POSITION PAPER 2019

ELECTRIC VEHICLES: THE MERGER OF THE AUTOMOTIVE AND ENERGY INDUSTRY

SAFER, SMARTER, GREENER

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accilium is founded on the idea that nothing is built to last unless it is built to evolve. This fundamental idea, paired with our expertise and industry insights with automotive manufacturers, infrastructure suppliers, utilities and public services drives us to solve hard problems, develop new mobility solutions and push digitalization initiatives together with our partners and clients. Our heritage is rooted in all three core areas along the value chain of an automotive original equipment manufacturer (research & development, production, sales & after-sales). Today, we venture out to expand our reach across the automotive manufacturers' borders to infrastructure suppliers, utilities and public services.

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DNV GL provides unique insights, thorough business and technology analyses, and modelling of energy markets, supporting the development of strategies that ensure compliance with regulations, while seizing opportunities within energy markets. Technical development in the fields of Smart Grids, advanced metering infrastructure, distribution automation, and enhanced communications capabilities demand quality guidance in the design and implementation of reliable and secure intelligent networks. DNV GL assists energy executives in the transition towards a Smart Grid.

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ELECTRIC VEHICLES: THE MERGER OF THE AUTOMOTIVE AND ENERGY INDUSTRY

ELECTRIC VEHICLES AS A GAME CHANGER FOR THE UTILITY BUSINESS?

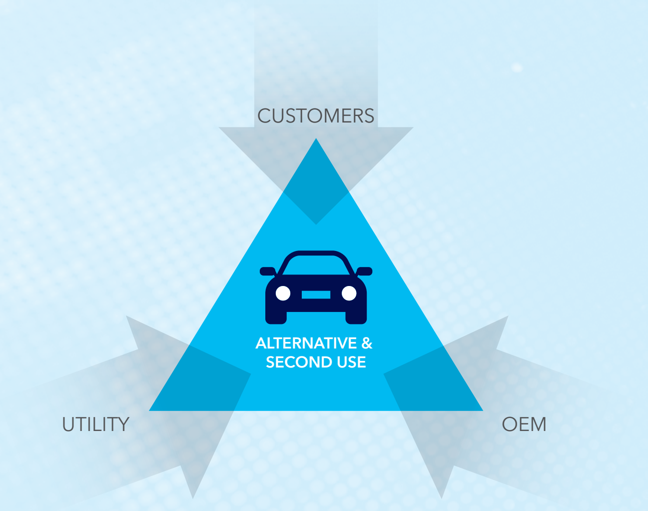
The electric vehicle (EV) revolution has begun, with the widespread adoption of EVs holding the potential for a more sustainable future for both the automotive and electric power industry. In this position paper we investigate how close collaboration between two historically distinct industries could reduce the total cost of ownership of an EV, improving the value proposition for original equipment manufacturers (OEMs), utilities, and most importantly, their (shared) end customer. If you were told you may never have to pay for the energy going into your vehicle, just by making your spare battery capacity available to the grid, you might well make the switch to an EV a little sooner.

Increasing EV sales could provide OEMs* with a means of complying with ever-stricter CO_2 fleet targets. However, despite EVs being sold by OEMs at lower margins than internal combustion engine (ICE) vehicles, and the closing gap between the total cost of ownership (TCO) of an EV and an ICE equivalent, range anxiety deters potential customers.

Meanwhile, for electric utilities, traditional revenue streams from conventional generation plants are becoming increasingly unprofitable. There are many reasons for this, most notably the rising penetration of renewable generation, at both transmission-grid as well as local level (e.g. rooftop solar panels). EVs have the potential to open up new revenue streams for those utilities that are willing to adapt their business models and transition from their traditional role as commodity providers to being service providers also.

In this paper, we investigate such a case for the German market (as is reflected in our parameters and calculations). However our findings can be considered as generally applicable to most other European countries.

* Throughout this paper vehicle manufacturers are referred to as OEMs



Customers

- Search for a more holistic e-mobility offering
- Shy away of the high upfront investment and generally prefer to pay their share of the use instead of owning the assets

OEMs

- Want to sell more EVs & PHEVs to comply with ever stricter CO_2 fleet targets
- Want to ensure a continuous participation in the EVs lifecycle revenue stream

Utilities

- Want to become service providers, and not remain solely commodity providers
- Lock customers into long-term contracts

Figure 1. Stakeholder perspectives

Markets are merging

EVs are currently being sold in practically the same way as ICE vehicles, although they represent a major paradigm shift for the automotive industry. Due to lower maintenance costs of EVs, OEMs face losing after-sales revenues. The connection between the EV and the electricity grid presents additional challenges, but also provides a very interesting set of opportunities – for OEMs and utilities alike. In order to compensate for after-sales revenue losses and to capitalize on new opportunities, OEMs will have to start selling an entire electric mobility solution and create new sources of lifecycle revenue. To roll out the necessary ecosystem, they will – most likely - need to partner with utility companies.

An OEM-utility partnership could work in many different ways. We do not need to look far to find examples of comparable partnerships that have occurred in other industries in the aftermath of a disruptive innovation. The mobile phone and carrier industry, for example, are characterized by their close relationships and strong inter-dependencies, in which heavy hardware subsidies and lock-in contracts are common practice. Additionally, there has been an increasing trend towards adopting the principles of a 'sharing economy', with the rise of such concepts as Airbnb and SHARE NOW (formerly Car2Go and DriveNow). Interest in owning assets is falling and some customers would instead rather pay for their share of the use. Such trends will inevitably also shape both the automotive and energy industries.

Inspired by such concepts, we envision a future in which the EV battery is an asset that alternatively may also be owned by the utility, rather than the EV user. In this new business model, the utility may seek close cooperation with an automotive OEM. Customers would need to make a smaller upfront investment for the EV (thereby increasing OEM sales), alongside periodic payments for sharing use of the battery with the utility. The utility could harness the flexibility of the battery as a means of energy storage to create value via two key concepts: alternative use and second use.

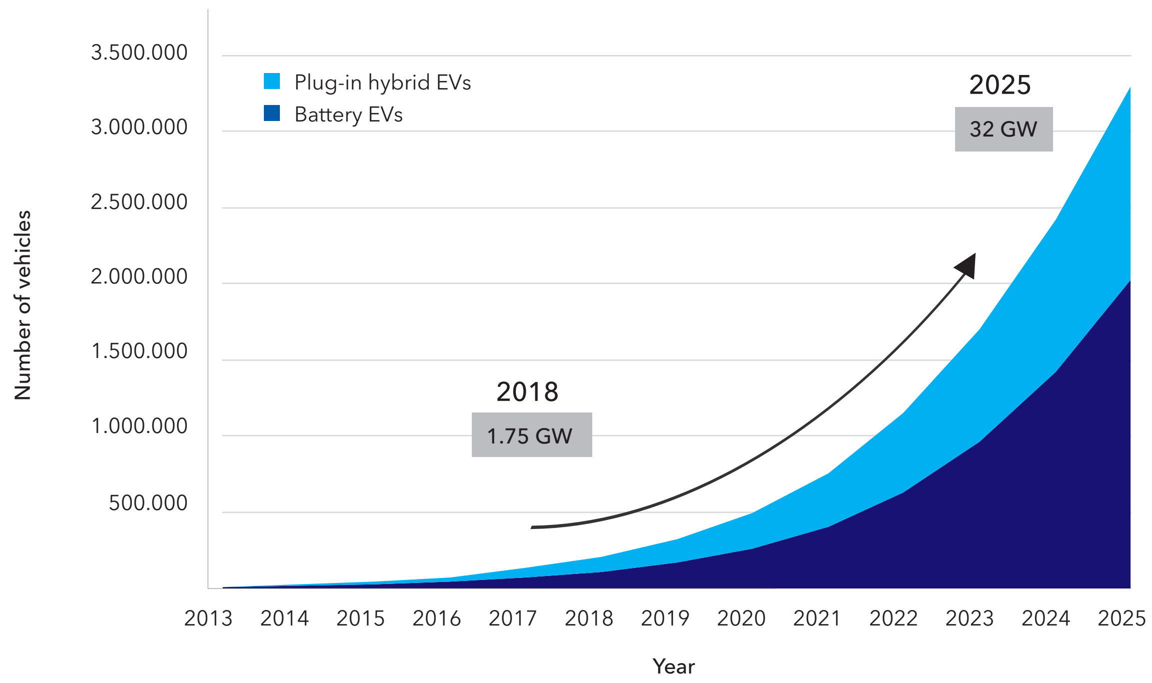


Figure 2. Forecast of electric vehicles (EVs) and their theoretical available battery power in the German market by 2025. Source: DNV GL & accilium research

Battery alternative use

The "alternative use" concept refers to the utilization of the battery pack in EVs for purposes other than providing the vehicle drivetrain with energy. Given that the average vehicle stands idle for between 22 and 23 hours a day, this can lead to various benefits.

