion, lithium polymer, nickel-iron and other electric accumulators [2].

Hence it can be assumed, that the data presented in the PRODCOM database meets the right order of magnitude. Due to the aggregation of battery technologies, the consumption value of LIB alone can however not be assessed by this data. Furthermore, the large price spread for LIB and the dynamic development of prices does not allow to reliably conclude on the demand of battery capacity (GWh). An assessment of market development and installed LIB stock in Europe is given in section 2.3 and 2.4 based on other data sources.

2.3. Market and stock data

2.3.1. General objective of subtask 2.2 and discussion of useful data sources

The objective is to compile market and stock data in physical units for the EU, for each of the product categories defined in Task 1.1, combined with a forecast 2020-2050. Therefore, the following parameters need to be identified:

- Market and installed stock assessment in units of number of systems (battery systems for xEV, battery systems for ESS) and corresponding battery capacity (MWh or GWh).
- Replacement cycles and lifetime data. This data is assumed to be strongly application dependent. At present, there is no comprehensive data available.
-

2.3.1.1. Useful data sources

Several market studies describing the present and future market situation for battery-based applications exist. Most of these studies have a global scope or focus on Asian countries due

to the structure of the battery market. Comprehensive studies providing market data for the EU and its member states are not known.

To give an overview about stock and battery markets for the EU28 member states, the following bottom-up sources were utilized to give model estimations:

- Fraunhofer ISI in-house xEV database [3]: The database has been developed in 2014 by Fraunhofer ISI and is updated since on an annual basis. The last update was done in November 2018. It covers global production and sales numbers for xEV models broken down to countries as well as information on battery capacity and range of the vehicles. The database aggregates information provided by Marklines Co, Ltd. [4], the European Automobile Manufacturers Association [5], the EV-sales blog [6] and other online sources (e.g. websites of automotive OEM). The ISI xEV database has been checked against the European Alternative Fuels Observatory [7] and is in well agreement.
- Fraunhofer ISI in-house LIB database [8]: The database covers information on the major industrial players in the Li-ion business from materials to cell production. The development and location of production capacities is frequently updated. Information on performance and cost of commercially available battery cells as well as the meta-analysis of several studies providing forecasts on the respective developments are also covered in the database. Information is collected from several online sources and available product data sheets.
- B3 corporation market studies: B3 corporation provides topical market studies on xEV, ESS and material markets for Li-ion batteries. The market data is updated on an annual basis. B3 studies have a global scope, but occasionally also cover local European markets.
- Additional market studies and databases as discussed in the following sections.

2.3.2. Direct market data on LIB cells

There are few sources providing direct data on battery sales. As compared to the PRODCOM scheme, more detailed data on LIB cells attributed to target applications is given in ProSUM [9] for the years 2000 - 2015. The amount of LIB cells placed on the market is given in units of pieces and weight. The data shows that the majority of cells sold in the EU are rather small cells with an average weight of 40 g/piece in 2000 and 250 g/piece in 2015 (a 18650 format cell has a weight of approximately 50 g). This is also reflected by the high share of cells designated for use in 3C applications (see [Figure 3](#) top, compare also to section 2.4.4 for global data). While this market segment featured moderate yearly growth rates of about 10% between 2010 and 2015, particularly the xEV battery market has been growing strongly (annual growth rate of about 60%).

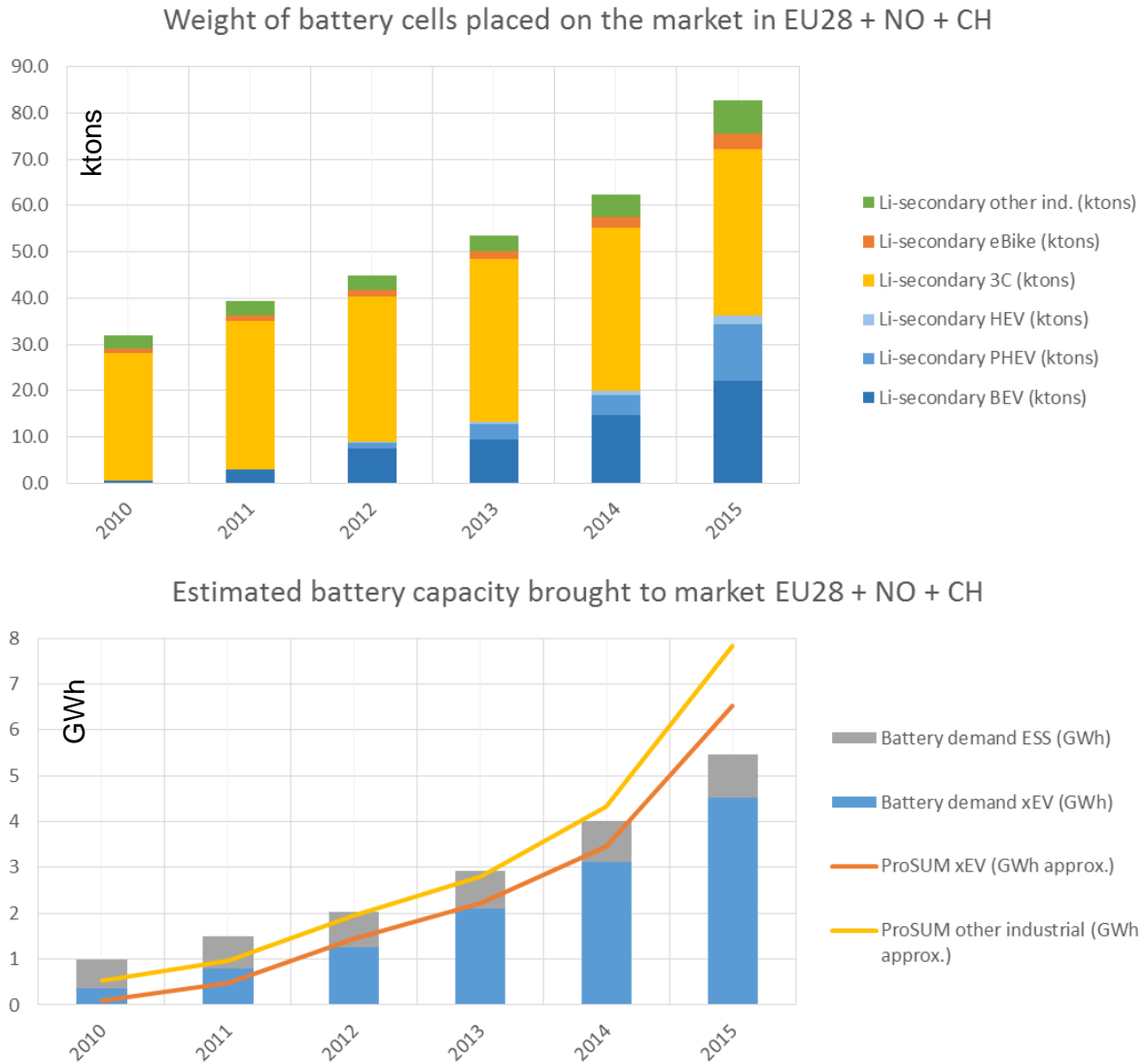


Figure 3: Top: Weight of battery cells placed on the market in the EU28 and Norway and Switzerland as obtained from [9]. Bottom: Approximated battery capacity for data provided in [9] and comparison with battery demand model (see section 2.3.5).

Assuming an average energy density of 150 Wh/kg in 2010 and 180 Wh/kg in 2015, the data on LIB cell weight given in [9] translates into an estimated total capacity of 15 GWh placed on the market in 2015. [Figure 3](#) (bottom) shows the development of estimated LIB capacity for xEV applications and non-motive industrial applications. In addition, the capacity demand for xEV and ESS as calculated in the frame of the demand and forecast model utilized in the study at hand (EU only) is shown. The model is introduced in sections 2.3.3 and 2.3.4 in more detail. Additional information can be found in section 2.7. With respect to the uncertainties regarding the estimated battery energy density in [9] and the contribution of Norway and Switzerland to the volume of batteries, both data sets are in well agreement.

2.3.3. Market stock and forecast for xEV in Europe

As will be shown in section 2.4, the stock of installed medium or large batteries in Europe is strongly related to the diffusion of electric mobility. In contrast to several Asian countries, xEV sales in Europe predominantly concern passenger cars. Ebuses as well as light and heavy

commercial vehicles still do not play a major role in terms of installed capacity, but might become growth markets in the future.

2.3.3.1. Production and sales of BEV

[Figure 4](#) shows the number of produced BEV [3] broken down to their production country from 2010 to 2018. A forecast until 2020 based on the average growth rates between 2016 and 2018 is shown in addition. This production data is a measure for the demand of battery cells in the individual EU28 countries.

Germany, France and the Netherlands lead the field of BEV producers in Europe. On European level, an average yearly growth rate of over 40% can be observed. It is expected that the number of 150000 produced BEV in 2018 will double in 2020.

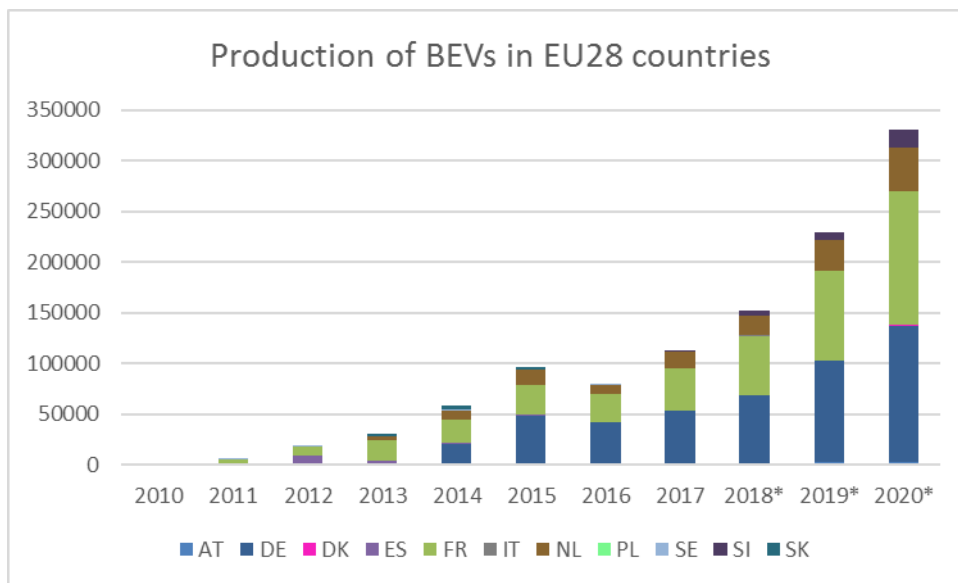


Figure 4: Production numbers for BEVs produced in EU28 countries and forecast until 2020. [3]

In contrast to the production data, the sales numbers for BEV reflect the amount of installed vehicle batteries in the individual EU28 countries. It can be seen in [Figure 5](#), that the distribution in terms of sold vehicles among the EU28 countries is much more even as compared to the production. Germany, France, the United Kingdom and the Netherlands lead the market, however significant sales numbers can also be found in other countries. The level and growth rates of BEV sales is comparable to BEV production. It should however be noted that there is significant trade with other regions of the world, e.g. BEV imports and exports with Asia and North America. Hence, the BEV market cannot be considered as an internal market.

In addition to the EU28 member states, [Figure 5](#) also shows sales numbers for Norway, which significantly contribute to the market volume in the European Economic Area (EEA).

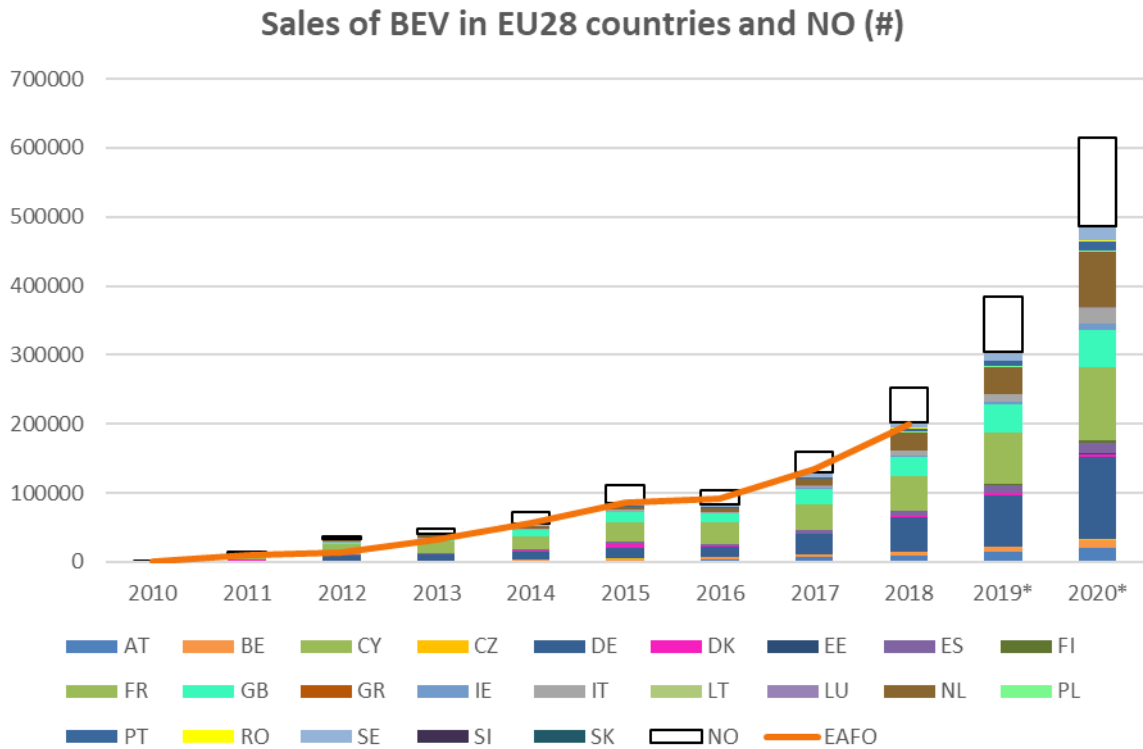


Figure 5: Number of sold BEVs in EU28 member states and Norway and forecast until 2020 [3, 7].

2.3.3.2. Production and sales of PHEV

Similar to section 2.3.3.1, production and sales numbers for PHEV resolved by country are shown in [Figure 6](#) and [Figure 7](#). Although on a comparable level in terms of produced and sold vehicles it must be emphasized that the contribution of PHEVs to the demand for battery capacity is, due to the smaller size of the battery, significantly below the demand generated by BEV. At present, the main production sites for PHEV are located in Germany. Sweden and Slovakia also significantly contribute to the production.

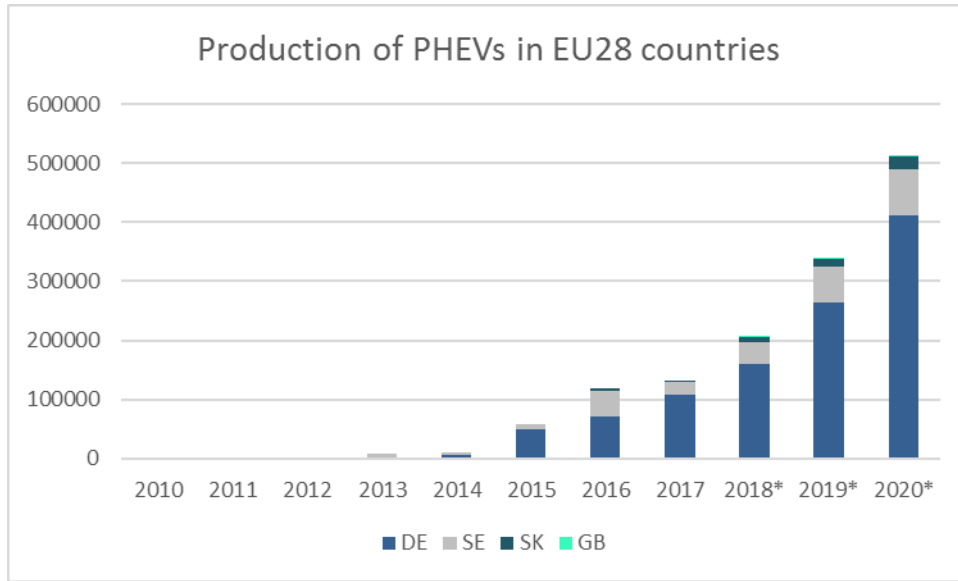


Figure 6: Number of produced PHEV in EU28 member states and forecast until 2020. [3]

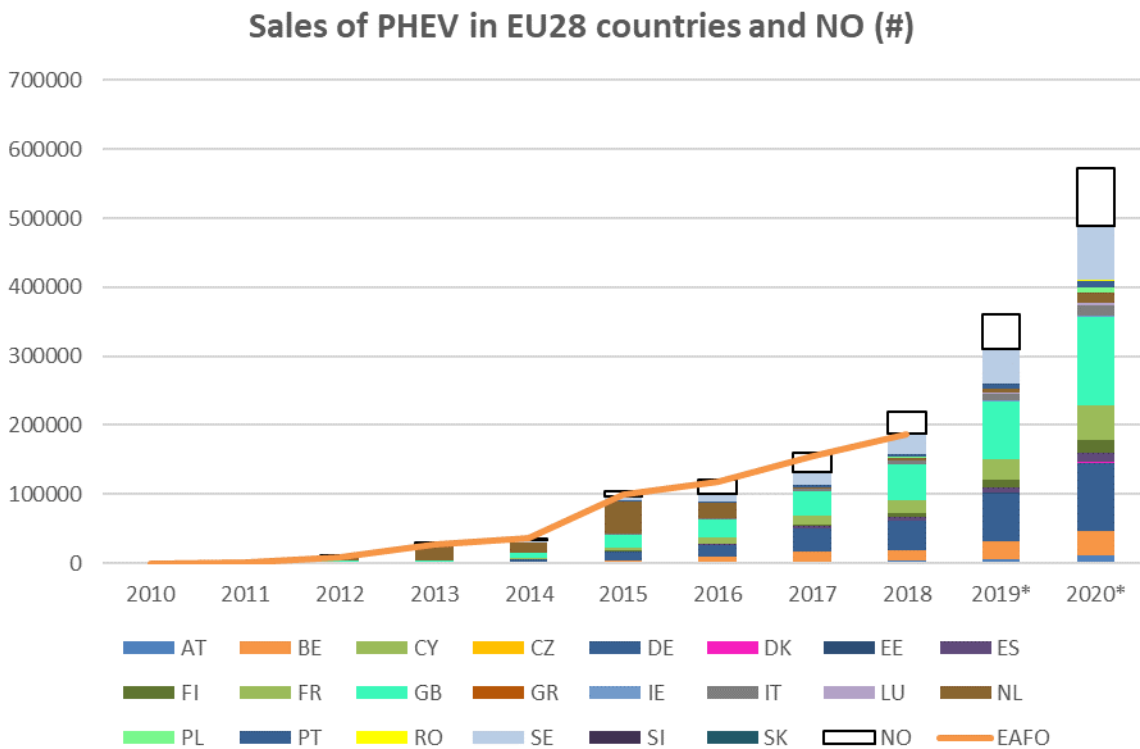


Figure 7: Number of sold PHEV in EU28 member states and Norway and forecast until 2020. [3, 7]

In terms of sales, the largest demand for PHEV is generated in the UK, Germany and Sweden. Interestingly, the share of sold PHEV also produced in the EU is higher as compared to BEV.

2.3.3.3. Forecast passenger xEV sales and stock EU28

The data presented in sections 2.3.3.1 and 2.3.3.2 was used as an input for a forecast model on passenger PHEV and BEV sales in the EU28 (see also [10] and section 2.7).

2.3.3.3.1. Minimum and maximum scenarios

Two different scenarios for the minimum and maximum market diffusion of BEV and PHEV were developed.

In the frame of the forecast model applied, xEV model availability (1, measure for the supply) as well as sales performance (number of sold vehicles per year per model) of xEV models (2, measure for the demand) are major determinants for the future growth of xEV markets. In the minimum scenario, sales numbers until 2025 were derived from (1) existing xEV models and additional models announced by different OEM. A linear forward projection for the sales performance of xEV models was assumed (2). In the maximum scenario it was assumed that OEM will introduce additional models, not yet announced, to the market (1). The sales performance per model was assumed to reach the level of the sales performance of combustion powered cars until 2025 (2). Today, the average sales performance of electric vehicles is significantly below the performance of combustion powered vehicles.

Long-term scenarios are based on the min./max. projection data until 2025 (see section 2.7). It was assumed that extrapolated EU wide sales numbers and growth rates for passenger as well as for light vehicles and buses of all technologies (particularly combustion powered) [5] represent natural boundaries for the growth of xEV markets.

As a third input parameter for min./max. scenarios, the market shares addressable by electric vehicle models and in particular addressable by BEV were included. It was assumed, that the range requirements of long-haul transport (e.g. heavy commercials or touring coaches, see section 2.3.3.4) cannot be met by full battery electric concepts. Hence hybrid (battery and combustion or battery and fuel cell) concepts might have a high market share even in the long term.

The model applied prioritizes the sales of BEV during market ramp-up. BEV will freely diffuse into the market until their addressable market share is reached. Sales of PHEV and HEV will hence decline, once electric vehicles have reached market saturation and there is a direct competition of the three electric drive technologies. The maximum scenario describes fast and deep market penetration of BEV and resulting smaller market shares of PHEV and HEV in the long term. The minimum scenario describes slower market penetration of BEV with a smaller addressable market and resulting higher market shares of PHEV and HEV in the mid to long term.

2.3.3.3.2. Assumptions

The sizes of vehicle markets as well as assumed growth rates are given in [Table 2](#). Minimum and maximum values for the model parameters are given in [Table 3](#).