Although the number of electric vehicles participating in smart charging or vehicle to grid trials today is relatively low, the chart above clearly highlights the huge growth in the battery power that could theoretically be made available to the German grid. Based on DNV GL and accilium calculations the total EV battery power in Germany is likely to rise to over 32 GW by 2025. This is equivalent to the output of 20 large power stations, and represents a significant potential for alternative use applications.

In conjunction with an appropriate wallbox, the battery pack can not only charge from, but also discharge to, either the EV user's home (vehicle-to-home (V2H) mode) or to the grid (vehicle-to-grid (V2G) mode). Through such a bi-directional connection, V2H use cases include storing rooftop photovoltaic (PV) energy, while there are several V2G use cases, ranging from portfolio optimization to offering balancing power.

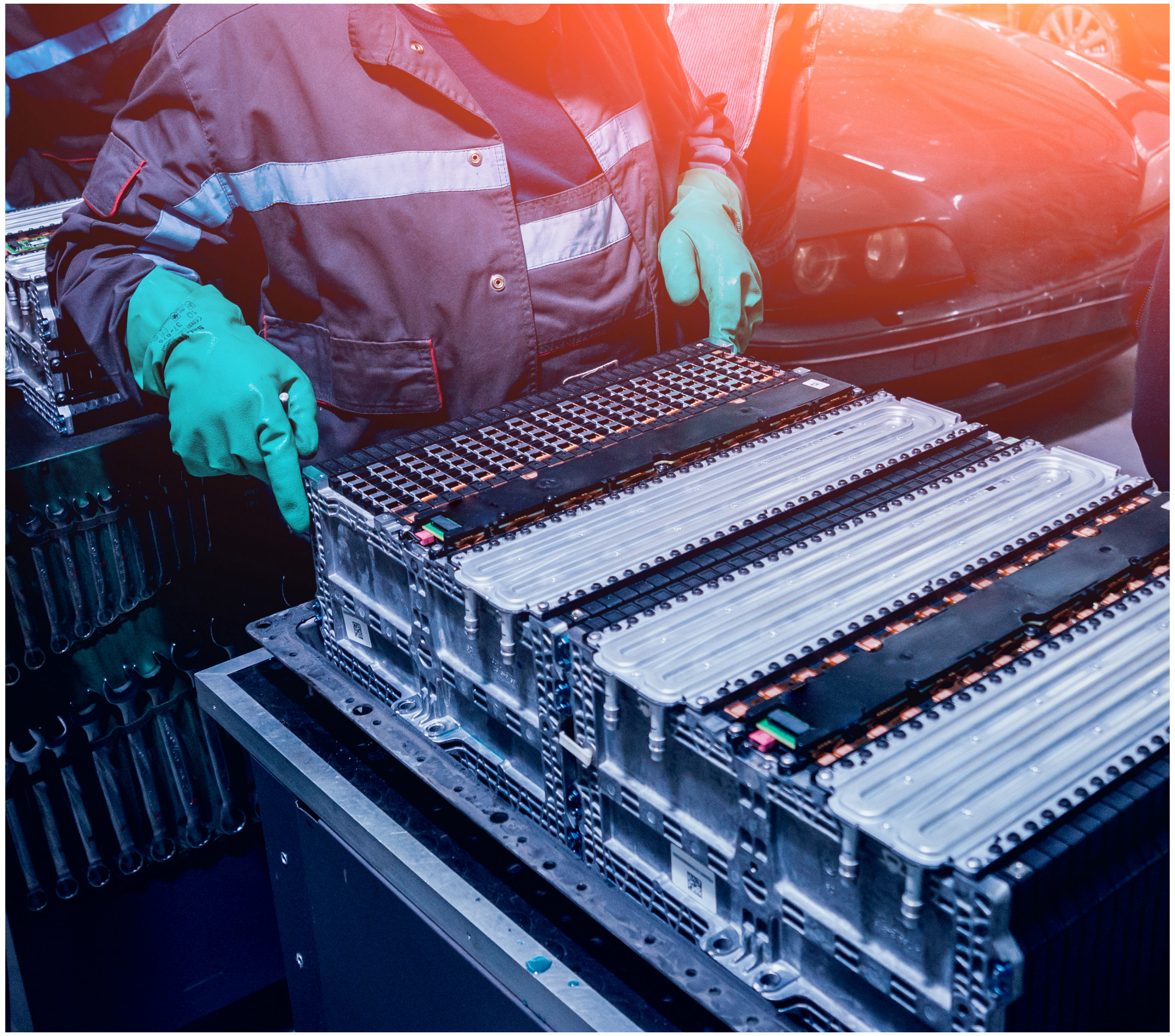
In order to unlock the potential of alternative uses for V2G use cases, a fleet of EVs should be controlled by a third party, which can be referred to as an *aggregator*. The aggregator is able to offer services that would not normally be possible with a single EV, as the level of power needed for V2G applications is in the range of megawatts rather than kilowatts.

We propose that the utility takes on the role of an aggregator. As incumbents in the power sector, utilities have a vast knowledge of electricity markets on which to capitalize. However, it is important to note that this role could also be adopted by an e-mobility organization, OEM, or a company that is specialized in, for example, demand-response services. In this paper, the terms aggregator and utility will be used interchangeably. Similarly, depending on the context, the utility may also be referred to as an electricity supplier - in reference to its (existing) role in electricity retail markets.

Battery second use

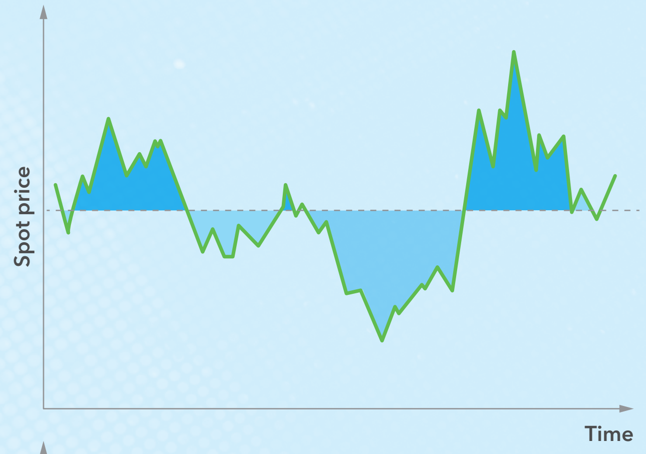
The “second use” concept refers to the utilization of the EV’s battery pack after it has been removed from the vehicle, either because the vehicle has reached its end-of-life, or because the battery’s performance characteristics are insufficient for providing the vehicle drivetrain with energy. The battery pack can still provide value as a stationary storage device, since the energy density and the power requirements are less important for stationary storage compared to the requirements of batteries in EVs.

With a rising EV stock, the number of potentially available second use batteries will also increase. Given the expectation that an EV (including its battery) will last at least 8 to 10 years, second use is a future business opportunity, and its value is hard to predict. Still this concept could increase the residual value of the battery and thus lead to a lower total cost of ownership for the EV.

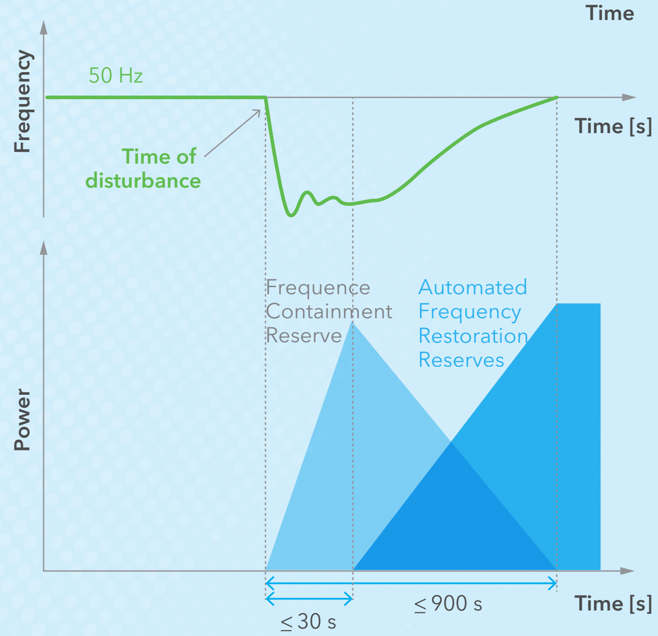


Use cases for alternative and second use

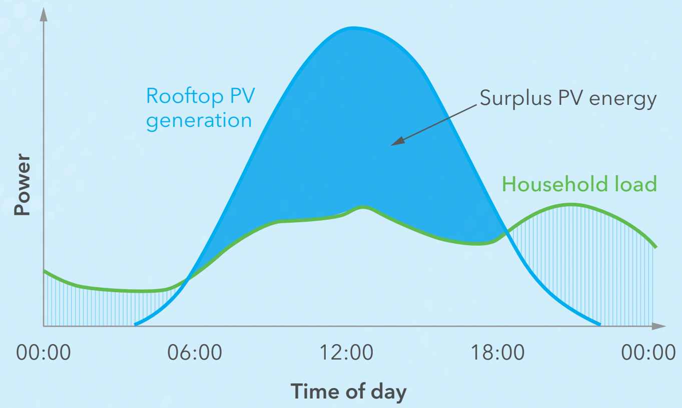
Portfolio optimization
A utility sells electricity to customers under a strategy which simply put, is ´buy low, sell high´. The difference between the price for which it buys electricity for on the wholesale market and the price it sells to customers ultimately ends up determining its bottom line. By operating as an aggregator, the utility can shift the charging and discharging of the EV battery to periods when the wholesale electricity can be bought cheaply - resulting in a large price difference.



Primary and secondary control reserve
The power system must always maintain a balance between the supply and demand of electricity in order to maintain a constant system frequency (50 Hz in Europe). Our use case involves using a fleet of EVs to provide one of two types of balancing products: Frequency Containment Reserves (FCR) or Automatic Frequency Restoration Reserves (aFRR). Although the technical nuances of these reserves are specific to each country, the fundamental concepts are the same. FCR is fully activated within 30 seconds in order to stabilize any deviations in frequency, and aFRR acts to return the frequency of the system back to 50 Hz, and must be fully activated within 15 minutes (in Germany aFRR must be fully activated within 5 minutes).



PV storage
Adding rooftop PV panels provides additional synergies to the aformentioned use cases. The battery can be used to store surplus PV energy not immediately required by the household, thereby uncoupling PV energy production and consumption. The surplus PV consumed by the household can therefore be valued at the retail electricity price, rather than the (typically lower) feed-in tariff received when surplus PV is exported to the grid.



UNLOCKING THE POTENTIAL

Despite the expectation that EVs will have a significant role to play in the future energy system, various developments must occur in order for this to happen. What needs to change in the energy markets for alternative use to become a reality?

Are existing technologies and infrastructure able to support this concept? What is the economic value of alternative use? We explore these questions further in this section.

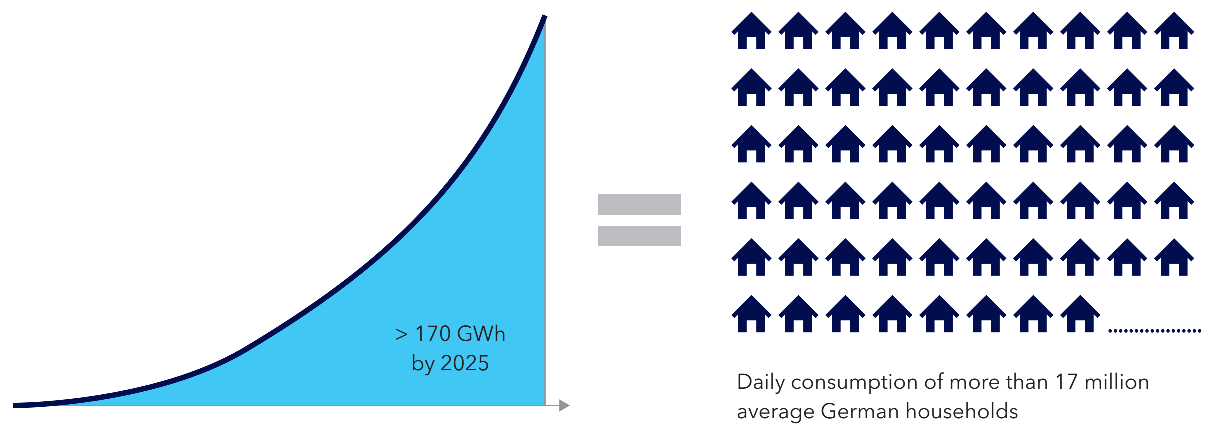


Figure 3. Total EV battery capacity in the German Market by 2025. Source: DNV GL & accilium research

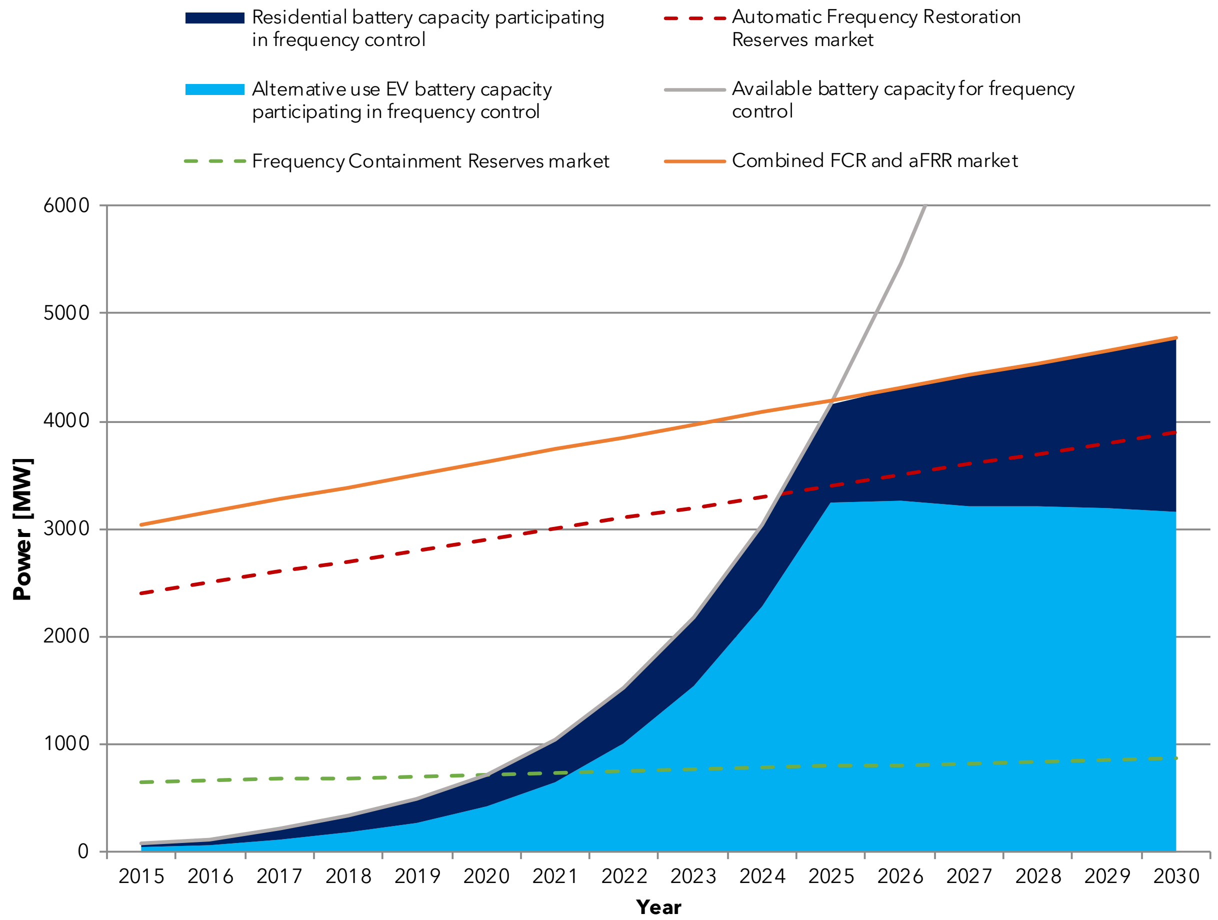


Figure 4. Potential alternative use and stationary battery (dis)charging capacity provisioning for balancing power. Source: DNV GL & accilium research

Market

Growth of electric mobility compared with energy markets

With the growing EV stock, the available battery capacity installed in vehicles will be considerable by 2025.