Market parameter	Value
Passenger vehicle market EU28, 2017 [3, 5]	15 mio vehicles per year
Passenger vehicle market growth rate EU28 [3]	1.3 %

Table 2: Assumptions and input parameters for the xEV market and growth model.

Model parameter	Min. value	Max. value
Share of passenger vehicle market addressable by BEV	60 %	90 %
Share of passenger vehicle market addressable by PHEV	90 %	100 %

Table 3: Assumptions and input parameters for the xEV market and growth model.

At present, there is no sufficient data on the battery and vehicle lifetime of xEV. Vehicle lifetimes were fixed on values for ICE powered vehicles (see section 2.7.1.5). While this might not necessarily be true, differing values would directly influence the overall vehicle market volumes (e.g. shorter lifetime would require higher sales volumes to keep the stock constant). Hence, in the frame of the model applied, vehicle lifetimes were fixed and the overall market volumes for vehicles were adopted from historic data.

Assumptions on battery replacement rates are given in section 2.7.1.4. The assumptions for the stock model are summarized in [Table 4](#).

Model parameter	Value
Passenger xEV lifetime	17 years
Passenger BEV battery replacement rate	10 %
Passenger PHEV battery replacement rate	66 %

Table 4: Assumptions and input parameters for the xEV battery demand and stock model.

2.3.3.3.3. Results: forecast passenger xEV and stock

Historic sales data (2010-2018) for passenger vehicles was aggregated to three segments: (mini) A and B; (comp) C and M; (lux) D, E, F and all SUV segments [11]. Logistic growth functions (see section 2.7.1.2) were fitted to the data for BEV, PHEV and HEV markets. HEV are considered for reasons of consistency. Due to their rather small installed battery capacity, they are not included in overall xEV sales numbers.

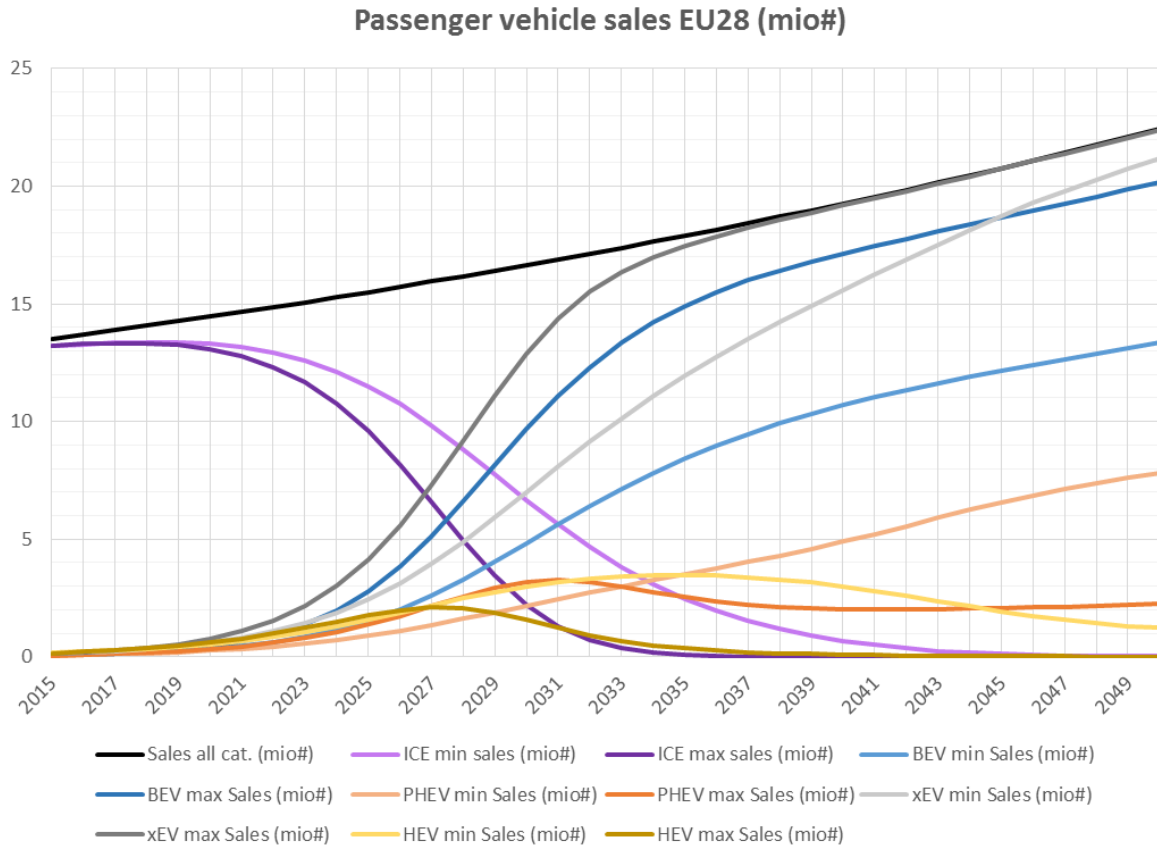


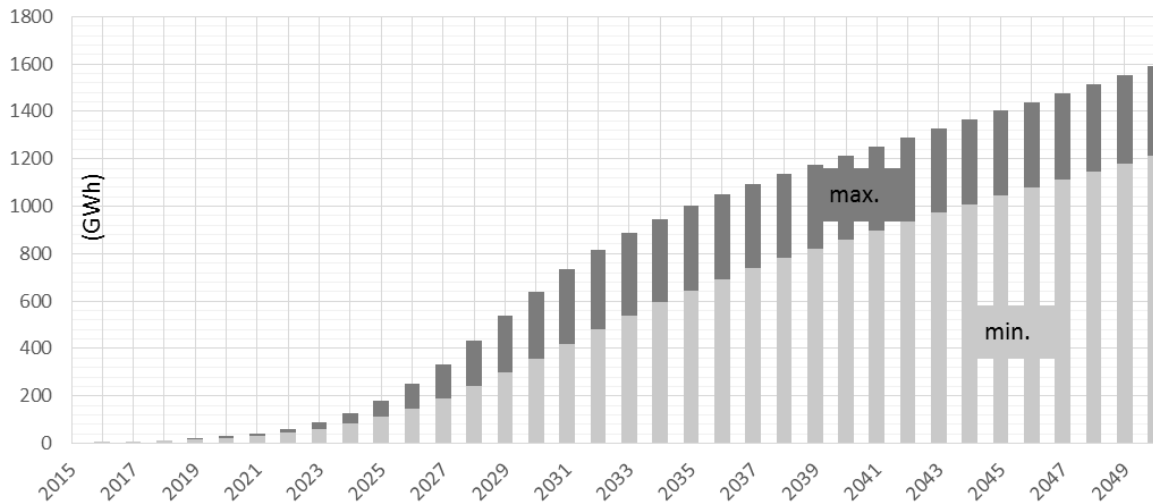
Figure 8: Forecast passenger xEV sales until 2050.

The model and forecast results for passenger vehicles are presented in [Figure 8](#).

Within the model, the major transition to passenger electric vehicles is expected to happen between 2025 and 2035.

The implications of market growth with respect to battery demand – either generated by sales of new vehicles or replacement of batteries – as well as the projected stock of electric vehicles are given in [Figure 9](#).

Battery demand generated by sales of new passenger xEV or by battery replacements (GWh)



Passenger xEV stock (GWh installed battery capacity and mio EVs)

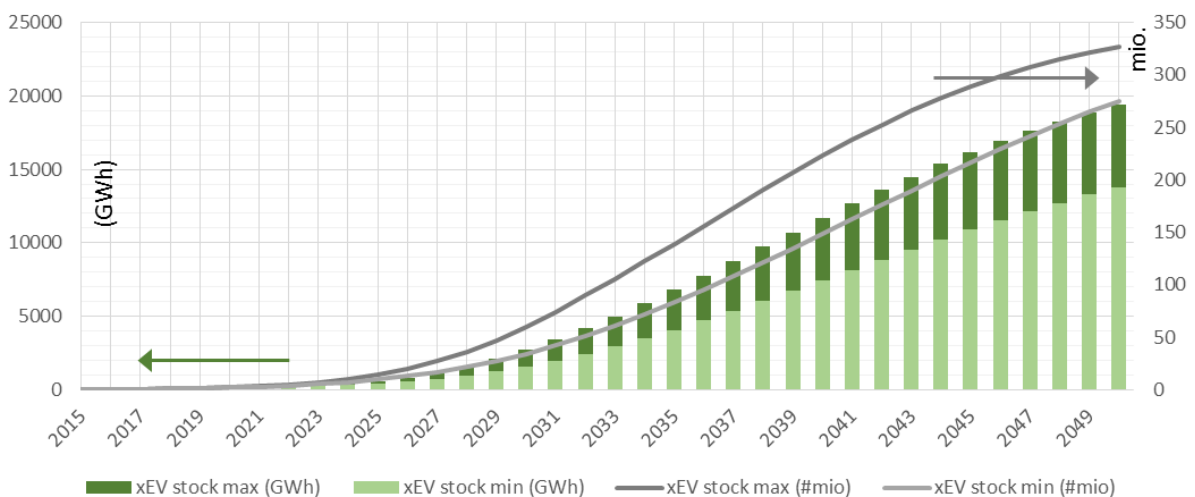


Figure 9: Battery demand generated by passenger xEV and xEV stock.

As noted in section 2.3.3.1, other countries part of the European Economic Area, particularly Norway, will contribute significantly to the market volume of batteries in Europe. With respect to today's sales numbers for passenger electric vehicles in the EEA and in the EU28, the battery demand projected in [Figure 9](#) (EU28) would be 10 to 20% higher if the whole EEA is considered.

2.3.3.4. Sales of commercial vehicles

In contrast to battery electric light commercial EV and eBuses, other commercial or industrial EV segments mostly have rather small market shares. [Figure 10](#) shows sales numbers for electric light commercial vehicles and eBuses for the EU as obtained from [7]. Notably, sales of light commercial EV as well as eBuses are dominated by BEV models. With respect to total market volumes, electric light commercial vehicles and eBuses reached a market share of about 1.2% and 2% in 2018 respectively.

With only few vehicles on the street, electric heavy commercials have a negligible market share.

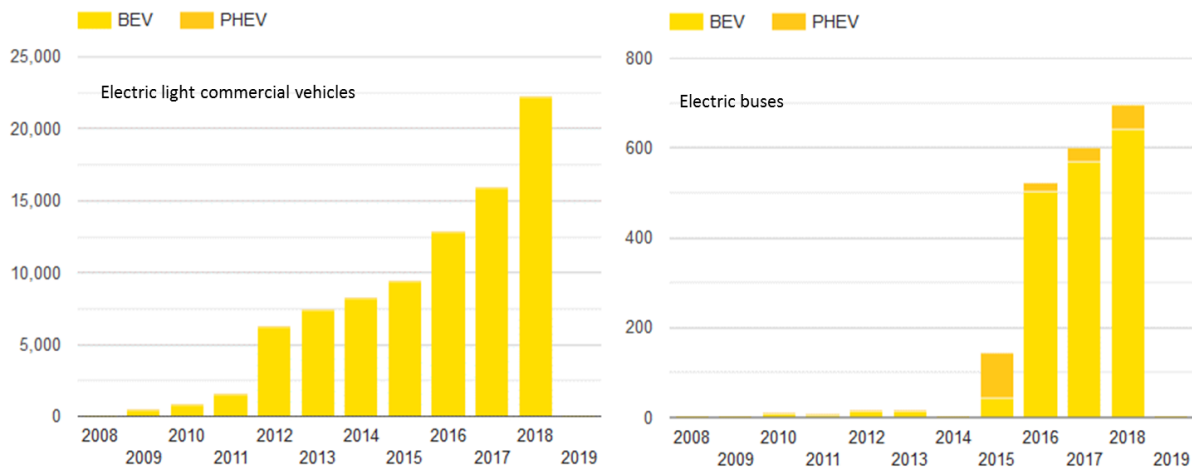


Figure 10: Sales numbers for light commercial vehicles and eBuses in the EU28 as taken from [7].

2.3.3.5. Forecast bus and commercial xEV sales and stock EU28

The sales numbers provided in section 2.3.3.4 were used as input to model the growth of the sub-markets BEV light commercial vehicles and BEV buses. Sales numbers for other sub-markets are comparably low and not sufficient to serve as input for long-term growth models. However, there are market targets for certain segments given by CO₂ or other legislation which allow for an estimate of future market volumes (e.g. procurement of public buses) [12, 13].

Hence, model results presented in section 2.3.3.5.2 should rather be interpreted as estimated scenarios than as forecasts. Minimum and maximum scenarios are used to present a certain range of potential market development.

2.3.3.5.1. Assumptions

The sizes of vehicle markets as well as assumed growth rates are given in [Table 5](#). Minimum and maximum values for the model parameters are given in [Table 6](#).

Market parameter	Value
Light commercial vehicle market EU28, 2017	1.8 mio vehicles per year
Heavy commercial vehicle market EU28, 2017	0.33 mio vehicles per year
Medium and heavy bus market EU28, 2017	34 thousand vehicles per year
Commercial vehicle market growth rate EU28	Light: 1.7 %, heavy and bus: 1 %

Table 5: Assumptions and input parameters for the xEV market and growth model.

Model parameter	Min. value	Max. value
Share of light commercial vehicle market addressable by BEV	65 %	85 %
Share of light commercial vehicle market addressable by PHEV	90 %	100 %
Share of heavy commercial vehicle market addressable by BEV	15 %	25 %
Share of heavy commercial vehicle market addressable by PHEV	70 %	80 %
Share of medium and heavy bus market addressable by BEV	60 %	80 %
Share of medium and heavy bus market addressable by PHEV	90 %	100 %

Table 6: Assumptions and input parameters for the xEV market and growth model.

At present, there is no sufficient data on the battery and vehicle lifetime of xEV. Vehicle lifetimes were fixed to values for ICE powered vehicles (see section 2.7.1.5). Assumptions on battery replacement rates are given in section 2.7.1.4. The assumptions for the stock model are summarized in [Table 7](#).

Model parameter	Value
Light commercial xEV lifetime [5]	15.5 years
Heavy commercial xEV lifetime	15 years
eBus lifetime	15 years
Light commercial BEV battery replacement rate	25%
Light commercial PHEV battery replacement rate	30%
Heavy commercial BEV battery replacement rate	80%
Heavy commercial PHEV battery replacement rate	80%
Bus BEV battery replacement rate	80%
Bus PHEV battery replacement rate	80%

Table 7: Assumptions and input parameters for the xEV battery demand and stock model.

Due to their high range requirements, commercial vehicles are candidates for the utilization of fuel cells in battery hybrid concepts (FCEV). The technology was considered as additional path for the time 2030 and later.

2.3.3.5.2. Results forecast passenger xEV and stock

The market diffusion scenarios for light and heavy commercial vehicles and eBuses are shown in [Figure 11](#) and [Figure 12](#) respectively.

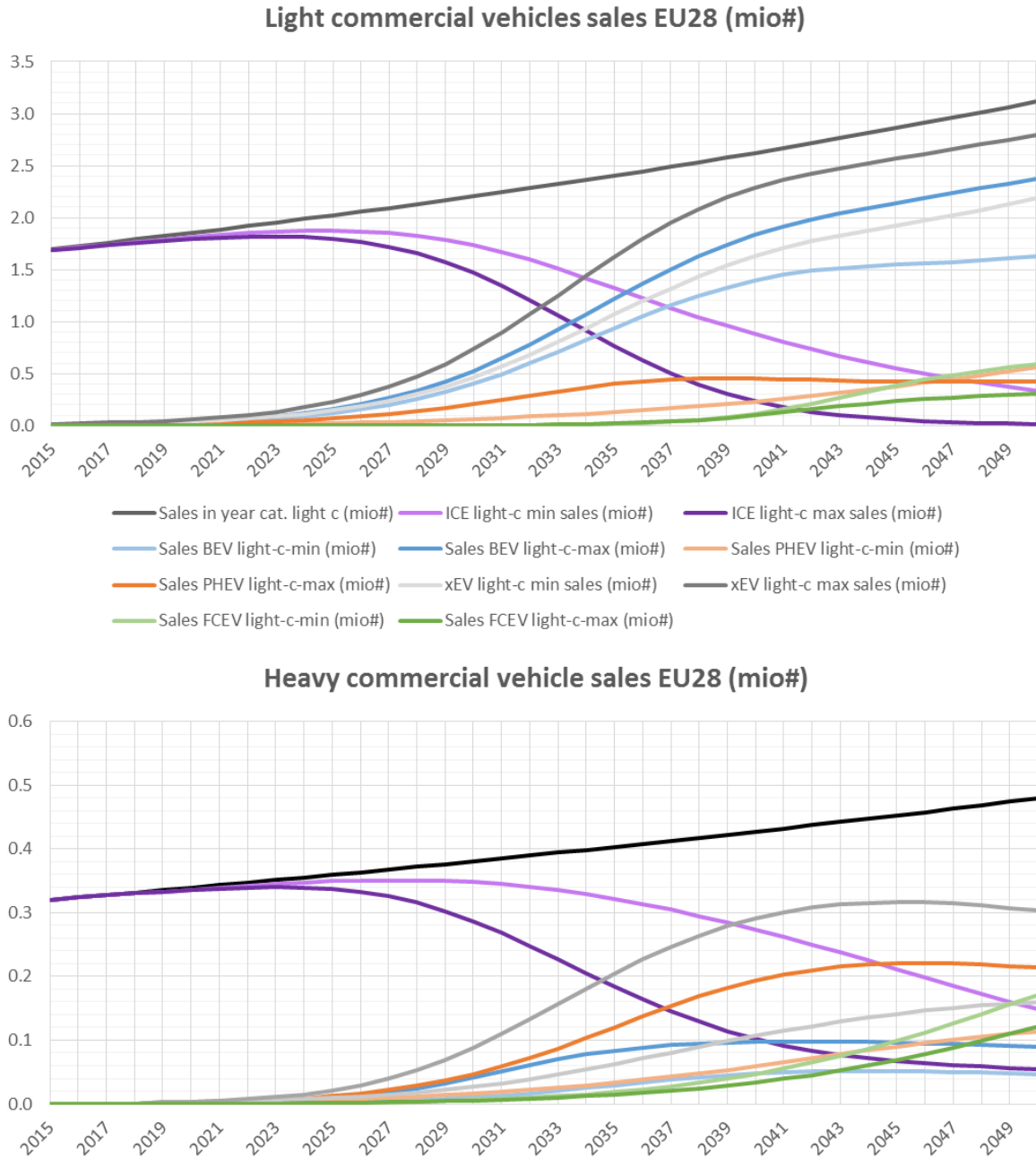


Figure 11: Market diffusion scenarios light and heavy commercial xEV sales until 2050.

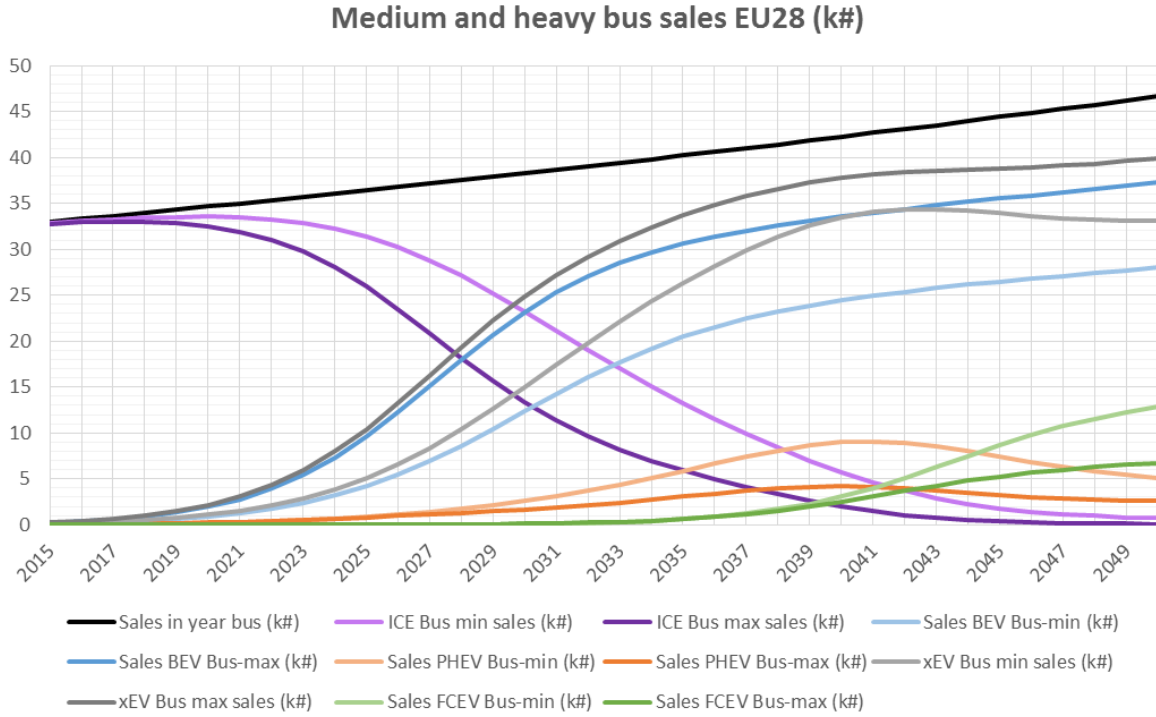


Figure 12: Market diffusion scenarios eBus sales until 2050.

Figure 13 shows the demand for battery capacity resulting from the three markets as well as the calculated EV and battery stock in the EU28.