Based on the projected EV penetration in Germany, Figure 4 shows the extent to which electric mobility is able to provide power to the main balancing markets*. For most European markets a similar graph can be drawn. This figure is based on the following assumptions:

- 1 out of 3 EVs sold will participate in the balancing market; plug-in hybrids (PHEVs) are excluded due to their low battery content.
- Balancing services provided by EV batteries (from alternative use) will gradually be replaced by residential stationary batteries (e.g. second use), as these are always available and expected to have lower marginal costs.
- The balancing market in Germany is growing steadily.

* Balancing power may be required in either an upward or downward direction. The market sizes shown for aFRR in the figure are single-sided; i.e. they indicate the balancing power capacity expected to be procured for a single direction.

From the graph we conclude that the aFRR market can be fully supplied through alternative use by 2024, although less power will be available when most cars are travelling, e.g., during peak commute periods. However commute times are still relatively short and spread out over several hours in the morning (6 – 10 a.m.) and evening (4 – 7 p.m.). This mitigates the risk of a severe drop in the available capacity for providing secondary reserve. The merging of European balancing markets (stipulated by the FC's Guideline on Electricity Balancing), will further mitigate this risk by enabling EVs to provide cross-border balancing power.

The balancing services provided by EVs will have a dampening effect on energy prices. The fading TCO benefits of providing balancing power are expected to be compensated by cheaper battery prices.

Where the value of alternative use is based partly on these balancing services, we expect that the main value of second use will be obtained by combining two services; PV storage and portfolio optimization (intraday optimization and self-balancing). This volume-driven market is far larger than the capacity-driven balancing markets.

Legal and regulatory barriers for alternative use
Although there is a strong drive from the EU to align and integrate the electricity markets further, electricity laws and market regulations still differ substantially between European countries. The barriers mentioned below apply to most European markets, with some exceptions.

Legal and regulatory barriers for alternative use

BARRIER 1:

Aggregator–Supplier relationship

An independent aggregator is, in general, not permitted to influence the charging pattern of an EV, as this may negatively impact the position of the associated electricity supplier. However, the EU directive on electricity market design stipulates that independent aggregation should be supported by the regulatory framework. The barrier still exists in most EU countries, but it is expected to be resolved between 2021 and 2023. In our proposed business model we circumvent this barrier by assuming that the electricity supplier will also take on the role of an aggregator.

BARRIER 2:

Ownership of energy

In our proposed business model, the battery is owned by the utility. Therefore, ownership of the energy does not need to be transferred to the home/EV-user when the battery is charged. However, this contravenes current regulations that state that the ownership of energy is transferred when it crosses the household connection. This principle obstructs the concept of alternative use (in fact, it obstructs every concept of storage systems providing grid support and balancing services). If the EV is charged and discharged several times per night, then taxes and VAT will be raised on the charged energy, and feed-in tariffs may apply to discharged energy. This would ruin the business case.

BARRIER 3:

Smart meters and wholesale settlement

The value of smart (dis)charging is based on the ability to adjust consumption and production according to wholesale and balancing market price signals. Consumers in most European markets are currently unable to offer their flexibility to these markets, as wholesale settlement is based on synthetic (rather than actual) consumption profiles. Therefore, two elements are required to enable this concept:

1. **A smart meter must be installed:**
   Smart meters are generally capable of supplying interval values for net consumption and net production.

2. **The wholesale processes should be modified:**
   An alternative approach is needed for retail customers regarding the allocation (or wholesale settlement) of electricity generation and consumption, based on smart meter measurements, in line with the allocation of large commercial and industrial customers.

BARRIER 4:

Market access, measurement, and validation

In several European markets, only large generators have access to balancing markets. Consequently, small loads and generators are not eligible to provide FCR and a FRR. Driven by the EU Energy Efficiency Directive and EC's electricity balancing guidelines, these barriers are currently being removed. Nevertheless, the question remains, how the contribution of an aggregator can be measured and validated, when considering the aggregation of large numbers of small batteries. This should be specified by the Transmission System Operator.
A basic requirement will be an electricity meter in the wallbox.

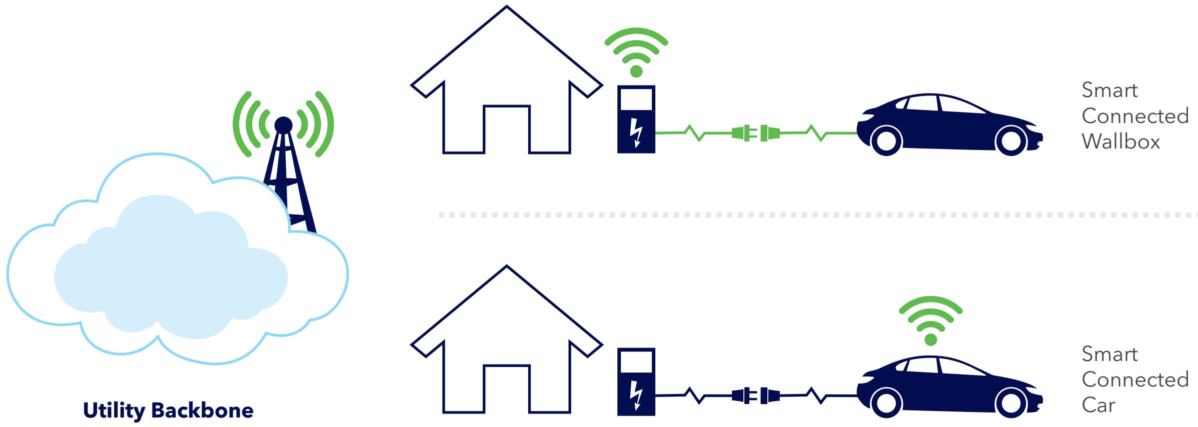


Figure 5. Connectivity options for alternative use.

Technology

Battery developments

Price reduction trends
Discussion of potential price declines for battery technologies is often clouded by the variety of technologies that are available in the marketplace. Each type of technology has its own price trajectory, and each of these trajectories depends on the design of the battery itself, as well as the expected future sales.

Lithium ion (Li-ion) battery cost learning rates of about 19% have recently been observed for each doubling of accumulated global capacity (source: DNV GL Energy Transition Outlook 2019). We expect this rate to continue. Therefore, with the 2019 wholesale prices of approximately 113 €/kWh for a battery pack, extrapolation places Li-ion at 53 €/kWh by 2025. This price reduction trend will result in EVs hitting price parity with an ICE equivalent from around 2023.

Costs of recycling
There are currently few organizations that can recycle Li-ion batteries. Based on recent DNV GL and accilium research the cost of recycling Li-ion batteries ranges from 1.5 to 3 €/kg. The majority of recyclers at the moment are not able to capture all of the valuable materials, but it is anticipated that their capabilities will advance substantially as the volume of batteries grows, resulting in the cost of recycling dropping further.

Third-party (dis)charging access
The alternative use concepts proposed in this paper assume that the aggregator has unhindered access to charging and discharging of the EV battery. Although control of the charging process is relatively easy to implement via a wallbox, gaining access to the battery for discharging purposes is likely to be more difficult, as it requires some degree of cooperation with OEM; e.g., the car circuitry must allow for bi-directional power flows. Furthermore, for an effective (dis)charging strategy, the state-of-charge (SOC) of the battery must be accessible by the aggregator.

Facilitating such access is a bold (and, in the view of the authors of this paper, necessary) step for OEMs. Any adverse consequences from enabling third-party access could impact the OEM's brand reputation, e.g. EV users may mistakenly blame their OEM if the battery is insufficiently charged when the vehicle is needed. It is expected that such risks would be extremely limited, as EV users would have to consent to any alternative use strategies in the first place.

For conservative OEMs however, this may be a risk that they are not willing to take. At present, very few OEMs provide access to the battery's SOC.

IT infrastructure
In the proposed business model, the utility (acting as a Supplier and Aggregator at the same time) will provide the wallbox to the customer as part of its service offering. The intelligent charging and discharging will be actuated by the wallbox upon receiving the appropriate signal from the utility. The main characteristics of the IT infrastructure are as follows:

- We assume the wallbox uses the consumer's Internet connection, as this bears no additional costs and requires a limited amount of data transfer.
- Protocols between the utility backbone and wallboxes that support smart (dis)charging are already available (e.g. Open Charge Point Protocol).
- The wallbox will determine the optimal (dis)charging strategy, based on price signals, battery SOC, and driver preferences.
- Protocols between wallboxes and EVs that support smart (dis)charging are being developed (e.g. ISO 15118), but are currently not supported by several EVs. For many EVs, the SOC cannot be determined by the wallbox, which is a vital element for enabling smart (dis)charging.
- The smart meter infrastructure is only used for settlement, not for controlling or monitoring the charging process.
- It should be possible to migrate the (dis)charging intelligence from the wallbox to a home energy management system, if this is available.

The "smart connected car" might replace the need to communicate over the wallbox altogether. Almost all EVs available today, and certainly all upcoming models, feature mobile online services that communicate SOC and allow remotely instructed charging. These services, along with the established infrastructure, could deliver the communication needs for alternative use. Communication is handled by the vehicle itself, implying use cases would not be restricted to the owner's wallbox.

Electricity infrastructure
The electricity infrastructure, in particular the household connection to the distribution network, should be able to support the (dis)charging of the EV. In Germany, a typical household connection is 3 x 63 A/43.5 kW, meaning the majority of households can incorporate EV (dis)charging without needing to upgrade their connection with the distribution grid. This may not be the case for all households in Europe, and those with smaller connections may need to upgrade their connection capacity, depending on their individual circumstances.

European standards require that EVs used in conjunction with a wallbox must have a dedicated final circuit serving the EV. Whilst the wallbox is expected to contain the necessary control and protection functions already, any location-specific devices for protection can be easily incorporated into this circuit. Should the wallbox be capable of consuming or injecting more power than safely allowed by the household's electrical installation (or country-specific regulation), the wallbox software settings should be adjusted such that (dis)charging is kept within safe limits.

Economics

A look at the German figures
In order to determine the value of using EV batteries for alternative use purposes, we calculated the potential TCO benefits based on two hypothetical EVs. The first, a 50 kWh 'medium-sized' model intended to represent a typical mid-range EV, and, second, a 100 kWh 'large' model representing the premium end of the EV market. PHEVs are excluded from this analysis as they can only provide a limited amount of flexibility. Hence a change in the PHEV:EV ratio will not invalidate the business model, provided the remaining EVs provide sufficient scale.

For our calculations we assume the following:

- The vehicle is parked at home from 6 p.m. to 6 a.m., and can be used for any one of the alternative use cases.
- The EV should be fully charged by 6 a.m.
- Utilization of the battery capacity is restricted in order to improve battery lifetime. For this reason, we set the EV SOC at between 20-80% of its original capacity.
- The EVs also charge during the day (e.g., at their owner's place of employment)
- For portfolio optimization, we assume that the utility optimizes the charging/discharging cycles of the EV against intraday market prices.
- For provision of FCR and aFRR, certain technical pre-qualification criteria must be met; e.g., offered reserve capacity must be continuously available for a specified period. Although it might not be possible to meet these criteria by aggregation of EVs alone, these requirements are not expected to be an issue as EVs are assumed to be part of the utility's larger generation portfolio.
- For provision of FCR and aFRR we assume that the EV is activated 30% of the time; optimization is performed ex-post.
- The value of storing PV energy is derived from the costs avoided from paying the retail price for energy.

Taking all assumptions into account, DNV GL's dispatch model was applied. This model can pool together various flexible energy sources (power plants, EVs, loads) into a virtual power plant, and optimize the use of this flexibility in various energy markets (intraday-, day-ahead), as well as self-balancing. Costs due to energy efficiency losses in (dis)charging are also included in the model. The economic potential of the use cases are calculated through estimating the energy produced and consumed in each scenario, and, subsequently, the revenues.

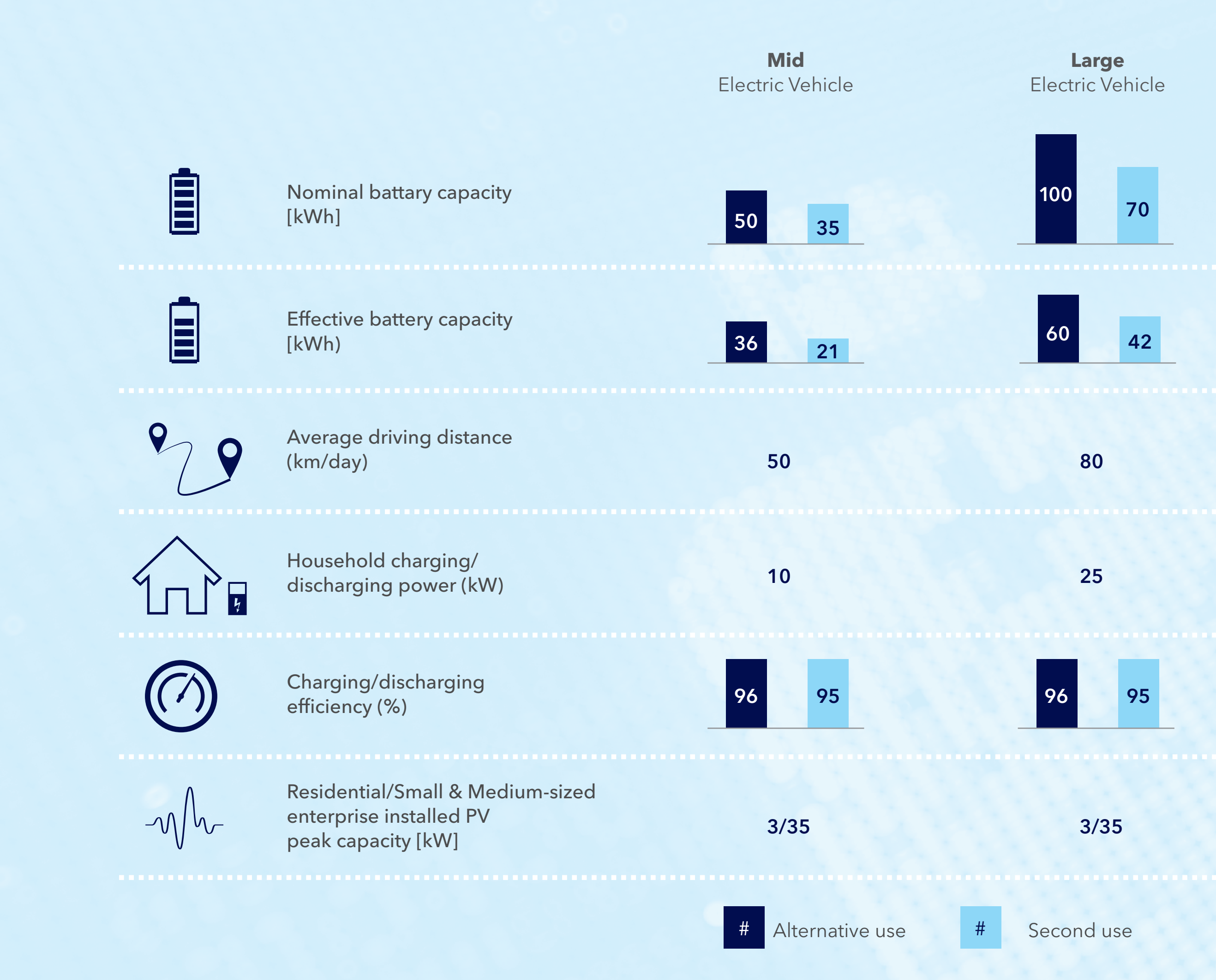


Figure 6. Business case calculation input parameters. Source: DNV GL & accilium research