Battery demand generated by sales of new commercial xEV* or by battery replacements (GWh)



Commercial xEV* stock (GWh installed battery capacity and mio EVs)

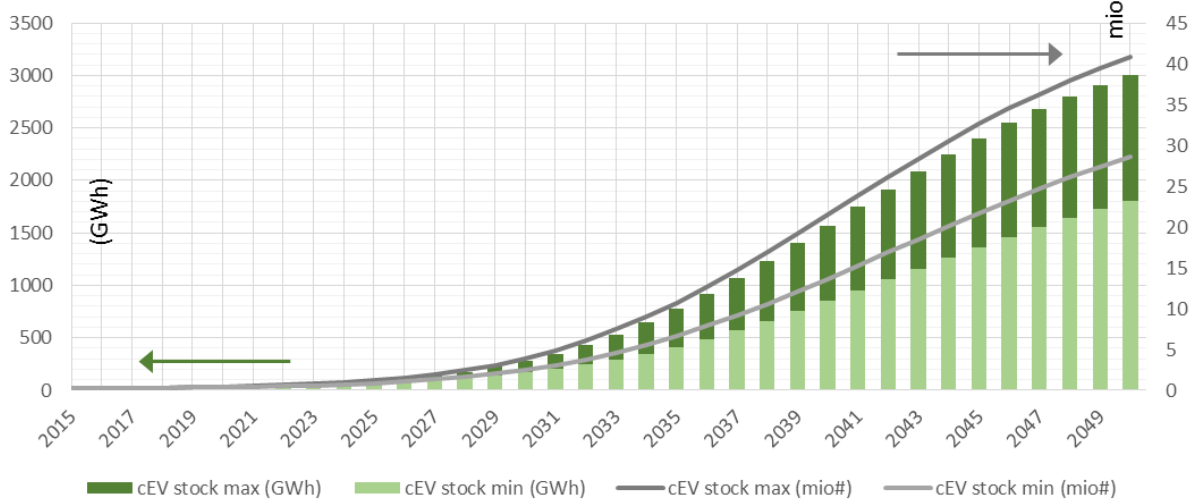


Figure 13: Battery demand generated by commercial xEV and commercial xEV stock.

2.3.4. Market stock and forecast for ESS in Europe

As discussed in Task 1, several stationary applications for batteries exist, ranging from grid support to home storage. As will be shown in section 2.4, the demand for battery capacity generated by ESS applications at present is rather small as compared to 3C and motive markets. There is no systematic registration of large-scale or small-scale stationary storage systems in the EU. Hence, the market stock and volume for respective applications can only be estimated based on indirect data.

2.3.4.1. Photovoltaic installations in the EU

Energy storage systems in combination with photovoltaic installations are one major application for batteries both for private as well as commercial purposes. Due to changes in reimbursement and subsidy policy as well as the physical capability of the energy system to buffer and process high shares of renewable energy, the use of local energy storage systems

is becoming more and more popular. There is no data on the share of PV installations equipped with an energy storage system for the EU. However, on regional level, some data is available. According to [14], approximately half of the new PV systems with a peak power below 30 kW installed in Germany in 2017 have been equipped with an energy storage system (amounting to about 30,000 storage systems with a cumulative capacity of 400 MWh).

At present, the installation of storage systems is strongly coupled to new installations of PV systems. As shown in [Figure 14](#) with data on Germany, the retrofit of existing PV installations with storage systems is however expected to contribute significantly to the demand for battery capacity in the PV segment in the future. Within the forecast shown, 50% of the storage systems sold in 2030 might be integrated into already existing PV-systems.

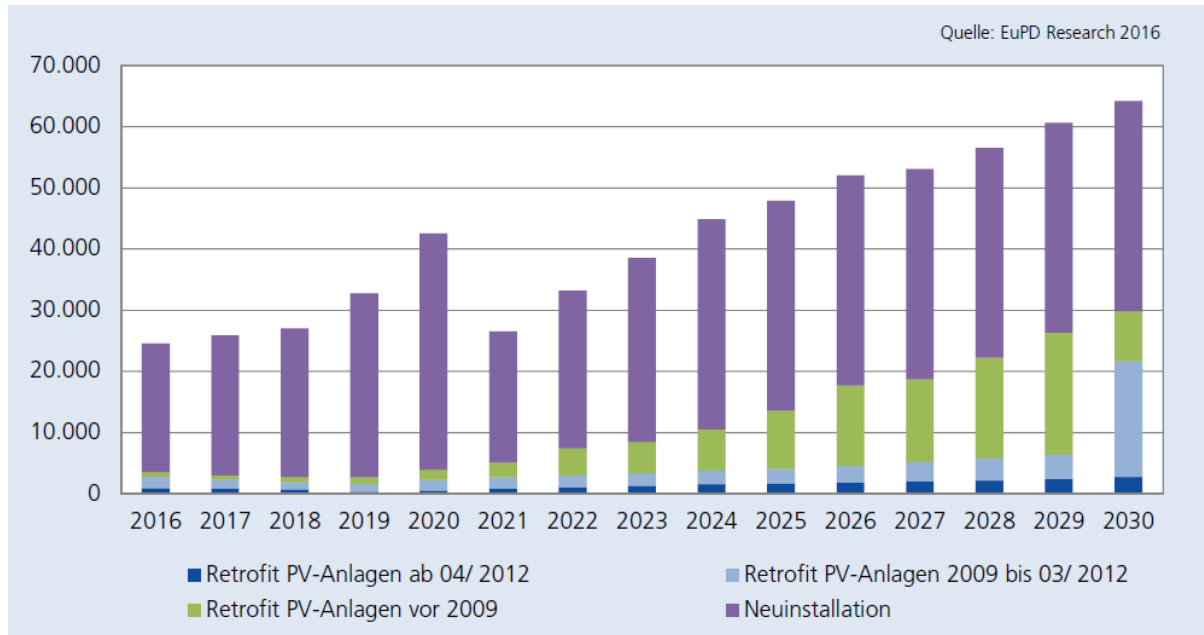


Figure 14: PV installations and retrofit of existing PV installations in Germany. Data and image taken from [15].

An overview about the yearly installed PV power (MW) in the EU28 can be found in [16]. In the years 2010 to 2012, the EU experienced a boom of PV installations, mainly driven by installations in Germany and Italy. Likely as a result of changing subsidy policies, the yearly installed PV power has since then steadily decreased in both countries. On the other hand, countries like the Netherlands and the UK have shown an increase in installations in the last years. In the forecast model applied in [16], a slight increase in new installations is expected until 2021, driven by installations in the UK and Portugal as well as other EU28 member countries, which so far do not have any considerable PV installations. Due to decreasing costs for solar panels and rather stable remuneration rates, this upward trend seems to be justified.

A more recent study in [17] projects higher growth rates of 20% to 50% for solar power installations until 2020. Main drivers are EU 2020 targets for renewable energies which still require significant expansion of renewable electricity generation capacities. The growing economic advantages of electricity self-generation and self-consumption might also trigger more and more private as well as industrial actors to install additional PV (and ESS coupled) capacity.

Particularly in the mid- to longer term, further legislative actions might influence the build-up of solar electricity generation, e.g. if solar installations or other renewable electricity generation would become mandatory for newly built homes.

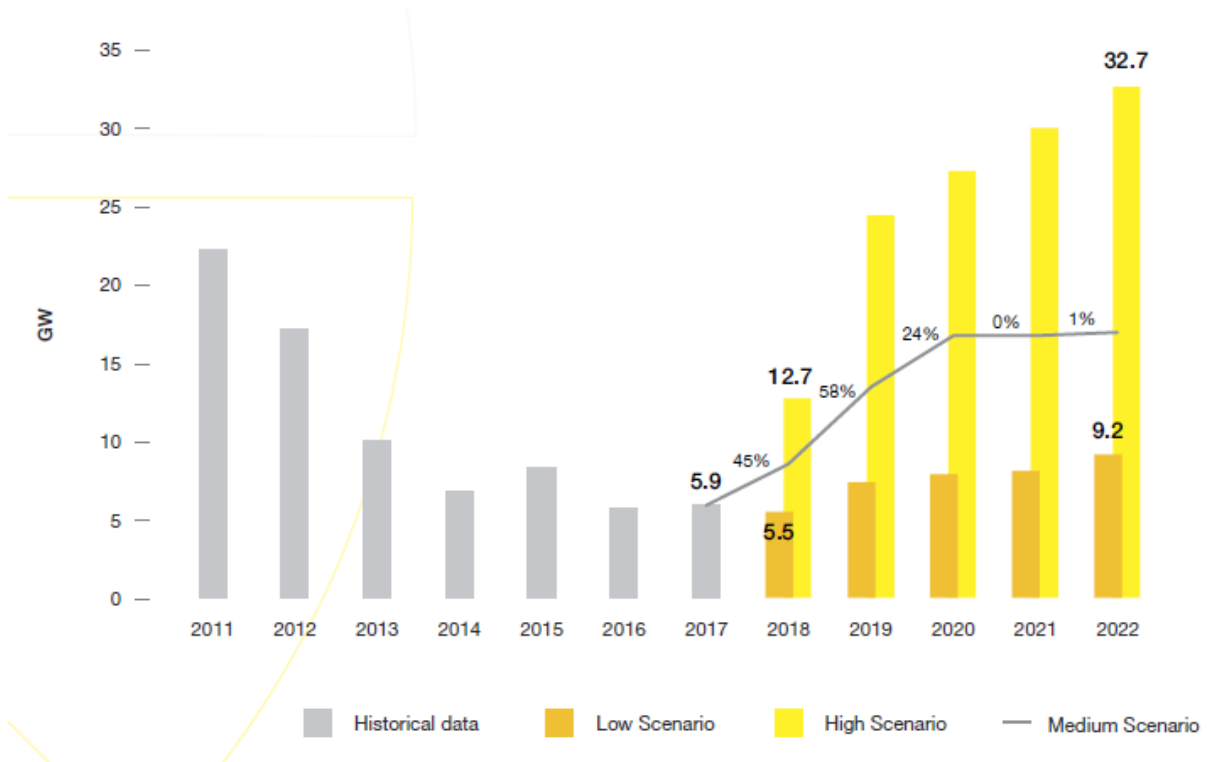


Figure 15: Market development and forecast for PV installations in the EU28. Image taken from [17].

Based on the data given in [14] for Germany, 80% of the installed PV systems (in number of units) can be attributed to small or medium sized installations (average of 10 kWp) directly feeding into the low-voltage grid. In terms of power, these systems amount to about 30% of the installed power. Projections in [17] point to an increase of the share of roof-top installed power in the next years. Suitable energy storage system feature an average battery capacity of 8 to 10 kWh [18].

Concerning installations in Europe, it can be argued that there is a trend towards smaller roof-top systems for more densely populated regions, while in particular in the southern European countries (e.g. Spain, [17]), utility scale solar parks experience a strong upward trend. Since no comprehensive data covering the whole EU is available, only a rough estimation for the demand of battery storage systems and capacity can be made.

Assuming that the number of new smaller roof-top installations (30% of power) as well as the number of new systems equipped with an ESS (50% of installations < 30 kWp) is above average for Germany as compared to the rest of the EU, the market data and forecasts given in [16] and [15] might lead to the range of demand for battery capacity as summarized in [Table 8](#).

Year	Yearly installed PV power EU28 [16, 17] (GW)	Share of power of new installations appropriate for home ESS (%)	Share of new appropriate installations equipped with ESS (%)	Yearly number of systems equipped with ESS	Average capacity per new ESS [14] (kWh)	Yearly demand for battery capacity (MWh)
2017	6 - 8	25	30	45000 - 62000	8.5	400 - 500
2018	9 - 12	24	33	65000 - 90000	9.5	600 - 800
2020	10 - 20	23	40	75000 - 150000	11	800 - 1500

Table 8: Estimation of the demand for battery capacity generated by PV-home ESS systems based on [15] and [16] for the EU28.

Note, that this estimation does not take into account ESS installations for larger scale (>30 kWp) PV-installations.

2.3.4.2. Wind Turbine installations in the EU

Similar to section 2.3.4.1 for PV installations, data and forecasts for wind turbine power installations in the EU28 can be found in [16]. In contrast to PV installations, wind turbine power is almost exclusively attributed to larger scale wind parks delivering power exclusively to the power grid. It can be assumed that the use of small scale ESS for the optimization of private energy consumption is therefore not driven by wind power installations.

Still, the ongoing installation of wind turbine power in the EU28 might become a driver for large scale decentralized energy storage systems, however there is no market data available, which would allow for a battery demand forecast.

2.3.4.3. Large battery ESS projects

The DOE Global Energy Storage Database [19] lists several utility scale ESS projects around the world. [Figure 16](#) shows the cumulated storage capacity (installed stock) for the EU28. Of the 450 MWh capacity installed until 2018 in total, 340 MWh were installed in Germany and 80 MWh in the UK. Since this is not an exhaustive list, it can be considered as lower boundary for the installed stock.

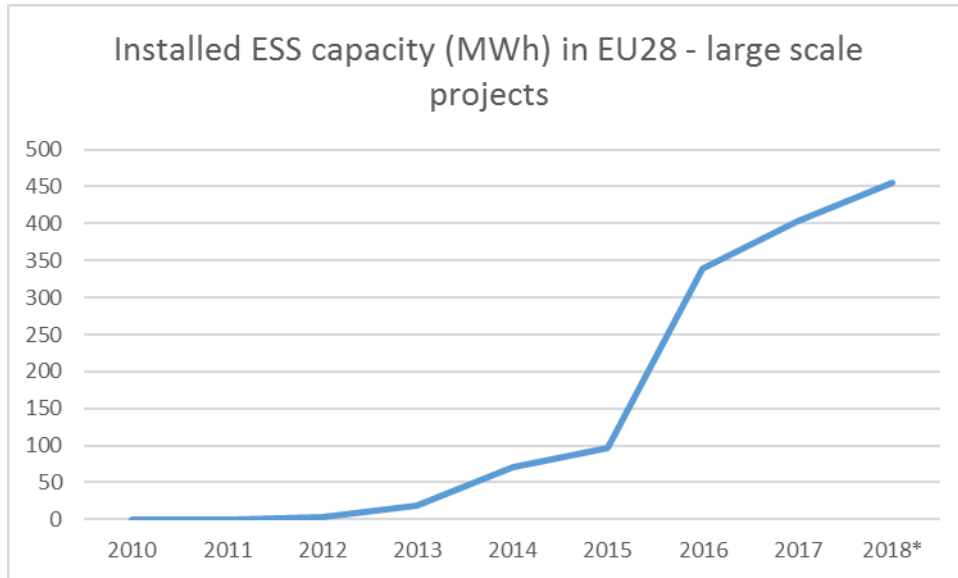


Figure 16: Installed ESS capacity (stock) in large scale projects in EU28. A ratio of 1:1 with respect to installed power and installed energy content (capacity) was assumed [19].

Table 9 gives an overview about larger scale (~MWh) stationary storage systems installed in the EU in 2017 [16]. 80% of these installations are categorized as substation storage, 6% relate to frequency stabilization, 5% to storage of wind-generated energy and 1% to storage of PV-generated energy.

Note that most of these installations are prototype or test facilities, which does not allow to use this split between applications as a template for future market developments. The total installed capacity of 340 MWh in 2017 suggests that the market volume of utility scale ESS is of the same order of magnitude as that of home storage. Note that the installed capacity for 2017 in [19] is only 65 MWh contradicting the data given in [16]. It is however not stated in [16] whether the listed ESS projects are still in construction or already operational.

Purpose	Capacity (MWh)
Wind	16.2
PV	3.1
Frequency	22
Substation	270.4
Other	29.9
All (sum)	341.6

Table 9: Utility scale ESS installations in 2017 [16].

2.3.4.4. Forecast ESS sales and stock EU28

The forecast model includes the market development of home storage ESS, utility scale ESS for inner day shift of fluctuating power generation and utility scale ESS for other grid stabilization purposes.

2.3.4.4.1. Minimum and maximum scenarios

For the forecast model it was assumed that both a higher demand for electricity generated by charging of electric vehicles as well as a higher share of fluctuating renewable electricity will necessitate a certain energy storage capacity to stabilize the grid and compensate for the mismatch of renewables production and electricity demand. For inner day peak shift (primarily PV generated electricity) or possibly intra-day peak shift (both wind and PV generated electricity), battery-based storage systems might be one option to fulfil this task.

Accordingly, minimum and maximum scenarios for the demand for ESS were derived from minimum and maximum additional electricity demand resulting from xEV charging¹ (see [Figure 17](#) and min./max. market penetration scenarios for xEV in section 2.3.3.3) and by the rate of build-up of additional renewable and fluctuating electricity generation capacity (see [Figure 18](#) in next section).

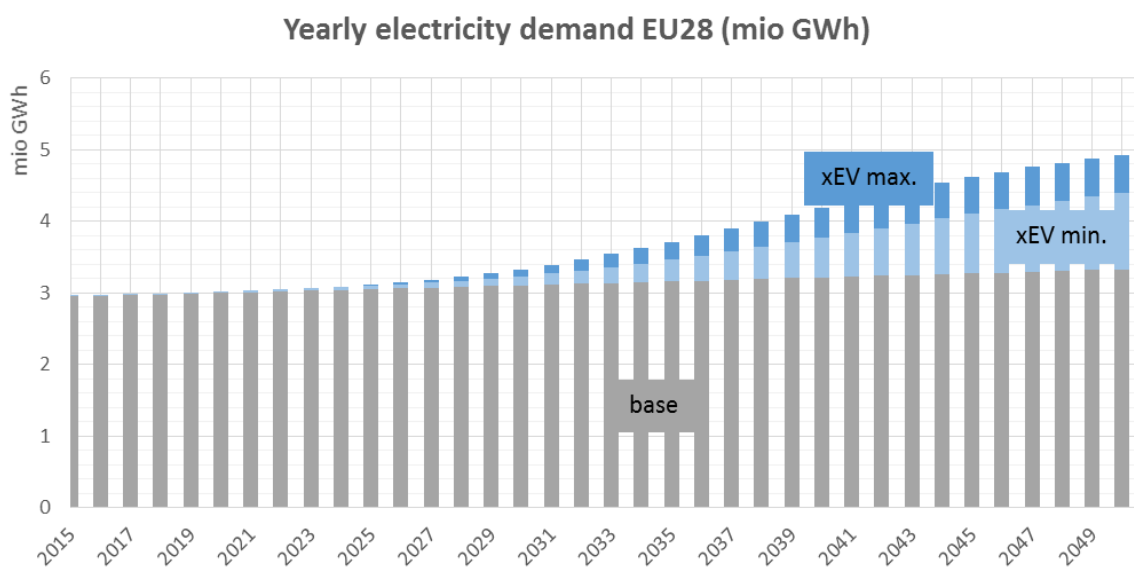


Figure 17: Yearly electricity demand in the EU28 and additional demand resulting from EV charging.

Home storage systems were considered separately. For home storage systems, minimum and maximum scenarios result from different growth rates of PV installations and different shares of PV systems equipped with an ESS.

2.3.4.4.2. Assumptions

The data presented in sections 2.3.4.1, 2.3.4.2 and 2.3.4.3 was used as an input for the forecast model on large scale and home ESS. EU wide sales numbers and growth rates for PV coupled home storage systems were extrapolated from the data presented in section 2.3.4.1.

In a broader picture, the generation of electricity by renewable and fluctuating sources necessitates a certain flexibility of the grid. Today, daily imbalances are met primarily by

¹ Assuming yearly travelled distances of 12,000 km (0.18 kWh/km) for passenger vehicles, 20,000 (0.25 kWh/km) and 65,000 km (1.2 kWh/km) for light and heavy commercial vehicles and 45,000 km (0.7 kWh/km) for buses. Combined charger / battery efficiency of 80%.

dispatching conventional power plants, e.g. after sunset. For the model it was assumed that the ability to match electricity demand and generation will not be possible by the deployment of highly flexible fossil-fuel based power plants alone. Above a certain threshold of the share of fluctuating electricity sources in the grid, some ESS buffer capacity might be necessary to efficiently use renewables and avoid high over capacities. To serve a possible inner-day mismatch of generation and demand, a necessary buffer capacity of 40% / 50% (min./max.) of the daily electrical energy generated by renewables was assumed.

EU 2030 targets [20, 21] for the share of renewable electricity generation as well as other forecasts were used as a benchmark for the min./max. scenarios (see [Figure 18](#)).

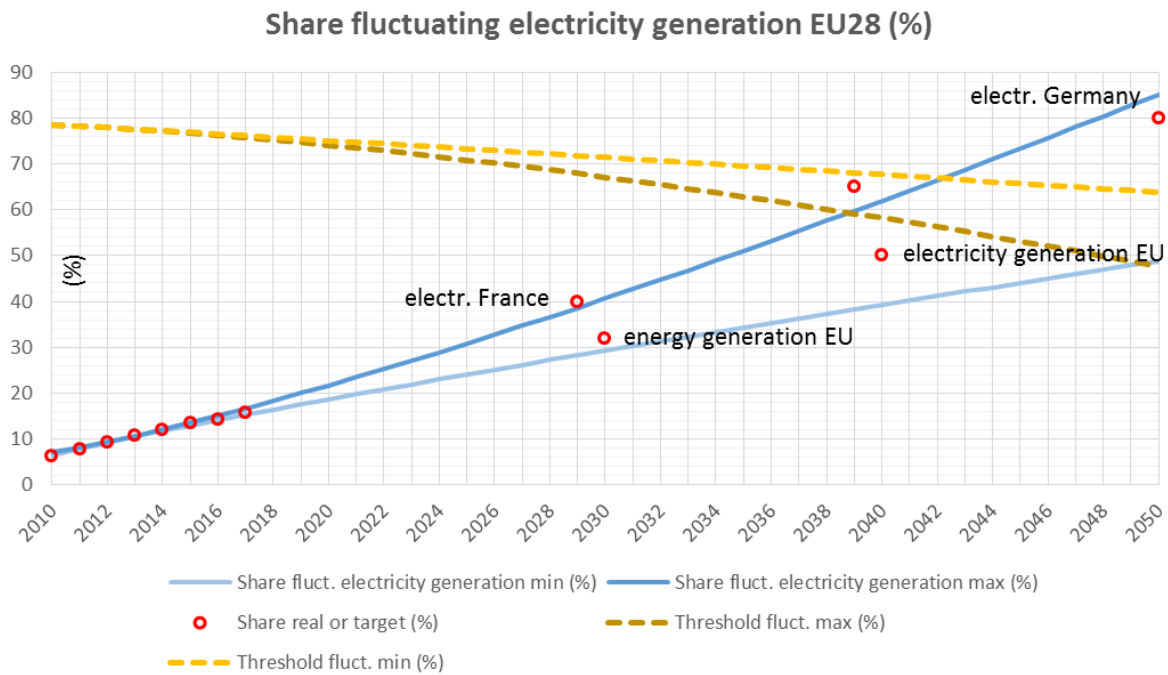


Figure 18: Share of fluctuating sources in the electricity generation mix of the EU28 and forecast model as well as targets for renewable electricity and energy set on national or European level and other studies and threshold share requiring energy storage systems [22–29].

Besides compensating for an inner-day mismatch between electricity generation and demand, battery storage systems can also offer other services for the electricity system, e.g. regulation of grid load and power line load, provision of balancing energy and others. In accordance to the data presented in section 2.3.4.3, a forward projection of the market growth of utility scale ESS was chosen to account for these other applications.

A lifetime of 20 years with a replacement rate of 5% was assumed for home ESS and a lifetime of 20 years with a battery replacement rate of 10% within this lifetime was assumed for large scale ESS (for further discussion see section 2.7.1.4 and task 6). System capacities were modelled by a power law (see section 2.7.1.3) based on present-day values. The assumptions for the market model are summarized in [Table 10](#) and [Table 11](#).

Parameter	Min. value	Max. value
Number of new rooftop PV installations EU28, 2017	190000	
Yearly growth rate of new rooftop PV installations EU28 until 2050	4%	7%
Share of new rooftop PV installations equipped with ESS 2014 / 2050	30% / 70%	30% / 90%
Utility scale ESS battery capacity installations EU28, 2017	500 MWh	
Daily energy storage requirements due to high share of fluctuating electricity generation: Share of daily fluctuating electricity to be stored in ESS.	40%	50%

Table 10: Assumptions and input parameters for the ESS market and growth model.

Parameter	Value
Home ESS lifetime	20 years
Large scale ESS lifetime	20 years
Home ESS battery replacement rate	5%
Large scale ESS battery replacement rate	10%

Table 11: Assumptions and input parameters for the ESS battery demand model.

The results of these calculations are shown in [Figure 19](#) and [Figure 20](#).

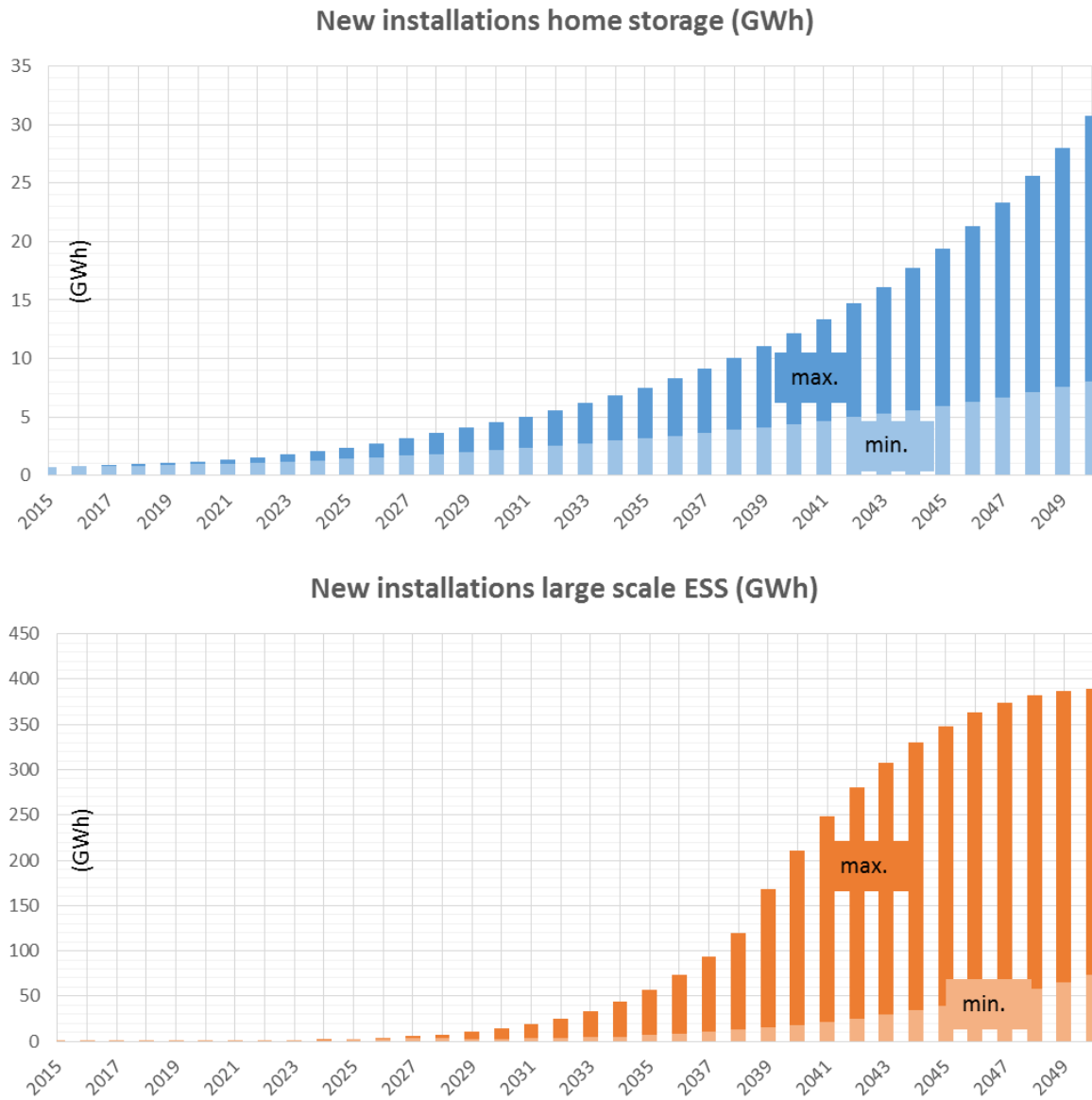


Figure 19: Forecast home storage and large scale ESS installations until 2050.

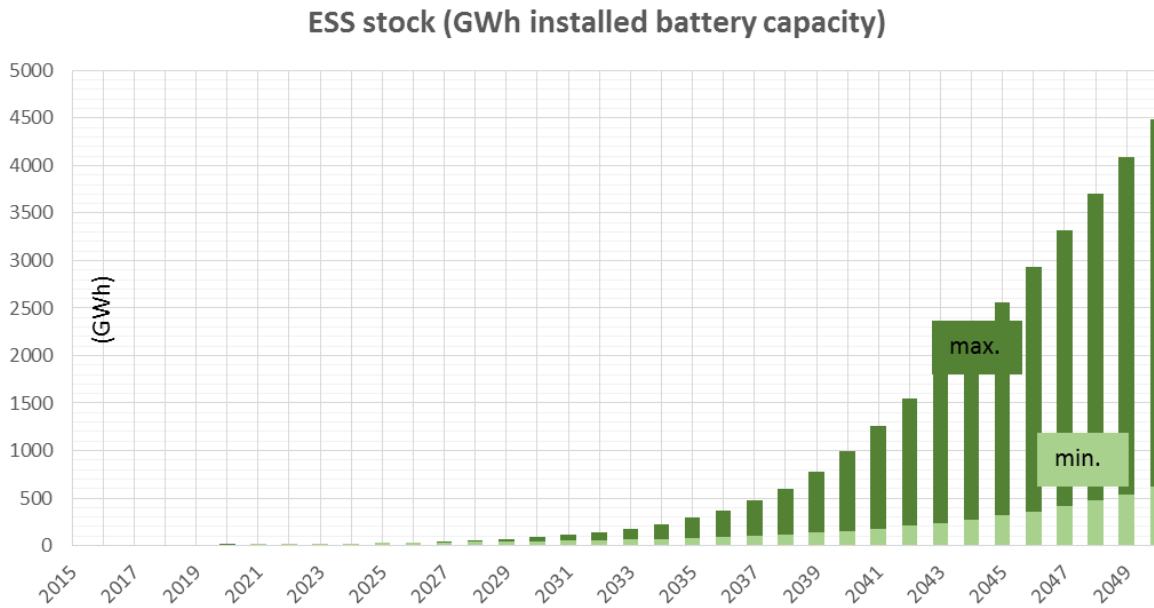


Figure 20: Forecast ESS capacity stock until 2050.

2.3.5. Summary of the market sales forecast and estimation of the future battery stock

As shown in sections 2.3.2 and 2.3.4, several drivers exist for the application of battery storage systems in stationary and motive applications. While the demand for battery capacity generated by BEV and PHEV passenger cars was on the level of several GWh for 2017, the ESS markets might still be below the 1 GWh mark in the EU.

With respect to the growth rates for the sales of xEV and ESS (see sections 2.3.3.3 and 2.3.4.2), forecasts for the total amount of new installations (including replacements) of batteries in the EU28 are shown in [Figure 21](#).

It can be expected that the demand for battery capacity in the EU28 will amount to 30 - 35 GWh in 2020, 180 - 230 GWh in 2025 and 500 - 800 GWh in 2030. The short-term demand will mainly be driven by passenger electric vehicles. Higher shares resulting from commercial vehicles and ESS can be expected in the mid- and long-term.

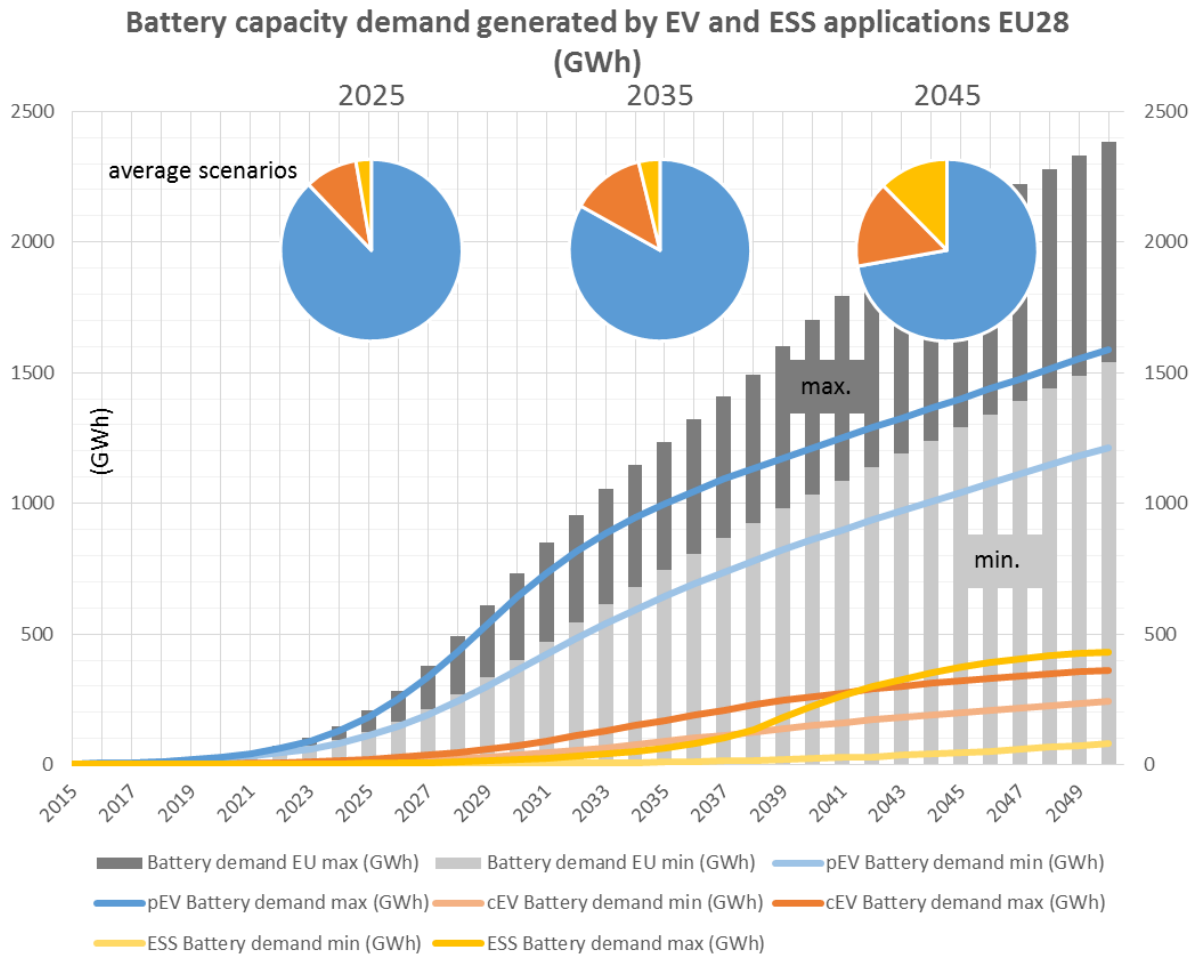


Figure 21: Battery capacity demand derived from new installations in xEV (passenger EV, commercial EV) or ESS and replacements in existing systems in the EU28.

It should be noted that the shown battery capacity demand scenarios are rather insensitive against changes in the set of input system lifetimes (1) and battery replacement rates (2). As discussed in the previous sections, rather long system lifetimes and accordingly high battery replacement rates were assumed. From the perspective of batteries designed to deliver a certain service, e.g. a fixed energy throughput over their lifetime or a certain driving range for electric vehicles, the total capacity needed is not heavily influenced by a possible mismatch of system lifetime and battery lifetime (replacement rate) in the model. In other words: the model results in units of GWh are the same for high vehicle lifetimes and high battery replacement rates or short vehicle lifetimes and low battery replacement rates.

Hence, although no sufficient information on system lifetimes (strongly depending on purchasing and reselling behaviour of end-customers) are available yet, the applied model can give estimates on battery capacity demand based on the assumptions in section 2.7.1.4.

The resulting calculated battery decommissions are given in [Figure 22](#).

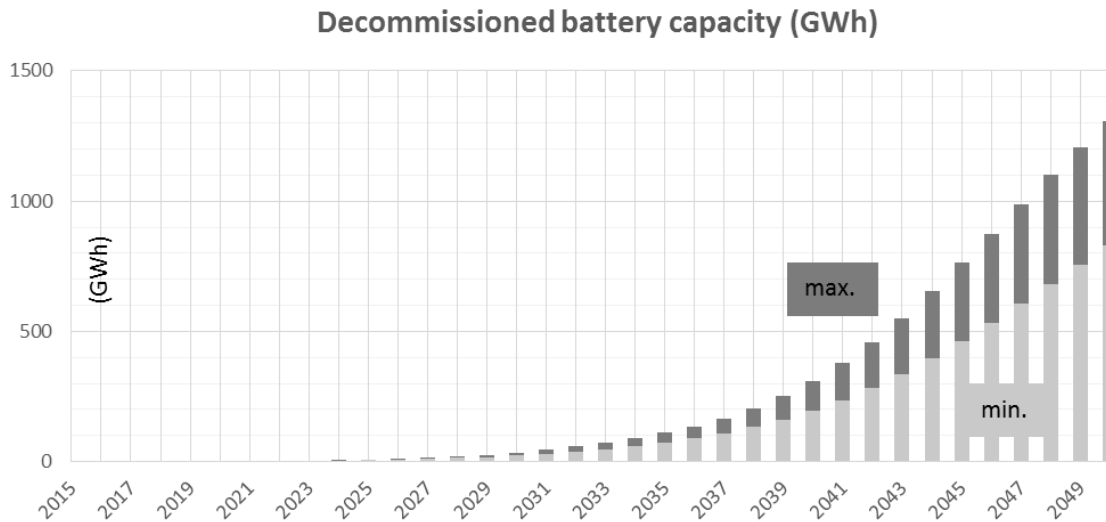


Figure 22: Decommission of batteries due to replacements or due to the end of life of applications.

2.4. Market trends

2.4.1. General objective of subtask 2.3 and approach

The following chapter provides a comprehensive market overview on global battery sales, demand, and players. As one potential technology for meeting the market demand, lithium-ion batteries are discussed in this section in detail. Starting with the market development of LIB between 2010 to 2017, scenarios until 2025 to 2030 are presented including a meta-analysis of several most recent market reports (e.g. [30–39]). Step by step, the regional markets and markets by applications will be specified.

2.4.2. Market drivers and CO₂ legislation [40]

Climate and energy policies are main drivers for the energy future and are expected to lead to an increasing demand for energy storage in the mid and long term (see [Figure 23](#)): According to the European Union’s decarbonization objective, a reduction of greenhouse gas (GHG) emissions to 80 – 95 % below 1990 levels should be achieved by 2050.

In particular, for the transport sector currently no full decarbonisation is foreseen [41], even in the longer term (other sectors have to compensate with higher GHG reductions). The overall reduction achieved in the transport sector by 2050 is only around 60 % below 1990 levels. The increasing trend in emissions seen over the past 20 years is expected to reverse by the CO₂ legislation. From 2020 on, the fleet average to be achieved by all new cars is 95 grams of CO₂ per kilometer (compared to 130 g/km in 2015).

Many other governments world-wide have specified CO₂ emission targets and are striving towards a low carbon economy. Particularly in the field of passenger and commercial vehicles, fuel consumption and emission targets have been installed, which significantly drive the introduction of battery or fuel cell powered electric vehicles. Among these emission policies, the targets set by the EU are among the most ambitious (see [Table 12](#)). Meeting them will require a significant share of electric vehicles.

	Japan	China	Korea	USA	EU
Fuel consumption target 2020, (l/100 km)	4.9	5	4.2	5.8	4.1
CO ₂ -emission target 2020, (g/km)	115	117	97	136	95 (until 2021)
CO ₂ -emission target 2025, (g/km)	-	94	-	91	81

Table 12: Overview about fuel consumption and CO₂-emission targets for passenger vehicles of the EU and other countries leading battery and electric mobility markets [42].

In this context, electric mobility is gaining importance since electric vehicles, especially plug-in hybrid and full battery electric vehicles can help to achieve or fulfill these limits due to improved CO₂ footprints compared to conventional cars. However, for low CO₂ footprints over the lifetime of electric cars, a high share of “low carbon” renewable energy sources (RES) in the energy mix is needed and important (Figure 23, left side).

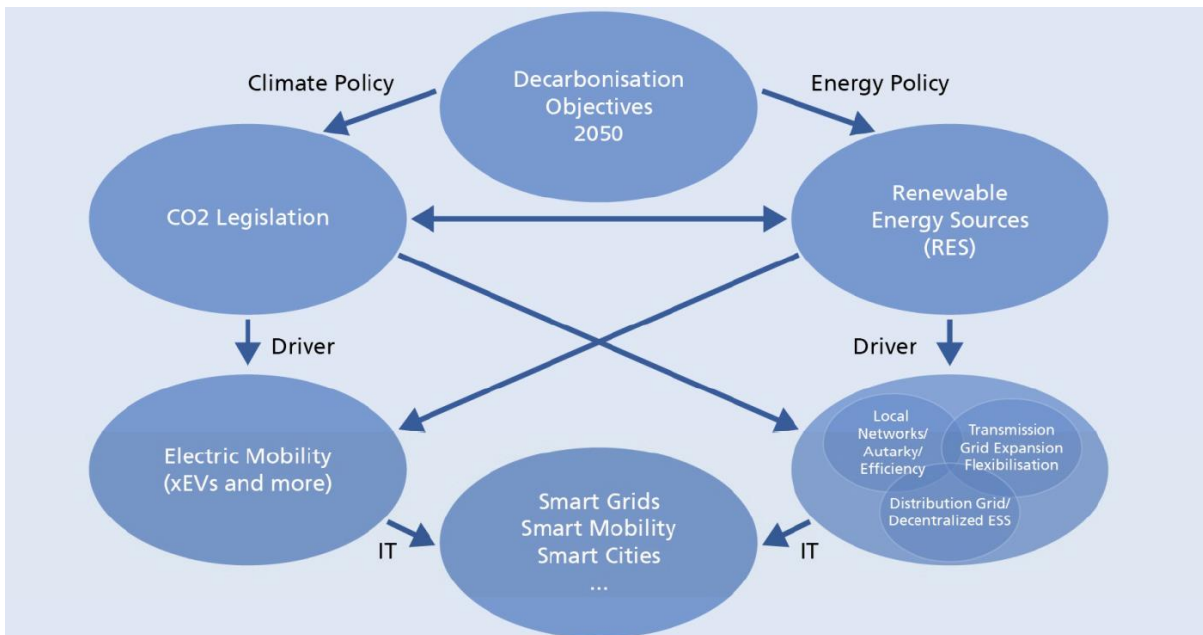


Figure 23: Climate and energy policies as drivers for future energy storage demand [40].

The EU Energy Roadmap 2050 [43, 44] has shown across six scenarios that the decarbonization goal can be achieved if the share of renewable energy sources (RES) among the power generation capacity is high (> 60 % until 2050) for all scenarios. Especially for the high RES scenario the share of fluctuating energy generation (wind, photovoltaic – PV) is the strongest which has to be balanced. Grid expansion and/or flexibilization measures (e.g. demand side management, power to gas, and vehicle to grid besides stationary battery storage) are potential solutions. Thus, the high RES scenario is the most interesting scenario with respect to a potential future demand for energy storage solutions (ESS) on local, distribution and transmission grid levels (Figure 23, right side). In order to have a significant GHG reduction with EVs it will also be important to achieve the RES targets.