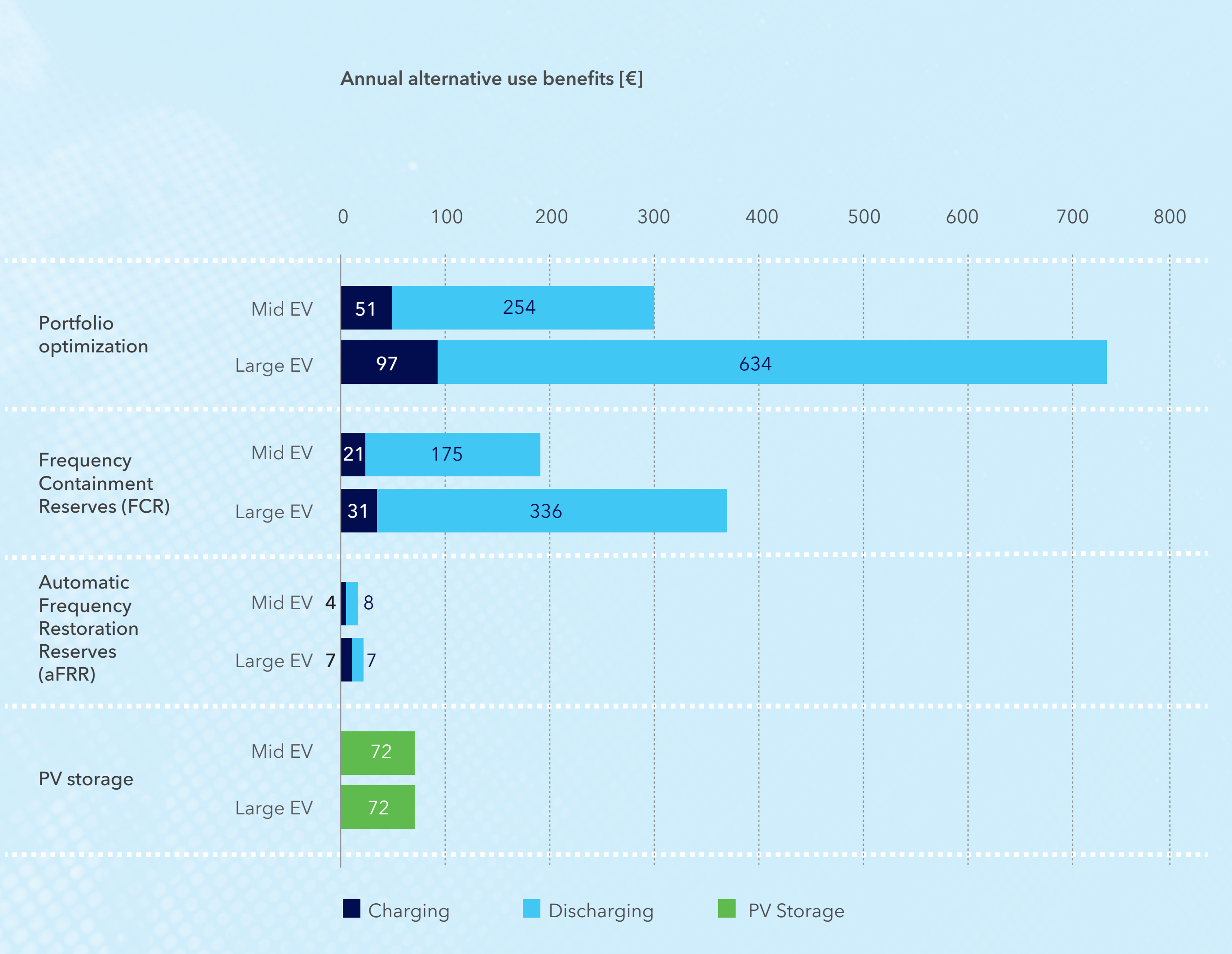


Figure 7. Annual alternative use benefits. Source: DNV GL & accilium research

Applying the concepts of alternative use for these EVs within the context of today's German market structure and using recent prices, we derived the results shown in Figure 7.

Alternative use results

The calculations show:

- Discharging capability always provides additional value compared with charging only. For FCR and aFRR this is because discharging allows for a greater capacity (kW) to be offered to the market, whilst still being able to meet the technical requirements necessary to provide these forms of power reserve. For portfolio optimization, discharging capability provides greater opportunity for arbitrage with respect to the spot price.
- The costs of energy efficiency losses (calculated against wholesale prices) are minimal.
- The large EV shows a greater benefit for all use cases compared with the mid-range EV, given its larger battery capacity and charging/discharging power.
- Portfolio optimization shows the most significant economic potential.
- Storing PV during the weekend can add extra value, and can be combined with any of the other use cases. There is no value during weekdays as EVs are not expected to be plugged in at home during the daytime, which is when there is a surplus of PV generation.

Although the calculations assume that the EV offers only one of the three alternative use services, these services are not necessarily mutually exclusive. Provided that the technical requirements needed for FCR and aFRR can be maintained, various charging strategies could be combined (e.g., portfolio optimization with PCR). Although this may mean that an individual service delivers lower benefits than shown in our results, the combination of services offered may lead to a greater benefit overall. Charging strategies (and hence overall financial benefit) would also be influenced by the EV owner's preference regarding whether the EV must be fully charged in the morning. However, finding the optimum charging strategy must also consider the impact on battery degradation.

Battery degradation due to alternative use
The alternative use cases show that varying amounts of extra revenue are possible through using the battery for different services. However, this may come at the cost of faster battery degradation. DNV GL's Battery XT model can be used to predict the lifetime of batteries based on their expected duty cycles. By comparing the degradation resulting from alternative use strategies to a baseline strategy (whereby the EV charges at full capacity upon arrival at home), we can observe the extent to which alternative use cases have an impact on battery life.

It should be noted that the results shown in Figure 8 below are based on DNV GL's Battery XT model, which is derived from laboratory testing of a range of battery chemistries, the latest EV batteries may achieve lower levels of degradation compared with the average results shown.

> Selecting an ideal charging and discharging strategy will be key

The results of the battery degradation model show:

- In comparison with the baseline battery loss, only the portfolio optimization (dis)charging use case shows significantly more degradation. This is mainly due to the large swings in the battery SOC that occur as a result of the frequent charging and discharging at maximum power in this strategy. The aFRR dis(charging) case is hardly affected, as the balancing power is activated far less frequently.
- The "charging only" use cases have a slightly positive effect, as the charging process is spread out over longer periods during the night.

The optimal (dis)charging strategy must take into account both market prices and battery degradation. The battery degradation results presented have been derived on the basis of a (dis)charging strategy that maximizes economic benefit. An alternative charging strategy could be one that preserves battery life by activating a given strategy only when there is high volatility in the markets.

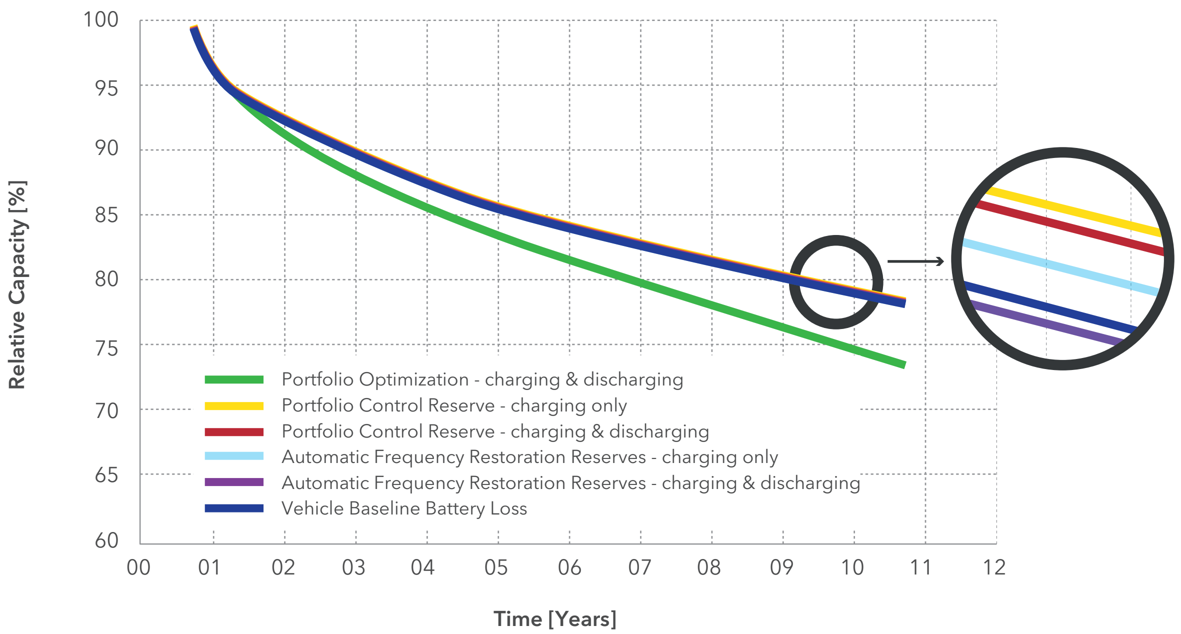


Figure 8. Battery degradation due to alternative use. Source: DNV GL & accilium research

Further improvements to the business case

OPPORTUNITY 1:

Market price development

The value of Demand Response is driven strongly by the volatility of the spot and balancing market prices. Several factors may suggest an increase in price volatility up to 2025:

- An increase in Renewable Energy Sources (RES) (PV + wind) with no marginal cost
- Phasing out of flexible gas-fired power plants

On the other hand, there are drivers that may mitigate a significant increase in price volatility:

- Improved capabilities towards the prognosis of RES feed-in (particularly wind)
- Increased cross-border connection capacities & European market integration
- Implementation of a capacity market
- Competing demand-side resources

General expectations are, however, that both volatility in spot market prices and the imbalance volumes and prices will increase up to 2025 (and beyond). Therefore, in comparison with the results presented, which are based on historic market prices, a significant increase in the value of alternative use can be expected.

OPPORTUNITY 2:

Smart charging during the day

The value of alternative use can be roughly doubled if alternative use can be applied during the day. However, as the utility owning the battery does not necessarily supply the electricity at the charging point used during the day, this leads to difficulties with the current market design, as explained in the *Market* section earlier.

OPPORTUNITY 3:

Emerging markets

New markets are currently being discussed, where demand-side resources can play a significant role, thus increasing the value of alternative and second use.

- **Local Capacity Markets**
  An additional earning model may emerge after 2021, by when the new directive on electricity market design needs to be implemented in each EU member state, leading to more explicit system optimization obligations at distribution system operator (DSO) level. Cost-benefit analyses show that the value of Demand Response for local capacity management is comparable to the value for optimizing the energy markets.
- **National Capacity Markets**
  National capacity markets are currently the subject of considerable discussion within Europe. This is in response to the expected generation inadequacy due to the high share of renewables.
- **Congestion on High Voltage Level**
  In more and more areas congestion occurs (or is anticipated) at high voltage level. Congestion management is permitted as a temporary measure. When allowed, demand-side flexibility can also participate in this market.
- **Connection Optimization (Transportation and Distribution Costs)**
  The peak consumption behind a connection can be reduced, thus decreasing the distribution costs that are based on the capacity of the connection. This may be relevant for residential households, but holds even greater promise for commercial buildings.

BATTERY SECOND USE

EVs (including the EV battery) have an expected lifetime of 8 to 10 years. Today, guarantees from the OEMs include a certain amount of km driven, or a certain amount of years; whichever is reached first (e.g. 160,000 km or eight years). An EV battery is considered to be at its "end of life" when its remaining capacity is 70-80% of its nominal capacity. When this point has been reached, it is considered insufficient for automotive purposes, due to high performance requirements, but it is still suitable for a range of other applications. Since the recycling costs of Li-ion batteries are relatively high (the costs for recycling exceed the value of recovered raw materials), OEMs are seeking applications that give the used battery packs a "second use", provided that they can offload the recycling obligation.

A second use market enables the new owner of the battery to tap the potential from its residual value. The battery pack can be utilized for either home applications (PV storage, emergency power supply) or to perform the same use cases as alternative uses. Given that the battery pack is no longer located in the EV, the use cases can be performed 24/7.

Making batteries fit for second use

While alternative uses can be established by providing suitable infrastructure, software, and services, the viability of second use applications depends on the design of the battery packs.

Formerly, battery packs were adjusted to fit existing ICE platforms and therefore resulted in awkward shapes, barely usable for dismantling and reusage. More and more vehicle manufacturers are building their EVs on platforms built exclusively for electric vehicles such as the modular electric drive matrix (MEB) by Volkswagen. With the development of such platforms the design of the battery packs is much more dismantling friendly and makes a reuse of battery packs more likely.

For second use, it is critical to be able to determine the battery's state of health (SoH). In order to understand its future lifetime, its past and future duty cycles must be known, or at least estimated. Based on historical records of duty cycles, the SoH of the battery can be determined. An algorithm that can estimate the current SoH of a battery and predict its remaining lifetime (such as the DNV GL battery XT model) should be built into future battery management systems.

Economics

Two factors will determine whether second use batteries can be an economically viable option:

1. The residual value must be positive
2. Second use batteries must compete with new stationary storage batteries on cost

The residual value of the second use battery is the total achievable benefits over the lifetime of the system, minus all the costs incurred such as retrofitting, installation, and recycling.

Investing in stationary storage for households and small and medium sized enterprise (SME) makes most sense if bundled with a PV system. Combination with additional use cases increases utilization and improves the business case. SMEs are interesting as they are likely to have installed more PV generation capacity than an average household, and because an EV is capable of storing more energy than can be generated per day by the PV installation of an average household.

The benefits from second use can be calculated by the different services provided. We expect that a large amount of flexibility will compete on the different energy markets after 2025, leading to price erosion, especially on the (relatively small) balancing market. Our calculations therefore focus on portfolio optimization, which is a far larger market, and on PV storage.

Based on the results illustrated in Figure 9, benefits for the utility can be realized when the applications of portfolio optimization and PV storage are combined. Both the benefits of the medium and large batteries at households and SMEs are limited by the size of the PV system. In all cases, the battery capacity is hugely oversized for the PV system. Portfolio optimization, on the other hand, scales in relation to battery size.