2.4.3. The developing battery market

The total annual battery market is currently on the level of 45-60 billion Euro representing approximately 400-500 GWh (including Lead-acid, Lithium-Ion and other batteries) [45]. Lithium-ion batteries (LIB) have succeeded because of their high gravimetric and volumetric energy densities and have a market share of about a third in terms of value among the whole battery market. The growth is driven by the decreasing cell costs of less than 150 €/kWh for a standard cylindrical cell (lowest prices) approaching the 100 €/kWh mark in the next years. This cost depression is result of increasing capacity demand and production and thus represents economy of scale effects.

Although the LIB market is drastically growing with annual growth rates of up to 30 percent on average (in terms of battery capacity demand), the dominating battery technology in terms of capacity is still lead-acid, representing about 90 percent of the global demand in volume around 2010 and 80 percent in 2017.

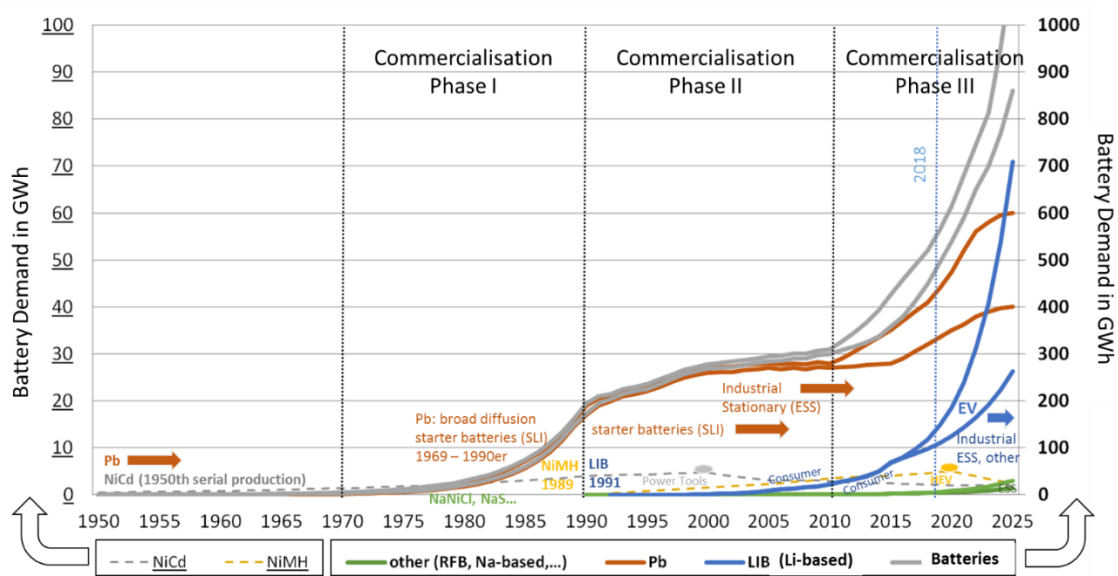


Figure 24: Historical development of the global battery demand in GWh (left axis for NiCd, NiMH, right axis for all other battery types; grey: total battery demand) [46].

Other mature battery technologies like NiCd (still partly used in power tools) and NiMH (still used in hybrid electric vehicles, HEV) are slowly declining. The diversification of future battery applications however will also broaden the range of battery technologies. Emerging technologies like Na-based, Metal-Sulfur or Redox Flow batteries are developing and may lead to attractive solutions e.g. with respect to cost and resource availability. However, due to very strict requirements on volumetric energy densities, these technologies are expected to be relevant for stationary or other special markets and less relevant for the passenger electric vehicle market. In general, each technology has its own strengths and weaknesses and none of them can satisfy all user demands. Hence, a broader application-specific technology portfolio is urgently needed in order to provide alternative technology solutions in the future.

Based on an expected high dynamic development of the global LIB demand, the TWh level will likely be reached before 2030 and grow further after 2030. It is therefore very likely that LIB will soon transform into the dominating energy storage technology.

Figure 25 shows three different scenarios for the global demand for LIB between 2010 and 2030 (green curves) along with global production capacities (orange and blue curve).[45] While at the beginning of the decade, the demand and sales numbers followed the medium growth rate scenario (trend), the market has been approaching the high growth rate scenario in the last years. This is mainly result of the strong engagement of politics and respective regulation and subsidy programs for electric mobility. As can be seen from the graph, the share of demand generated by motive applications is expected to significantly grow in the next years and might account for more than 75% of the total LIB demand by 2025.

To face this increasing demand for LIB cells accordingly, production capacities need to be build up in the near future. Based on the currently existing cell production capacities and the global announcements from established and new cell producers until 2025, the LIB cell production capacities (blue line in **Figure 25**) have been identified. Compared to 15 GWh added production capacity between 2013 and 2016, around 50 GWh will be added annually in the next years leading to around 700 GWh production capacities until 2025 (in the optimistic case, see blue line in **Figure 25**). The announcements include established players such as Panasonic (JP), LG Chem (KR), Samsung (KR), SKI (KR), BYD (CN), Lishen (CN), CATL (CN), CALB (CN), OPTIMUM (CN) and several further Chinese cell producers. Also, new players such as BMZ/TerraE (DE), Northvolt (SW), Boston Energy (US, AU), Energy Absolute (Thailand), are included, while accounting for the different stages of expansion [32, 39].

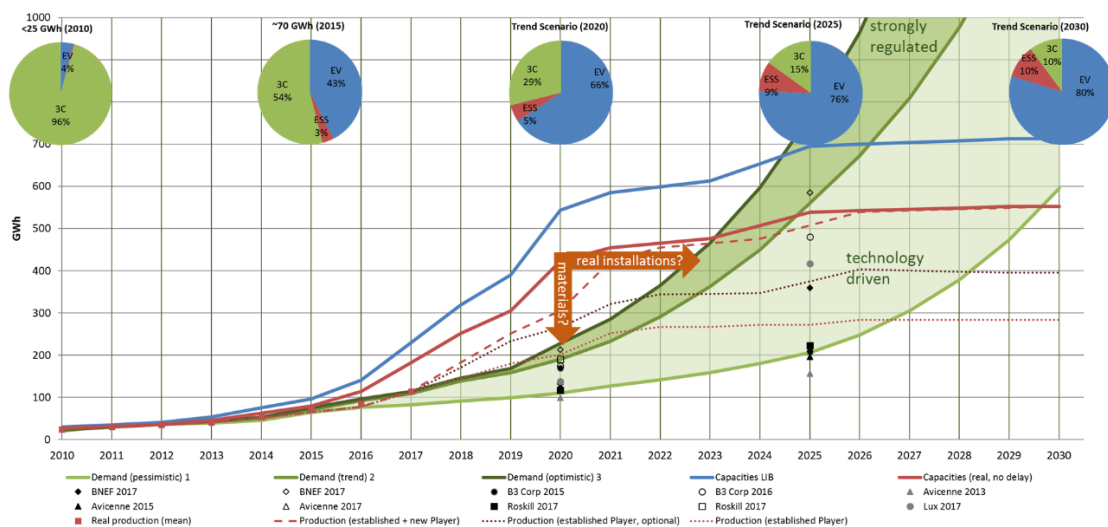


Figure 25: Global LIB cell production capacities vs. demand 2010 to 2030 [45].

2.4.4. Battery markets by application

Diversification of applications for batteries

The above described global developments of battery demand and production strongly concern high-energy lithium-ion batteries with the cell chemistries NMC, NCA (Ni-rich and Co-reduced cathodes) and Si/C (high capacity Si/C anodes with 5-10% or higher Si content) and cell formats cylindrical (e.g. 21700), large pouch or prismatic cells. The target is to develop and produce cells with improved gravimetric and volumetric energy densities and reduced costs in order to meet the requirements of the automotive industry. Electric passenger cars are driving

the demand and thus the development of the battery technology. The resulting optimized and cost reduced batteries define the benchmark today and in the future.

LIB demand by applications

In [Figure 26](#), the global LIB demand is broken down to the three main sectors for battery demand, which can be characterised each having different profiles of requirement:

- electric mobility or electric vehicles (EV, including e.g. passenger cars, light commercial vehicles, buses, trucks, scooters, ebikes, etc.),
- stationary energy storage systems (ESS), and
- portable devices (3C – Computer, Communication, Consumer).

Since their market introduction in the early 1990s, the LIB cell demand developed to almost 25 GWh dominantly resulting from portable devices. In 2015 the cell demand of about 70 GWh was distributed already almost 50:50 between 3C and EV applications.

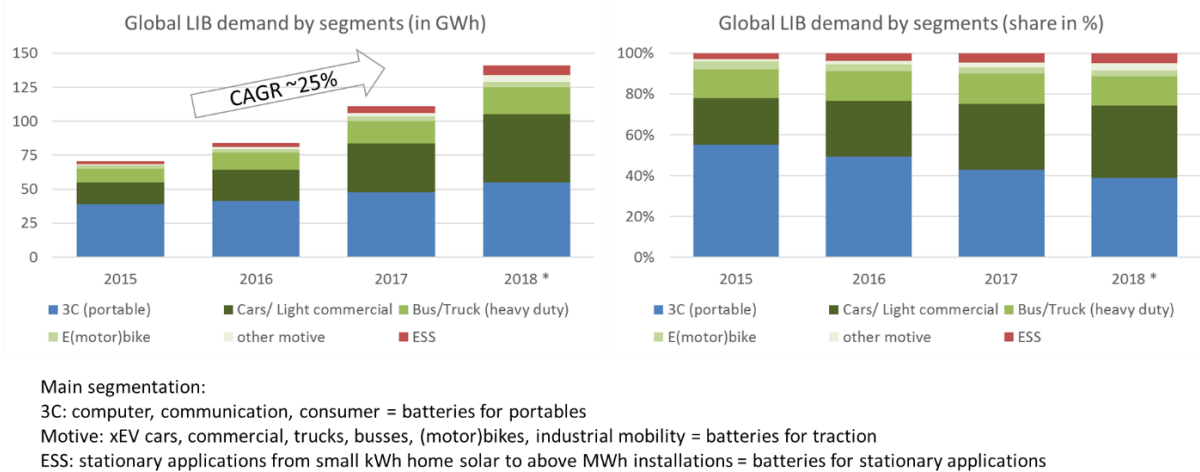


Figure 26: Global LIB demand (in GWh and share in %) by segment [46].

Since 2015, the global LIB demand has increased with compound annual growth rates (CAGR) of ~25% from about 70 GWh to about 110 GWh in 2017. The market for electric vehicles currently grows with 30-40% (and more depending on the application and region) and a diversification in applications (e.g. buses, trucks, other light to heavy commercial vehicles, marine applications, drones, etc.) can be observed.

With the diversification of future markets and applications, cost sensitive markets will arise for which optimized high-energy and cost reduced automotive cells of certain cell formats will be used. However, also applications with stronger requirements on long lifetime, high cycle life, fast charging capability, safety, etc. will emerge and diffuse, where cost is not the most relevant factor and other battery technologies (i.e. cell chemistries, formats) can provide a unique selling proposition and hence lead to a product differentiation.

2.4.4.1. LIB markets for 3C applications

Portable devices (3C) have been the main applications for LIB cells in the past. Power tools, medical devices and wearables are expected to be products with an emerging future market for small LIB cells but with enormous quantities. The price per kWh does not play a dominating role for these applications. As far as charging is concerned, technologies such as energy harvesting and wireless charging are expected to be introduced in the future. For many

markets and products such as household devices, garden, cleaning, power tools, other mobile leisure applications, etc. today mostly cylindrical LIB cells of the format 18650 or smaller pouch type cells are used. With the introduction of 21700 cells also larger cylindrical cells become available now and are expected to be used in such applications. Although different specific cell chemistries might be suitable, it can be stated that the 3C segment is expected to lead to a comparably small battery capacity demand compared to the EV segment and will not be the limiting segment with respect to the risk of resource dependencies. From the perspective of recycling however, resource issues might be more significant for smaller devices as collection rates are smaller as compared to industrial batteries, and batteries may more easily end up in wrong waste streams, limiting the amount of resources that may be recovered.

In the next few years, growth rates of about 5 to 10 percent are expected for the 3C markets, while laptop battery demand is developing at lower growth rates and power tools, medical devices, etc. are supporting the growth rates for the battery demand.

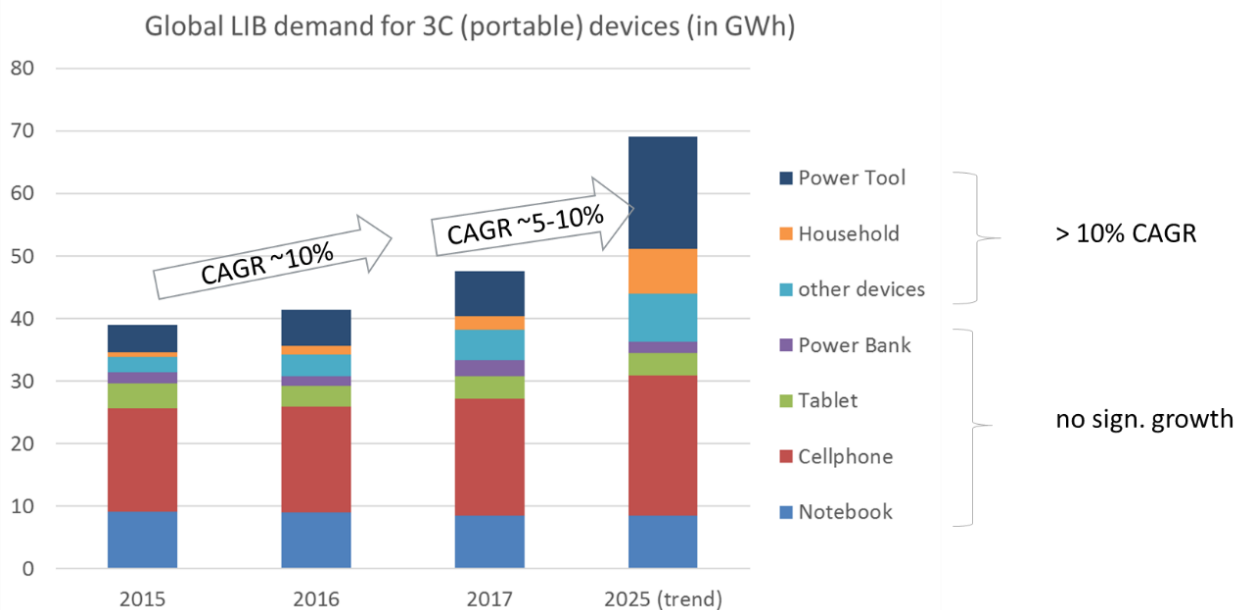


Figure 27: Demand and growth of the 3C LIB market [46].

2.4.4.2. LIB markets for stationary (ESS) applications

Stationary energy storage systems (ESS) can be divided into different size classes with regard to the capacity and charging times. Both parameters decide about the application area (e.g. small PV storage at home, peak load to long-term storage) [47]. Beyond that, the price per stored kWh over the lifetime is the economic key factor (as synthesized by the LCOE: levelized cost of energy). In contrast, gravimetric and volumetric energy densities play a subordinate role. Due to that, lead-acid batteries were often used as storage technology for off- and on-grid storage. Currently, LIB is being established for commercial use and meanwhile reach an annual demand of some few GWh. Other electrochemical storage technologies such as sodium-sulfur batteries are still used but the demand for LIB is strongly increasing for ESS. It is expected that 2nd life concepts for batteries that had their first life in electric vehicles will gain importance together with market diffusion in the EV segment, as the requirements on the batteries are less demanding in the ESS segment (e.g. maximum currents). This however will require the development of according business models, standardization, etc. The much broader available technology portfolio for ESS applications, the use of 2nd life batteries and the fact that electric vehicle batteries that are connected to the grid on a large scale with higher

market diffusion can be regarded as stationary storage systems as well (vehicle to grid V2G, grid to vehicle G2V) help to reduce the risk of technological and resource dependencies in the future.

The market for stationary storage applications (ESS) is experiencing growth rates of 20 to 30 percent depending on individual market forecasts (in the last years CAGR have even been on the level of 60%, but decrease with increasing size of the market, see [Figure 28](#)).

The market is currently on the level of few GWh including applications from smaller PV storage systems of 5-10 kWh to larger industrial and grid connected installations for self-consumption, peak shaving, etc. on the MWh level. Regarding these growth rates, LIB for ESS applications rapidly gain importance as decentral storage solutions compared to the currently dominating central pumped hydro storage (PHS). Forecasts to 2025 differ, but expect an ESS LIB demand between 20-50 GWh (partially higher, e.g. in [35]) but all forecasts identify high growth rates.

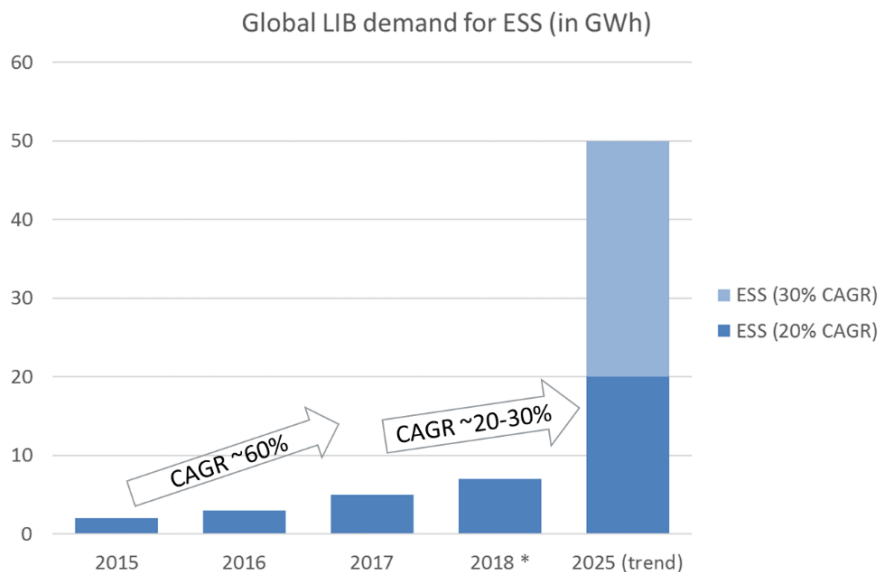


Figure 28: Demand and growth of the ESS LIB market [46].

2.4.4.3. LIB markets for electric vehicle applications

One of the biggest challenges for batteries for electric vehicles (EV, including electric cars, buses, trucks, etc.) apart from their price, is the increase of their volumetric and gravimetric energy densities. The volumetric energy density is even more important for OEM due to restricted and fixed space and location of the battery in an electric vehicle. A very relevant parameter of a battery is its charging and discharging power, in particular in continuous operation. It determines the fast-charging capability, which is an important argument in the use and the establishment of the market. At the same time, this sets limits to the high-performance operation (e.g. vehicle acceleration) since the battery might be derated to protect it from damage. This illustrates the conflicting effect of different parameters on the battery lifetime. Price, volume, weight, and thus charge density as well as charge/discharge rate in terms of usage and durability are the most urgent challenges for battery manufacturers.

The market for EV batteries is currently at the level of about 50 GWh (including electric passenger cars, busses, trucks, ebikes, scooter, forklifts, etc.). Growth rates are at 20 to 40 percent and the demand for EV batteries will lead to a LIB demand share of about 66 % in 2020, 76 % until 2025 and 80 % or higher in the long term. Electric passenger cars (BEV and

PHEV) define the by far largest market within the EV segment and are clearly driving the technology development of high energy Lithium-Ion or Lithium-based batteries in the future.

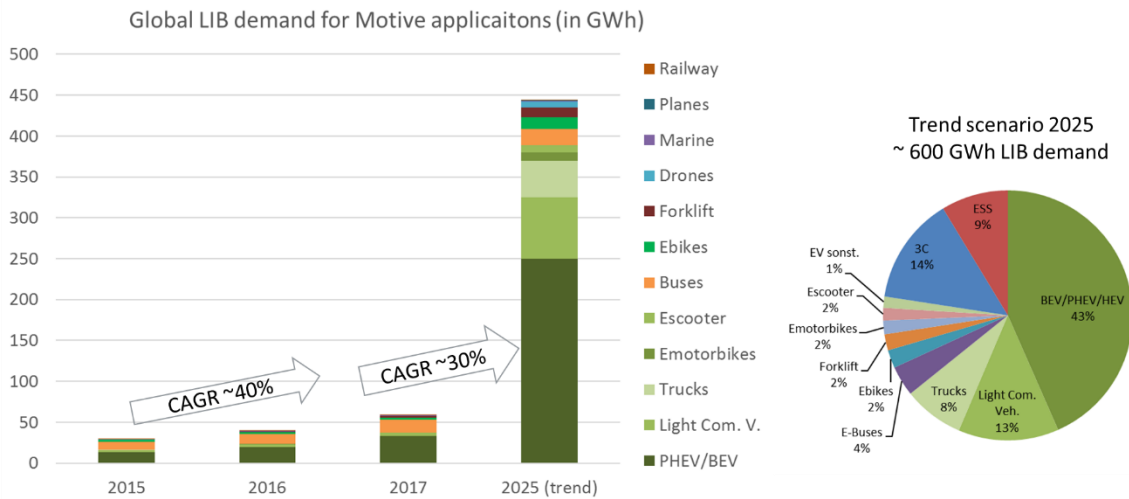


Figure 29: Demand and growth of the EV LIB market [46].

Other motive (or stationary or portable) markets / applications besides the highly competitive electric passenger cars therefore can offer interesting growth markets also for smaller cell producers beyond the large Japanese, Korean and Chinese cell producers. These markets or applications very often define concrete requirements for the battery performance, they require an in depth understanding and design from the cell chemistry, format to the module/pack and system integration and they still vary strongly by region and are connected to individual system integrators or OEM. This is because each technology has its own strengths and weaknesses and none of them can satisfy all user/application requirements. Hence, a broader application specific technology portfolio is even urgently needed in order to provide alternative, individual technology solutions for these emerging markets/applications.

2.4.5. Market channels and production structure

2.4.5.1. Global production capacities and major players

Since their commercialization in the 1990s, LIB have predominantly been produced by Japanese and Korean companies. Driven by the Chinese government, particularly cell producers but also companies covering other steps of the LIB value creation chain have been established in China. Due to a policy of simultaneous support for LIB production as well as for application markets and due to an extensive subsidy scheme, a large share of LIB production capacity is located in China today.

Figure 30, Figure 31, Figure 32 and Figure 33 show the global LIB production capacities of major cell producers in 2018 as well as forecasts for 2020, 2025 and 2030 respectively [48]. The data is based on announcements made by the cell producers (until November 2018). As discussed in section 2.4.3, the actual time-frame for the implementation of the capacity expansions is often delayed with respect to the original announcements. Hence, minimum and maximum values for the production capacities are given.

Preparatory study on Ecodesign and Energy Labelling of batteries

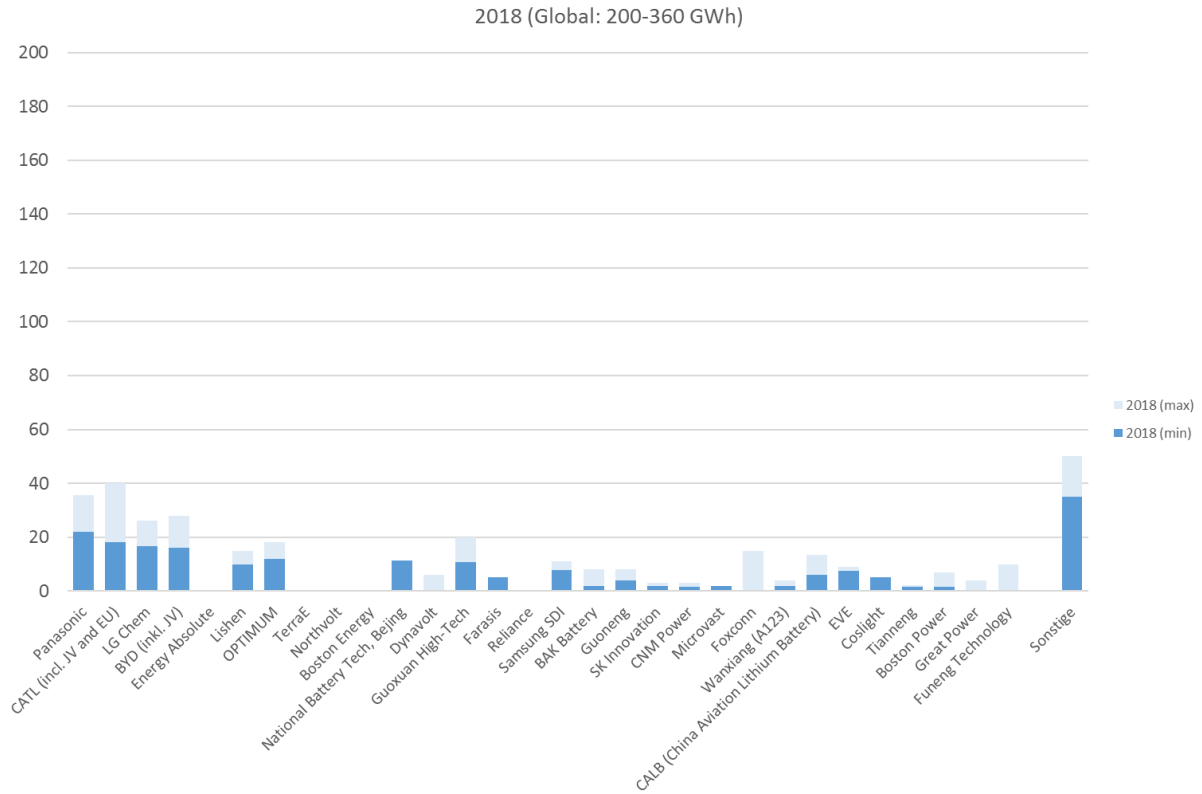


Figure 30: Global LIB production capacities of major cell producers in 2018 [48].

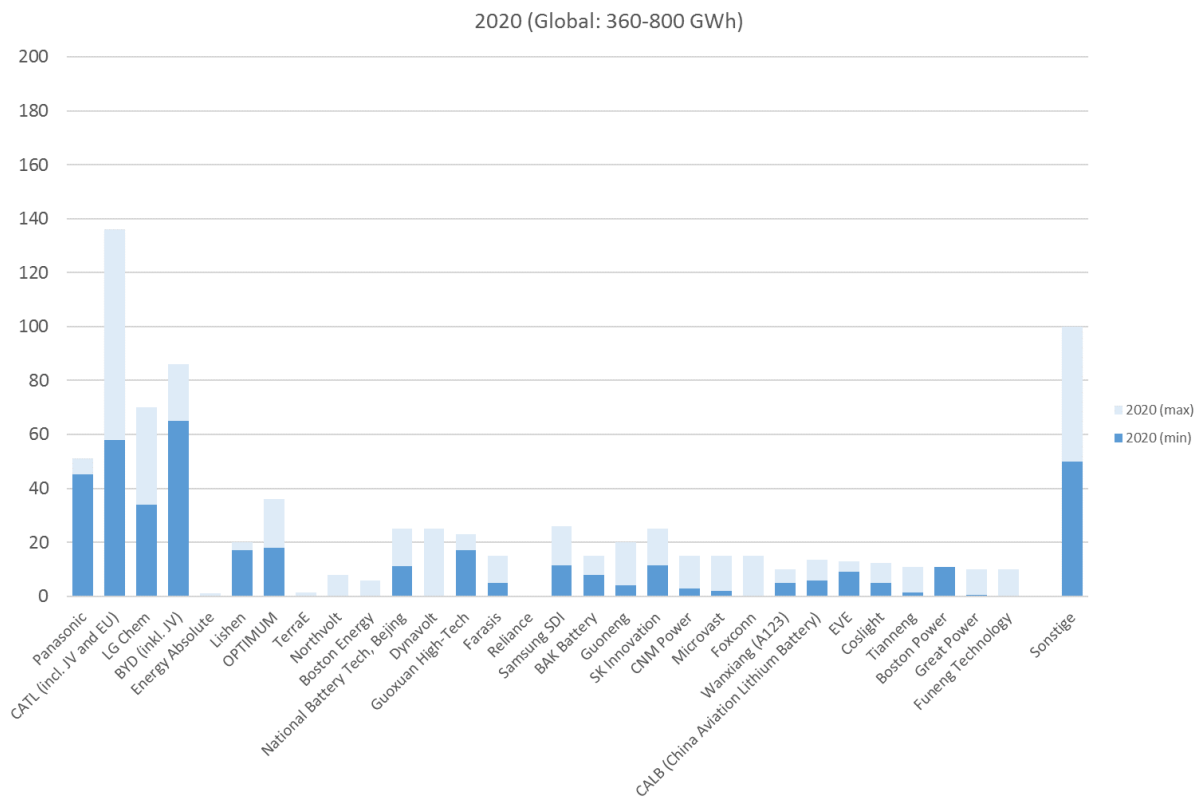


Figure 31: Global LIB production capacities of major cell producers in 2020 [48].

Preparatory study on Ecodesign and Energy Labelling of batteries

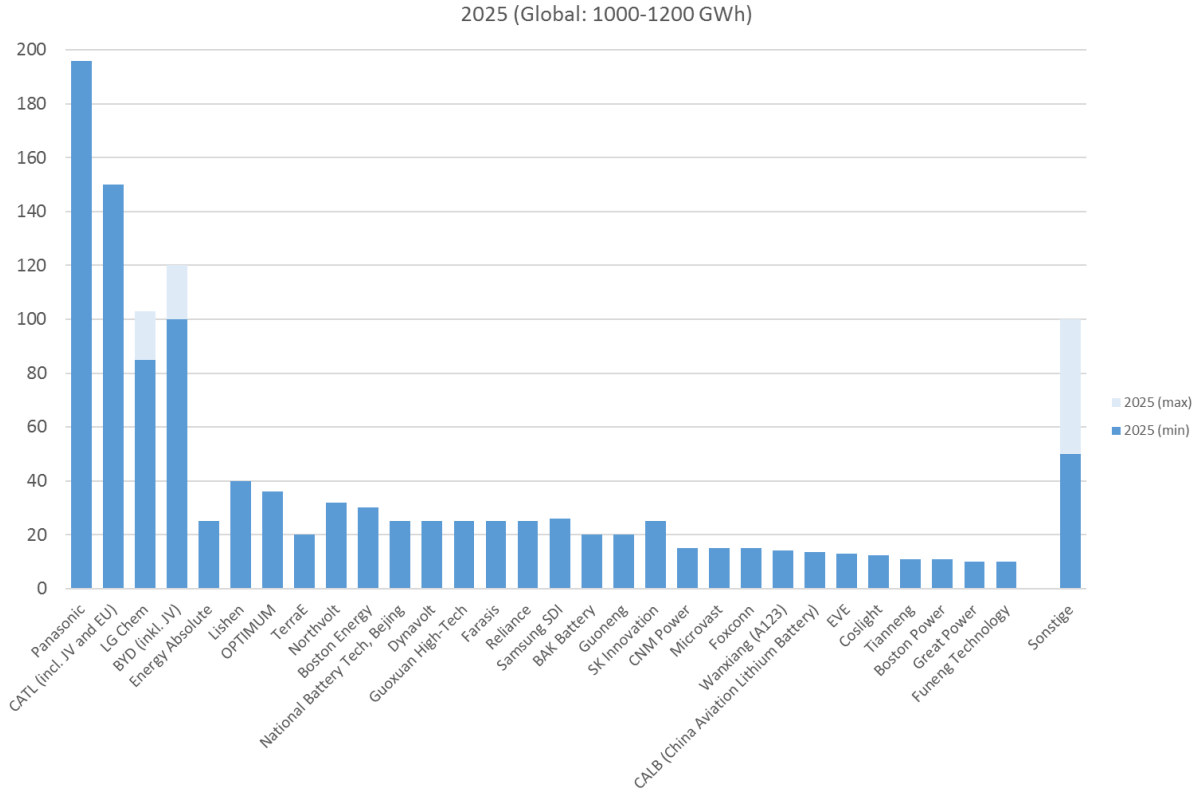


Figure 32: Global LIB production capacities of major cell producers in 2025 [48].

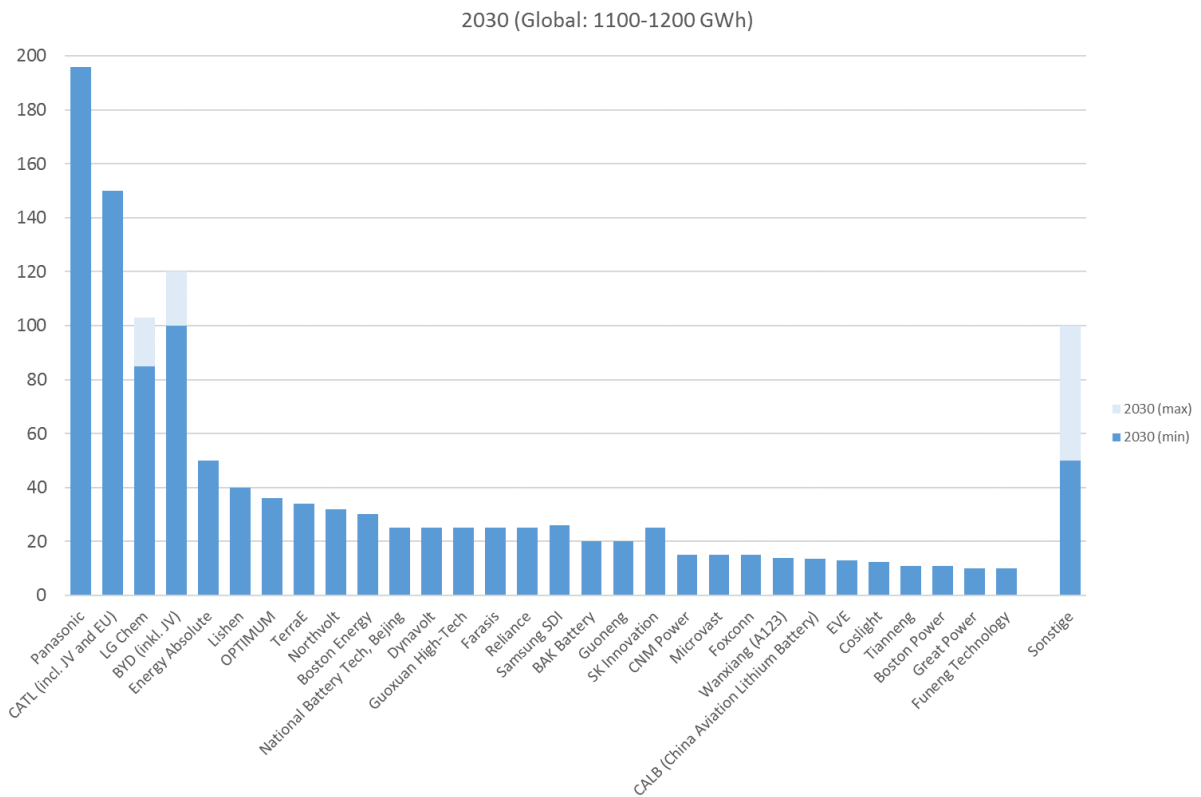


Figure 33: Global LIB production capacities of major cell producers in 2030 [48].

Until 2030, the announced production capacities add up to more than 1 TWh. In total, there are about 30 cell producers which have announced to build up production capacities of more than 10 GWh/year, which can be considered to be a threshold in order to be able to produce at competitive cost [48]. If the announced capacities are fully utilized, the “big 4” (Panasonic, CATL, LGC and BYD) will be able to fully cover the market demand (>550 GWh) until 2025.

2.4.5.2. Employment effects of battery manufacturing

Due to the high dynamics of the industry, exact estimations on the job creation potential of battery manufacturing and the upstream value chain are not known yet. Up to now findings are based on medium sized factories, while future large Giga-factories and advances in automation might yield high efficiencies and change the structure of employment found in today's factories.

Several studies give estimations on current and future employment effects. A study published in 2016 [49] estimates a job potential of 1,050 to 1,300 full time equivalents for a 13 GWh cell factory. Additional 1,400 to 3,100 full time equivalents could be created in the associated supply chain and logistics sector. Data aggregated by the JRC suggests 90 to 180 direct jobs in cell production per GWh production capacity and a factor of 3.7 to 7.5 translating direct jobs roughly into 300 to 1000 indirect jobs per GWh [51].

A recent study from 2018 [50] considering engineering and equipment manufacturing as well as the associated supplier industry suggests a global employment of 24,000 full time equivalents until 2025 (assuming a global market of 500 GWh) or 90,000 full time equivalents until 2033 (assuming a global market of 3.3 TWh). The job-creation potential for the engineering industry of the European Union is estimated at 25,000 full time equivalents until 2033.

Based on these estimations, employment effects of 100 to 150 jobs per GWh of production capacity can be assumed for battery cell production. Indirect jobs might be in the order of 100 to 500 per GWh.

2.4.5.3. Europe's position in the global battery value chain

In the EU, several actors are positioned which cover production steps along the whole value chain of LIB, starting from raw material production to production of cells and systems and finally recycling. However with respect to global markets, only few organizations within the EU have a market share of more than 1% in their specific segment, e.g. BASF, Germany in the field of electrolyte production [42].

Due to the strong base of automotive OEM in Europe, particularly battery pack manufacturing and system integration is taking place on large scale in Europe. A particular gap in the value chain is caused by the lack of a large-scale cell production, capable of serving the volumes and prices required by the automotive industry.

An overview about the present and future position of European cell manufacturers and production plants located in Europe is provided in [Figure 34](#) and [Figure 35](#).

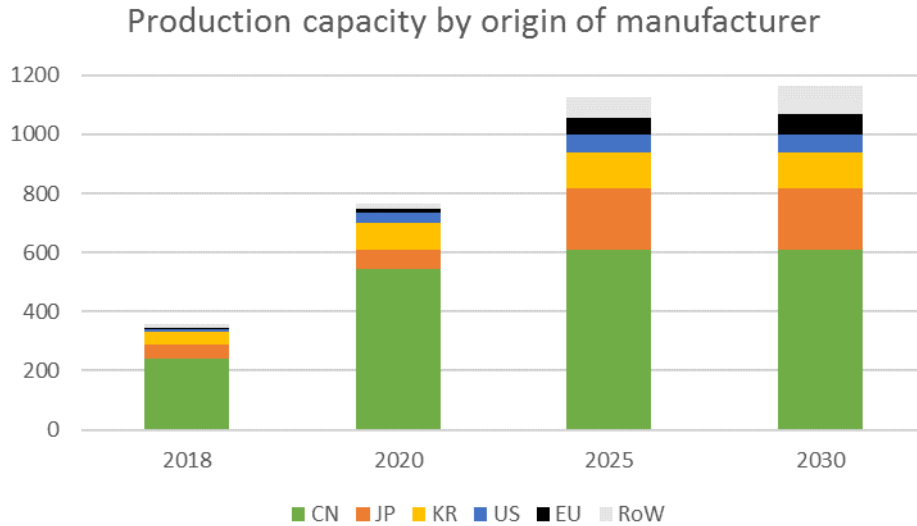


Figure 34: LIB cell production capacities in GWh/year by origin of manufacturer (company) [52].

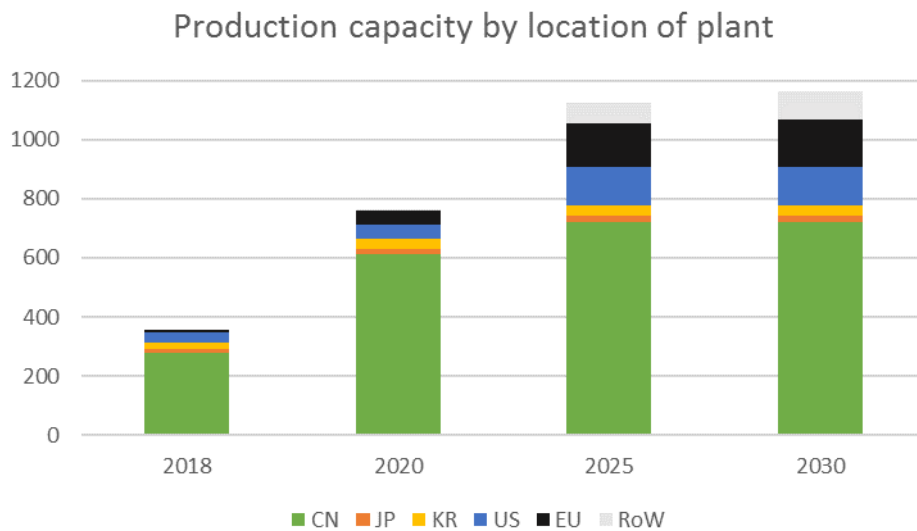


Figure 35: LIB cell production capacities in GWh/year by location of plant [52].

Several consortia are currently attempting to build up a European large scale cell manufacturing such as Northvolt (Sweden) with 32 GWh until 2023 or Saft (together with Siemens and Manz) [53]. Recently, the German government announced plans for funding of a Battery-Cell-Alliance between Germany and Poland with cell production capacities in the regions Lausitz (Germany) and Westpoland [54, 55]. At the cross section between R&D and large-scale production also a Research Production with 600 Mio EUR funding is foreseen, whereas the Fraunhofer Society should coordinate and run such a research production [56]. The announced funding from the German government sums up to 2 bn EUR. Other announcements concern the joint German-French strategy for a potential funding and build-up of a cell production [57].

Given all these announced investments and production capacities to build up in the next years, the cell production capacities of European cell manufacturers could sum up to over 40 GWh beyond 2025. In contrast, main Asian cell manufacturers have already started with cell

production (e.g. LG, SDI) or plan to build up production capacities until 2020 to 2025. In concrete, there are plans from: [58–67]

- CATL (China) to build 14 GWh in Germany, Erfurt beyond 2020
- LG Chem (Japan) to build 15 to 24 GWh (for 0,3 Mio EVs) in Poland beyond 2020
- Samsung SDI (Japan) to build 10 to 15 GWh beyond 2020 in Hungary (including a recent 5 GWh announcement for 21700 cells for Land Rover
- SK Innovation (Japan) to build 7,5 GWh in Hungary beyond 2020
- Panasonic/Tesla to build a Gigafactory in Europa around 2025
- as well as from BYD (China), GS Yuasa (Japan) and Farasis (US) to build production capacities between 2020 and 2025.

The production capacities from Asian (or non-European) cell manufacturers might sum up to well above 82-96 GWh by 2025 and including BYD, GS Yuasa, Farasis, etc. capacities far above 100 GWh can be expected. Together with the new EU cell producers this could easily sum up to serve the demand in Europe. But it also clearly indicates the competition the emerging European players will have to face (besides the fact that the plans of the Asian companies are expected to be realized already several years earlier compared to the plans of the novel EU companies).

2.4.5.4. Product design trends and technology roadmap

Concerning the battery technology or type (by chemistry, format, etc.), which will most likely be produced to address this increasing demand, the global roadmaps of cell producers are basically similar: Based on state-of-the art cell design (e.g. LFP, NCA based “generation 1” and NMC:111 to NMC:532 “generation 2a/b” Li-ion batteries) [68] and state-of-the-art production equipment, incremental improvements are expected in the next few years but with the target to get to higher-energy lithium-ion batteries. Concerning the electrolytes, still liquid electrolytes will be used but will be adopted to the changing electrode materials (e.g. with additives). Current trends for layered oxide cathodes describe the development of Ni-rich (Co reduced) materials (NMC or NCA). A few cell producers are already using NMC811, NCA+ or comparable cathode materials, others are still adopting NMC622 (also referred to as “generation 3a”). On cathode side maybe even lower-cost Li-rich high energy NMCs (HE-NMC) with a high share of Mn might be produced and applied within the next ~10 years, as Mn is cheaper than Ni (also referred to as “generation 3b”). On anode side, the trend is to incorporate Si-nano particles to make use of the alloying reaction between Si and Li yielding a high capacitance. This however comes at the cost of cycle life.

All-solid-state batteries are on the roadmap of many battery producers but also of OEM (also referred to as “generation 4”). Their theoretical key performance parameters (KPI, volumetric and gravimetric energy density above 300 Wh/kg and 500 Wh/l and respective power density) are suitable for electric mobility (EV). Main R&D-challenges result from a missing larger scale manufacturing process, particularly for ceramic solid.state electrolytes which promise to yield the highest advantages over state of the art technologies. It is possible that first all-solid-state batteries might not be competitive in terms of energy density, but might feature superior safety properties. Theoretically, energy densities of 350-400 Wh/kg and higher are possible which might be realized in optimized future cell concepts.

Out of the broad range of alternative battery technologies, other cell chemistries might feature certain USP (unique selling proposition) compared to Li-ion batteries, but (according to the current level of knowledge), do not reach the necessary KPIs in terms of combined volumetric

(above 400 Wh/l on cell level) and gravimetric energy density (above 200 Wh/kg on cell level), power density and cycling stability (corresponding to a range of 150,000 to 300,000 km for passenger EVs) necessary for electric mobility. USPs of these alternative technologies might however be their cost due to a high availability of resources (e.g. Na-based), their gravimetric energy density (e.g. S-based) or others. From today's perspective, it is however unclear which alternative battery technologies will reach commercial feasibility, since often fundamental challenges are not yet solved (e.g. concerning the manufacturability, stability of materials and electrochemical systems, reaction kinetics, etc).

2.5. Consumer expenditure base data

2.5.1. General objective of subtask 2.4 and approach

Subtask 2.5 gives an overview about average production costs and consumer prices, incl. VAT (for consumer prices; street price) / excl. VAT (for B2B products), as well as an estimation of repair and maintenance as well as installation and disposal costs.

Due to their recent larger scale market introduction, there is still little experience with maintenance as well as disposal expenses. Hence, only estimations can be made based on isolated sources.

2.5.2. Development of LIB cell costs

As the core of LIB based energy storage systems, the battery cell exhibits the highest cost share. During the last years, particularly standardized 18650 format LIB cells have experienced a steep cost learning curve, benefiting from production scale effects, but also from technological advancements on material level increasing the energy density per volume and weight and decreasing the amount of cost intense Cobalt-based components. Compared to this benchmark, larger format LIB cells (pouch, prismatic) utilized in xEV and ESS feature lower energy densities at higher cost per kWh. There are however no principal limitations, which would prevent a performance and cost development similar to what was observed for cylindrical cells. [Figure 36](#) shows the cost learning curves for cylindrical as well as larger format LIB cells [45]. Today, costs for cells suitable for automotive use are around 150 €/kWh (cylindrical) and around 200 €/kWh (pouch/prismatic). In specific cases, prices around 100 €/kWh have been reported already [69]. It should however be noted, that with the current market situation, LIB prices being below costs are not unlikely to occur.

Assuming more or less constant resource prices, production costs of the different cell formats are expected to approach and fall below the mark of 100 €/kWh between 2020 and 2025. Taking further developments on material level into account, costs around 60-100 €/kWh seem feasible past 2025.

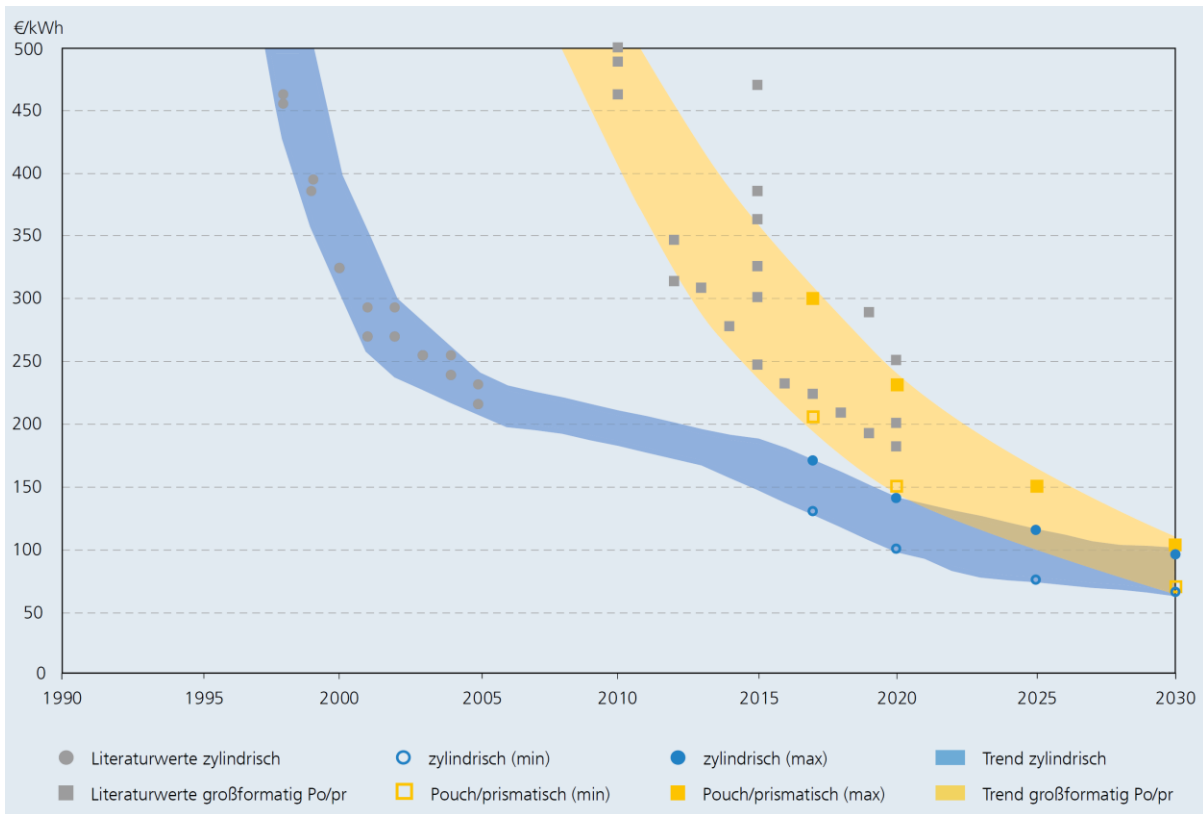


Figure 36: Cost learning curves for large LIB cells (cylindrical and pouch/prismatic) [45].

Similar cost learning curves have been observed for other battery technologies (see [Figure 37](#)). In principal, cost depression can be limited by demand (compare NiCd) or by reaching material cost limits (compare Pb). Also, the diffusion of battery technologies in new markets or applications can lead to further technological improvements and justify higher production costs (compare deviation of NiMH, Pb). Following the available data for LIB cells, approx. 100 \$/kWh (~89 €/kWh) are reached at a cumulative yearly production of 1TWh. This mark is expected to be reached between 2020 and 2030.

Beyond 2030, LIB production costs are however expected to start deviating from this curve due to limiting raw material prices.

Battery cost experience curves

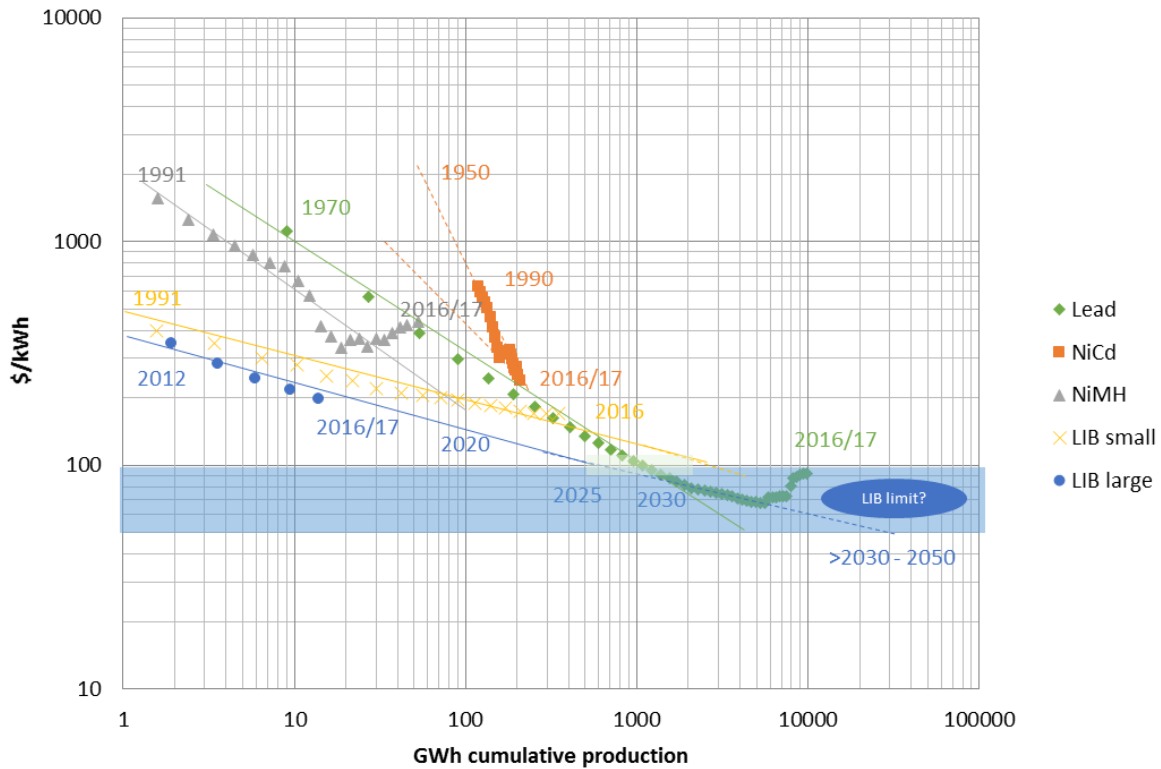


Figure 37: Cost learning curve for different battery technologies [48].

2.5.3. Development of storage cost for xEV and ESS

2.5.3.1. Consumer prices for xEV batteries

From end-customer perspective, prices for xEV batteries only appear as either replacement costs for a battery module or system (in case of failure not covered by warranty) or as price difference of several versions of the same car model, e.g. as long-range and mid-range version. At present, there is no information on replacement or spare part prices available. [Figure 38](#) shows the price difference of base and extended range versions of five car models launched in 2018 and 2019. The data available so far is very limited. Prices for upgrades are in the range of 200 – 500 €/kWh. Note however, that the range upgrade often comes with a performance upgrade also resulting in higher cost for the whole drivetrain including motor and breaks.

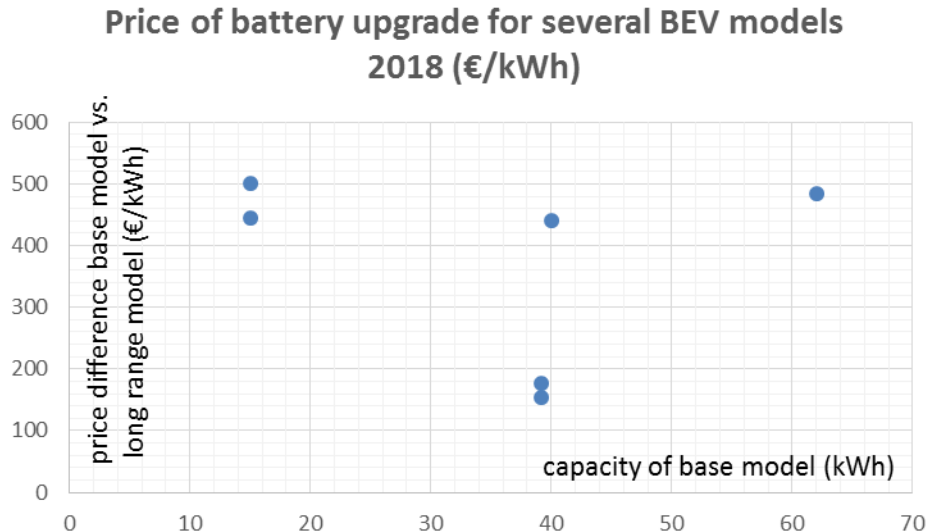


Figure 38: Difference in end customer price of base version and high range version of several BEV models launched in 2018 and 2019.

2.5.3.2. Consumer prices of home storage systems

According to recent end-customer price data provided in [70] for 2018, typical consumer prices for small scale (~10 kWh) stationary home storage systems are between 5000 and 15000 Euros, leading to a relative price of 800 to 1200 €/kWh. It is expected that these system prices will benefit from the growing battery markets (also xEV), since similar LIB cell types can be applied in both application areas. With respect to inverters and other system related costs, the smaller market volume of home ESS indicates lower economy of scale effects as compared to battery cells.

2.5.4. Installation, repair and maintenance costs

So far, no comprehensive information on repair and maintenance costs for the battery system of xEV are available. The price range for refurbishing of batteries might be of the order of 100 \$/kWh [71].

Installation costs of home storage systems are estimated to be between 900 – 3500 € [72]. So far, there is no comprehensive information on repair and maintenance costs available.

2.5.5. LIB life-cycle, disposal and recycling considerations

After their end of life in a respective application, batteries can either be disposed, recycled or, if suitable, be used in a second life application. Recycling or re-use heavily depends on a working collection and return system. Today, respective systems are installed for consumer batteries on national level. With respect to EV or ESS applications, no comprehensive / EU wide collection system exists. OEM have different strategies for the collection of used batteries.

With respect to second life applications, several pilot scale activities are taking place. There is still considerable remaining effort regarding the development of reliable techniques determining the state of health of used batteries as well as regarding efficient methods to integrate used battery(-systems) in second life applications (e.g. EV → ESS).

The future volume of available batteries for a potential second life application is still not clear, since it will heavily depend on battery design and usage patterns. The strategy of automotive OEM regarding second life applications is not known. A design matching battery and vehicle lifetime would mean no available battery capacity for a second life use. The over-engineering of batteries for reasons of reliability would add to the cost of EV, however, might yield batteries with a state of health acceptable for second life use.

Second life applications might extend the overall operation time of batteries. At the final end of life, recycling of batteries might either yield regenerated cathode materials or recovered metals (particularly aluminium and steel from the case/housing and Cu, Mn, Co, Ni and potentially Li from the cells). The metals value of an NMC622 battery is around 20 Euro/kWh [48]. Hence, recycling techniques will have to be energy and cost efficient in order for battery recycling to make a self-sustainable business case. Otherwise disposal and recycling costs might become additional cost components adding to battery prices.

2.6. Recommendations

2.6.1. General objective of subtask 2.5

This task makes recommendations with regard to a refined product scope from an economical/commercial perspective (e.g. exclude niche markets) and identify barriers and opportunities for Ecodesign from the economical/ commercial perspective.

2.6.2. Refined product scope from the economical/ commercial perspective

Secondary batteries, particularly LIB, will become a TWh market in the next years. As a main component of EV and of ESS, their production and use characteristics will have major impact on the overall greenhouse gas footprint of these applications.

Considering the typical lifetime of 10 to 20 years of batteries, significant numbers and volumes of batteries will be decommissioned starting around 2030. Hence, not only the production and use phase, but also the treatment of batteries after their end of life will have a high impact on their environmental footprint.

From market perspective, it is reasonable to consider all stages of LIB life from their production to treatment after their end of service life.

2.6.3. Barriers and opportunities for Ecodesign from the economical/ commercial perspective

The battery markets as discussed in the previous sections are strongly growing. Any Ecodesign or other battery relevant regulation implemented in the near future hence has the chance to steer the development during the crucial phase of scale-up of production capacities. If this time frame is however missed, the implementation of regulations by producers might become more difficult, since production infrastructure investments have already been placed.

The largest markets for batteries will be passenger electric vehicles. Important vehicle performance parameters, which determine their competitiveness (e.g. the vehicle range) are predominantly determined by the battery. A possible Ecodesign regulation should aim at reducing the environmental footprint of batteries (and thereby of electric vehicles) in the context of a high battery performance.

Since a high competitiveness of EV (particularly against combustion powered vehicles) will be necessary to achieve a fast transition and any associated CO₂ targets, Ecodesign regulations should not increase battery costs substantially and/or get in the way of a massive deployment of EV to decarbonise road transport.

2.7. Annex

2.7.1. Sales and stock model description

2.7.1.1. Modelling of addressable electric applications markets

Vehicle markets (in units of registrations in the EU28 per year) and ESS markets (in units of number of installed home PV systems or in units of overall renewable (PV, wind) electricity generation in the EU28 per year) were modelled by exponential functions.

$$Mt_{app.}(t) = M_0 \times Exp(t/\tau)$$

With $Mt_{app.}(t)$ being the total market volume of an application, M_0 the market size in 2015 and $\tau \times Ln(2)$ the time t necessary to double the initial market volume M_0 . M_0 and τ were chosen to fit existing market data.

$$M_{app.}(t) = c \times M_0 \times Exp(t/\tau)$$

With $M_{app.}(t)$ being the addressable market and c a factor equal or smaller than 1. Parameter $c < 1$ was chosen to take into account that not the whole existing market $Mt_{app.}$ might be addressable by battery electric technologies. E.g. a share of vehicles primarily used for long distance travel might not be addressable by BEV, but by PHEV/HEV only.

The market addressable for passenger PHEV/HEV (as a transition technology on the path to full electric vehicles) was modelled as the difference of total vehicle sales and BEV sales:

$$M_{PHEV}(t) = c \times Mt_{passenger}(t) - S_{BEV}(t)$$

The market addressable for passenger BEV was modelled like $M_{app.}(t)$ with $c < 1$.

2.7.1.2. Modelling of sales numbers of xEV and new installations of ESS

Yearly sales numbers $S_{app.}(t)$ for the different applications were modelled by logistic growth functions. Logistic functions can model diffusion of technologies into existing markets with a given market volume M . The market volume can be a moving target $M = M(t)$. The relative change of sales numbers $S'_{app.}(t)/S_{app.}(t)$ is proportional to the market volume not yet developed by a technology $M_{app.}(t) - S_{app.}(t)$.

$$S_{app.}(t) = M_{app.}(t) \times \frac{1}{1 + Exp(-M_{app.}(t) \times (t - t_0)/\tau) \left(\frac{M_{app.}(t)}{S_{app.}(t_0)} - 1 \right)}$$

With τ being a time constant and $S_{app.}(t_0)$ being the yearly sales volume at year t_0 (e.g. 2015).

Short time constants τ of few years were used to model ESS sales. Due to limitations of the existing electricity grid to only buffer a certain share of fluctuating PV and wind generated electricity, the further expansion of renewable electricity generation might be strongly coupled to ESS installations. Hence, ESS sales were modelled to closely follow the assumed installations of renewable power in the limit of "very fast" market diffusion ($\tau \rightarrow 0$).

The following applications / sub-markets were considered and modelled:

- Passenger electric vehicles: (1) small (mini), (2) compact and vans (comp), (3) upper / luxury class and SUVs as (a) BEV, (b) PHEV, (c) HEV
- Light commercial vehicles (1) as (a) BEV, (b) PHEV, (c) FCEV

- Heavy commercial vehicles (1) as (a) BEV, (b) PHEV, (c) FCEV
- Buses (1) as (a) BEV, (b) PHEV, (c) FCEV
- Home ESS (1) as “BEV”
- Large ESS (1) as “BEV”

2.7.1.3. Modelling of battery system capacities

At present, the average energy content of a BEV passenger electric vehicle battery is above 40 kWh. Small vehicles offering space for one or two persons often feature a capacity of less than 10 kWh, while the models with highest capacity sold in EU28 countries approach the 100 kWh mark. The amount of battery capacity installed in passenger PHEVs is about 10 kWh and has remained on a constant level over the last years (see [Figure 39](#)).

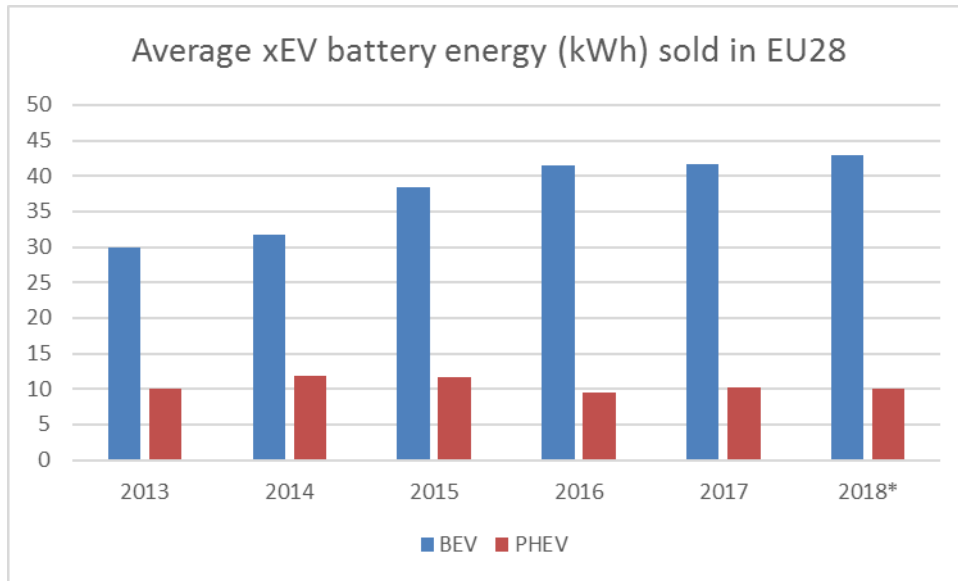


Figure 39: Averaged battery capacity of xEVs sold in EU28 member countries based on sales volumes of xEV models [3].

In particular BEV battery capacities increased in the last years from 30 kWh in 2013 to more than 40 kWh in 2018 (EU sales and production averages). With respect to announcements made by OEM and information on models launched in 2018 and 2019, we expect average capacities to approach the 60 kWh mark. In the long term, we expect BEV capacities to converge towards a value sufficient to provide average driving ranges of some 100 km. Battery capacity growth rates are hence supposed to slow down.

Some movement can also be expected for the system capacity of home storage ESS once systems are used for self-consumption optimization of EV charging.

Battery capacities $E_{Batt.}(t)$ of the different applications were modelled by power laws.

$$E_{Batt.}(t) = E_0 + k \times (t - t_0)^b$$

With E_0 being the average battery capacity in year t_0 , k the growth rate, t the time in years and b an exponent < 1 . The parameters were chosen to fit existing data.

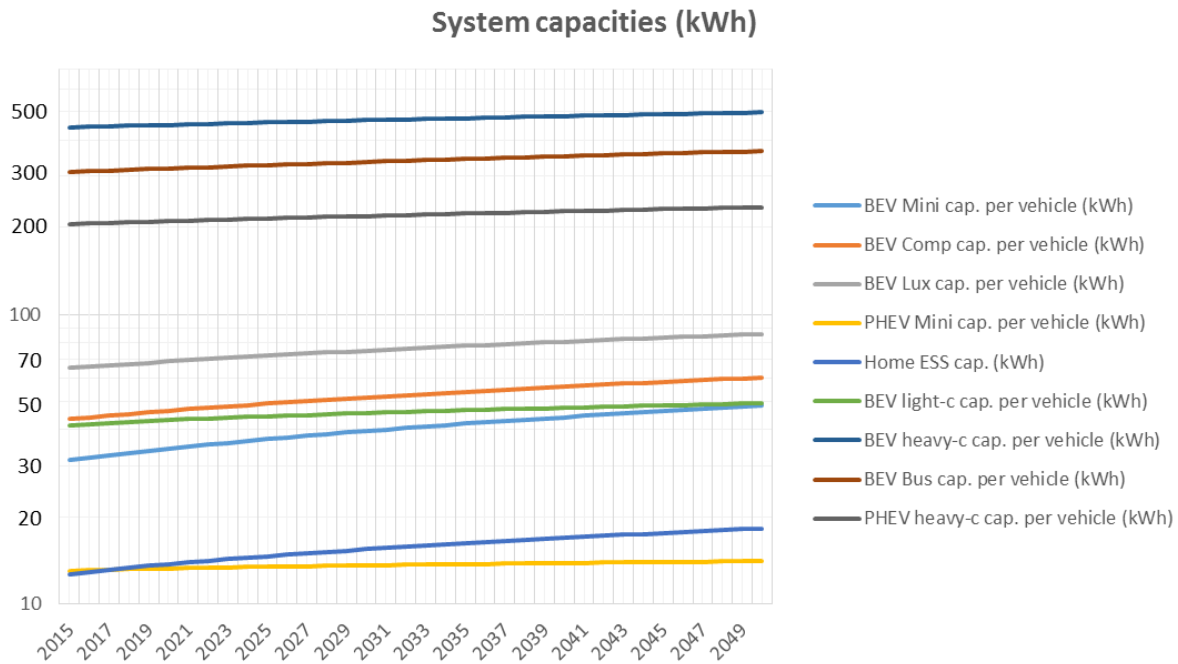


Figure 40: Average system battery capacity model forecast.

Large scale ESS capacities were not modelled in the frame of this study.

2.7.1.4. Modelling of battery replacement rates [70, 73–78]

The replacement rate defines the share of batteries installed in year t that has to be replaced within the lifetime of a system (xEV, ESS). This might either be interpreted as partial replacements in every system sold, e.g. one battery module in a system consisting of several modules, or, more likely, complete replacements of the battery in only some systems.

At present, there is no sufficient data available on the average lifetime of batteries in electric vehicles or stationary storage. Battery lifetime largely depends on the usage profile of applications as well as on the ambient and operational temperature.

Since passenger vehicles mostly remain parked, calendar ageing might be an important factor determining the battery lifetime. Depending on the type of cells and ageing conditions, calendar lifetime (SoH down to 80%) of LIB can be assumed to be between 10 and 30 years.

Usage and cycling is a deteriorating factor, which might be of high importance particularly for commercial or ESS applications. The cycle life of LIB (SoH down to 80%) ranges from 500 to 1000 full cycles for high energy batteries and up to several thousand full cycles for industrial grade batteries. The total energy throughput of batteries can be significantly improved, if maximum depth of discharge and maximum state of charge are limited. Besides energy throughput (cycling), temperature as well as charge and discharge power are decisive factors for deterioration. Frequent use of fast charging of electric vehicles for example is supposed to accelerate ageing of the battery.

Development of SoH of several vehicles over time (%)

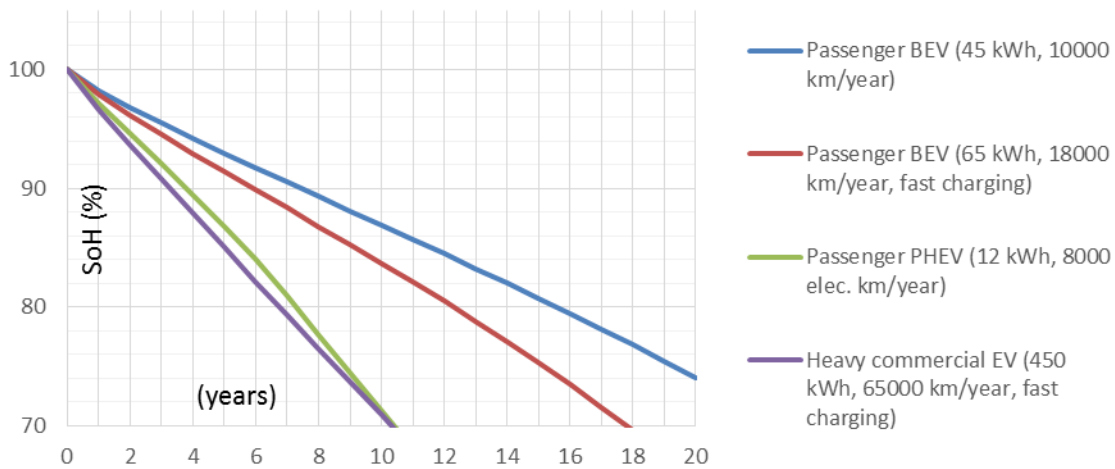


Figure 41: Calculated development of the SoH of vehicle batteries over time. A battery cycle life of 700 full cycles (100% DoD) was assumed for passenger BEV and of 2000 full cycles (100% DoD) for passenger PHEV and of 3000 full cycles (100% DoD) for heavy commercial EV. Utilization of 60% (45 kWh BEV) to 80% (450 kWh heavy EV) of the nominal installed battery capacity per charge/discharge cycle. Ageing at an average temperature of 15 °C.[8]

Figure 41 shows exemplary calculations for different EV models and usage scenarios. According to this data, the state of health of a passenger EV used with a usage profile typical for the majority of cars in the EU, is supposed to remain sufficient (larger than 80%) during the lifetime of the vehicle. Hence, battery replacement rates are expected to be rather low. Other usage forms, particularly commercial usage of heavy and light vehicles with frequent use of fast charging and long operation time (meaning longer periods at elevated battery temperature) might however deteriorate the battery much faster.

As compared to xEV batteries, batteries for ESS applications may exhibit a better cycling stability and lifetime, since they are not as strongly optimized on high energy densities, but have to stand frequent (e.g. daily) cycling. Typical usage profiles of storage systems also feature a comparably low load. Dimensioning of system power and system storage capacity often does not exceed currents of 1C.

Within the battery demand and stock forecast model, battery replacement rates $R_{p_{Batt.}}(t)$ were assumed to be constant over time $R_{p_{Batt.}}(t) = R_{p_{Batt.}}$.

2.7.1.5. Modelling of average system lifetimes (xEV, ESS)

Average system lifetimes $L_{t_{system}}(t)$ were assumed to be constant. $L_{t_{system}}(t) = L_{t_{system}}$. Parameters were estimated based on manufacturer statements and typical lifetimes for combustion powered vehicles.

According to statistics provided in [5], the average vehicle age in the EU28 in 2016 for passenger cars was 12 years, for light commercial vehicles 11 years and for heavy commercial vehicles 12 years. The vehicle average age seems to be increasing by about 0.1 to 0.2 years/year. With respect to the stock of 250 to 260 million passenger cars in the EU28, the market volume of 13 to 14 million vehicles per year would translate into a passenger car lifetime of 17 to 18 years.

2.7.1.6. Calculation of battery replacements

Battery replacements $Rp_{Batt.}(t)$ (either in units of GWh or units of number of systems) were calculated by assuming a uniform distribution of battery replacements over the lifetime $Lt_{system}(i)$ of battery systems installed in year i .

$$Rp_{Batt.}(t) = \sum_{i \geq t - Lt_{system}(i)}^t \frac{Rr_{Batt.}(i) \times S_{app.}(i) \times E_{Batt.}(i)}{Lt_{system}}$$

2.7.1.7. Calculation of system and battery decommissions

In addition to batteries replaced and decommissioned during the lifetime of an application (replacements), batteries installed in an application at the end of life of the application are considered as additional decommissions.

Decommissions of batteries $Dc_{Batt.}(t)$ (either in units of GWh or units of number of systems) were assumed to happen at the end of life (EoL) of the applications. Within the model, EoL was distributed in a range of +/-25% of Lt_{system} around the average lifetime Lt_{system} (see [Figure 42](#)). Any second life usage was neglected.

$$Dc_{Batt.}(t) = \sum_{i=t-1.25 \times Lt_{system}}^{t-0.75 \times Lt_{system}} \frac{S_{app.}(i) \times E_{Batt.}(i)}{0.5 \times Lt_{system}}$$

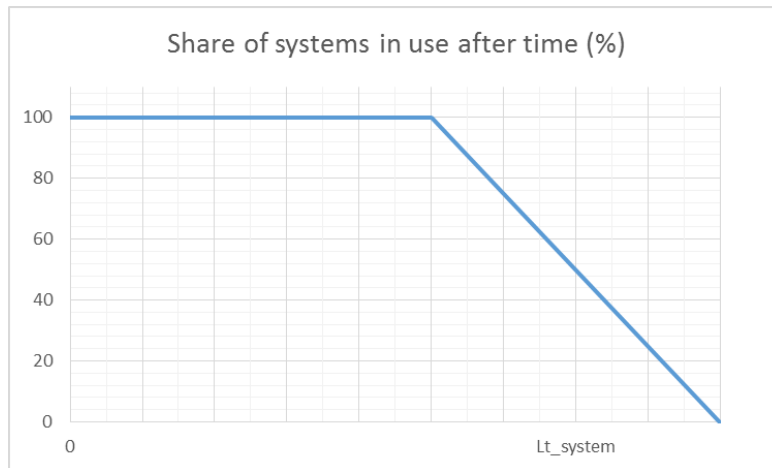


Figure 42: Share of systems in use after time.

2.7.1.8. Calculation of yearly installed battery capacity

The yearly installed battery capacity $Sb_{app.}(t)$ in the EU28 was calculated as:

$$Sb_{app.}(t) = S_{app.}(t) \times E_{app.}^{Batt.}(t) + Rp_{app.}^{Batt.}(t)$$

2.7.1.9. Calculation of battery capacity stock

The stock of battery capacity $C_{app.}$ installed in the EU28 in year t was calculated as:

$$C_{app.}(t) = \sum_{i \leq t} S_{app.}(i) \times E_{app.}^{Batt.}(i) - Dc_{app.}^{Batt.}(i)$$

2.7.2. System/BMS related PRODCOM categories

Within the NACE2 classification, there are no explicit categories for LIB system components like the battery management system, however there are categories including components, which are likely to be applied in the power electronics or BMS of battery packs and systems. A selection is listed in [Table 13](#). Automatic circuit breakers, as a part of technology crucial for battery management systems, are aggregated under PRODCOM categories 27122250 and 27122230.

27122370	Electrical apparatus for protecting electrical circuits for a voltage ≤ 1 kV and for a current > 125 A (excluding fuses, automatic circuit breakers)
27122350	Electrical apparatus for protecting electrical circuits for a voltage ≤ 1 kV and for a current > 16 A but ≤ 125 A (excluding fuses, automatic circuit breakers)
27122330	Electrical apparatus for protecting electrical circuits for a voltage ≤ 1 kV and a current ≤ 16 A (excluding fuses, automatic circuit breakers)
27122250	Automatic circuit breakers for a voltage ≤ 1 kV and for a current > 63 A
27122230	Automatic circuit breakers for a voltage ≤ 1 kV and for a current ≤ 63 A
27904155	Inverters having a power handling capacity $> 7,5$ kVA
27904153	Inverters having a power handling capacity $\leq 7,5$ kVA

Table 13: PRODCOM categories related to batteries [1].

2.7.3. Circuit breakers as an example for BMS electronics

LIB cells as gathered in category 27202300 are only one of the subunits of battery systems. Housing, protection, cooling, electrical and electronic components are supposedly measured in different PRODCOM categories (e.g. 27122250 Automatic circuit breakers for a voltage ≤ 1 kV and for a current > 63 A and 27122230 Automatic circuit breakers for a voltage ≤ 1 kV and for a current ≤ 63 A).

[Figure 43](#), [Figure 44](#), [Figure 45](#) and [Figure 46](#) show production, import, export and EU sales and trade data for automatic circuit breakers as potential component of BMS. EU consumption values do not show a clear upward trend comparable to the values for battery technologies. Although an increase of export and import values can be observed, no clear correlation with the production of battery systems for xEV or stationary storage in Europe can be observed.

We conclude that the analysis of individual storage system related PRODCOM categories does not allow to assess the market development for complete battery systems.

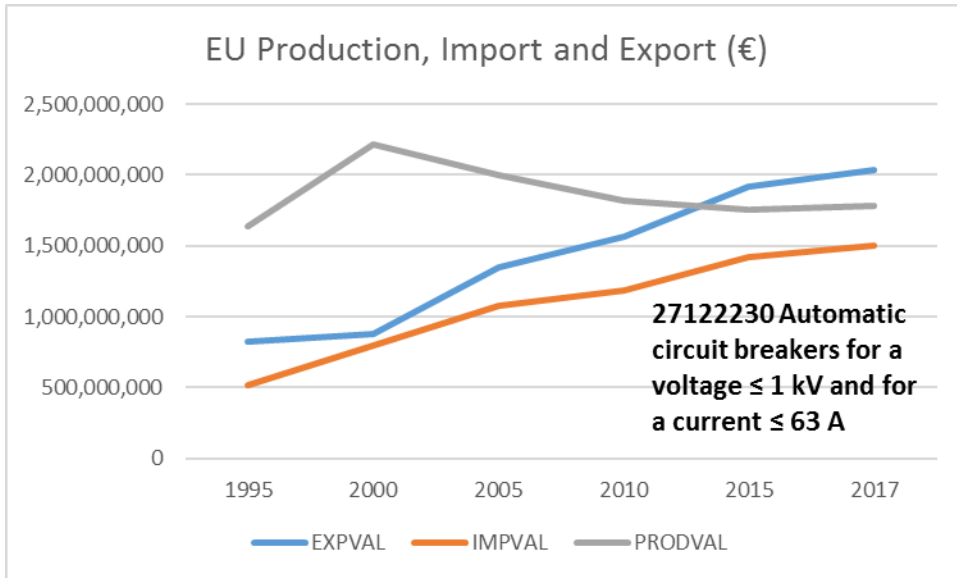


Figure 43: EU production, import and export summarized in PRODCOM category 27122230: Automatic circuit breakers for a voltage ≤ 1 kV and for a current ≤ 63 A [2].

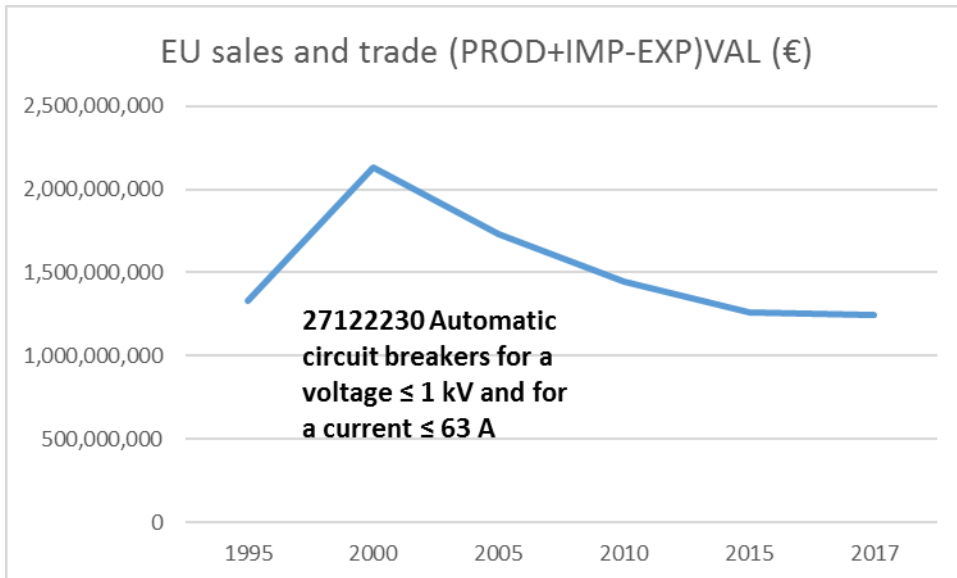


Figure 44: EU sales and trade (PROD+IMP-EXP) summarized in PRODCOM category 27122230: Automatic circuit breakers for a voltage ≤ 1 kV and for a current ≤ 63 A [2].

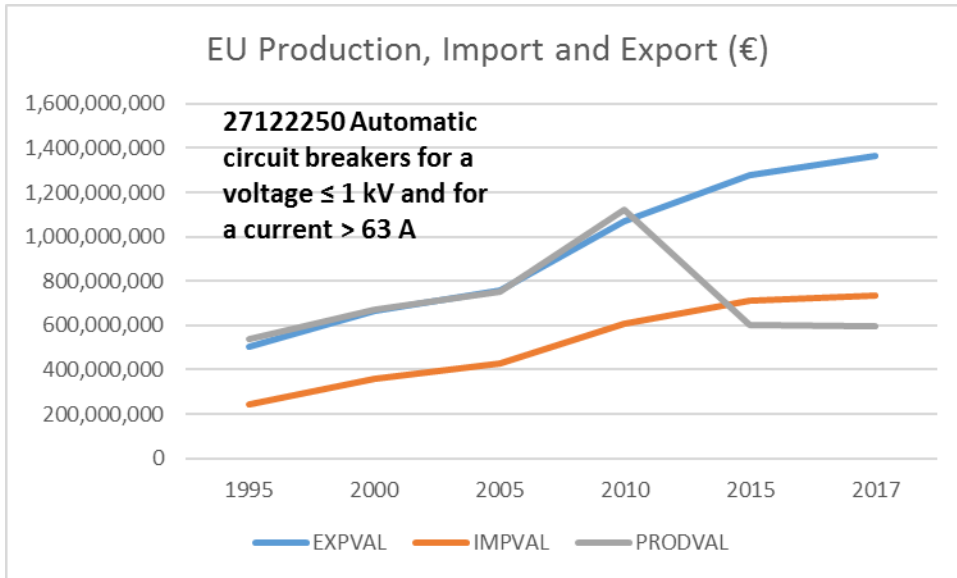


Figure 45: EU production, import and export summarized in PRODCOM category 27122250: Automatic circuit breakers for a voltage ≤ 1 kV and for a current > 63 A [2].

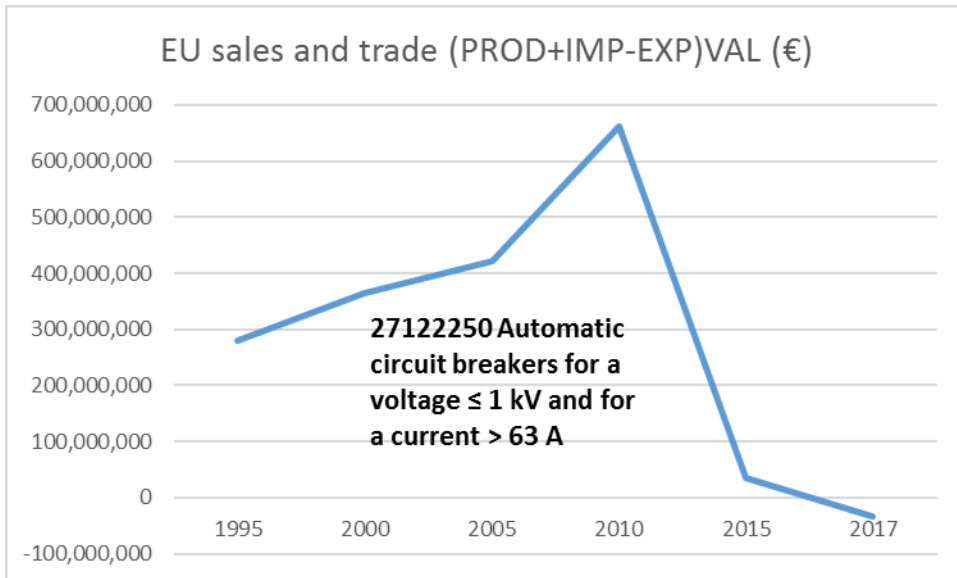


Figure 46: EU sales and trade (PROD+IMP-EXP) summarized in PRODCOM category 27122250: Automatic circuit breakers for a voltage ≤ 1 kV and for a current > 63 A [2].

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