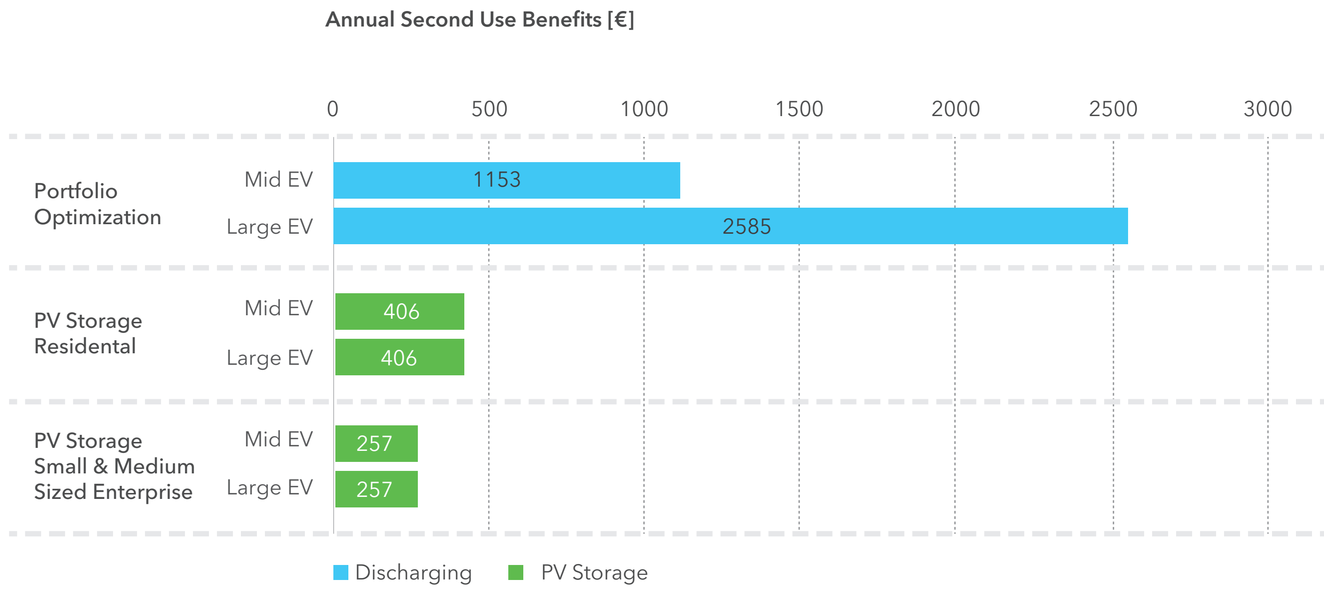


Figure 9. Annual second use benefits. Source: DNV GL & accilium research

Costs and benefits of reusing batteries

Several activities are needed to place a used EV battery in this new application:

- EV collection (battery dismantling, visual battery pack inspection)
- SoH measurement or appraisal
- Repackaging or refurbishing of batteries
- Adding a converter and an energy management system to control the charging and discharging of the battery in the new application
- Transfer of all recycling obligations and other legal issues, like warranty, transport, and installation

The costs of retrofitting can be a showstopper for battery reuse. A case for second use can only be made if the entire system can be reused, by avoiding the need to replace the battery management system. The lifetime of the second use battery can be safely assumed at 5 years. As the benefits for PV storage remain with the household or SME where the storage is installed, the utility can charge an additional user fee of 900 €.

Figure 10 shows the business case for the utility for a large battery (with an effective size of 42 kWh), which is installed for second use at an SME site.

Taking these costs and the expected lifetime of the battery as 5 years in the second use application, the benefits for the utility company of the second use case, as shown in Figure 10, will be around 7700 €/battery for large battery systems.

In this model, consumers (SMEs) earn about 1200 € over 5 years from PV self-consumption. During this period they have to pay 900 € customer fee as a rent for the battery. This results in a profit of 300 € (net present value) for the consumers in 5 years. Figure 10 shows the business model of the utility, not the business case for the consumer, while these numbers show that it is an attractive proposition for the utility, there is also a moderate benefit for the consumer.

Figure 10. Business case for the utility with a second use battery. Remaining lifetime of the battery is 5 years.

Compete against new batteries

New stationary storage systems can perform the same use cases. The higher investment cost per new storage unit will be partly offset by:

- Decreasing battery prices (a substantial price reduction can be assumed until second use batteries become available)
- Especially designed application for stationary storage and batery chemistry optimized for this use case
- No retrofitting costs
- Overall longer lifetime
- Lower recycling costs

Figure 11 shows the business case for the utility for a large battery with 42 kWh effective battery size, and that is installed at an SME site.

Taking these costs and the expected lifetime of the battery as 15 years in the new battery application into account, the benefits for the utility will be around 8000 €/battery for large battery systems.

These results highlight that there are clear benefits for both the second use and new battery system, and that the value of the alternative approaches are very similar. In this case the new battery option is slightly more valuable; however, the benefit of second use batteries is that the revenue is generated in 5 years instead of 15 years. In an energy market that is making a transition, it can be valuable to earn your money in the shortest time frame.

It should also be noted that the results are relatively sensitive to the assumptions; for example, just a small increase in the lifetime of the second use battery to 6 years would result in an increase in value of more than 2200 €, or over 20% more valuable than the new battery system.

In our example the second use battery has reached its end of life in the vehicle with a SoH of 70%. Today most second use batteries come from battery pack recalls or malfunctional battery packs. In most recall cases the batteries are still relatively new (SoH >90%), but there is something wrong with the power electronics, software or something else that is not related to the battery cells. However, to recall batteries is hardly scalable and therefore probably not worthwhile pursuing.

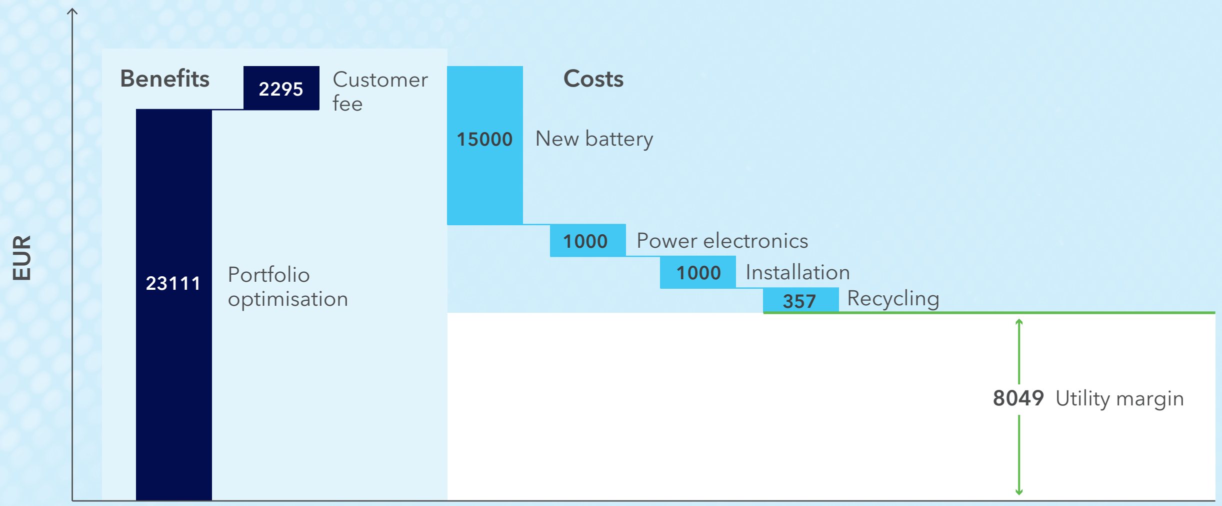


Figure 11. Business case for the utility with a new battery. Lifetime of the battery is 15 years.

IMPACT ON THE BUSINESS MODEL

With the potential of the concept presented, the question remains of how to best capitalize on these opportunities for OEMs and utilities. Alternative and second use, once implemented, could unlock a further set of new opportunities for OEMs and utilities, whilst providing the customer with a superior overall solution.

Separate ownership of the battery and the vehicle

Buying an EV but having only a lease contract for the battery is not an entirely new paradigm. The former EV company Better Place pioneered the model of separating ownership of the EV and the battery pack leading to the implementation of similar models at several OEMs. The idea was that if the leasing rates reflect only the actual degradation incurred by the customer's use of the vehicle (or value lost during the period of usage) an absolute TCO benefit exists for the EV customer. Eventually Better Place failed with this model and almost every OEM, which formerly adapted a separate ownership model, is no longer pursuing it.

Despite the expiring model of OEMs owning the battery, bringing a utility partner into the equation can reactivate separate ownership. Additionally, alternative and second use concepts add several more aspects to a shared ownership model. As the customer does not own the battery in the first place, the task of reclaiming the residual value of the battery lies with the utility, which can do it much more efficiently and provide a possible second use. Ownership might also extend to the energy content in the battery. Secondly, customer anxiety over battery degradation through alternative use will be eliminated, provided that the leasing contract guarantees a minimum SoH level for the battery.

OEM and utility partnership – selling a solution together

With the utility taking ownership of the battery, new possibilities emerge for selling an e-mobility solution together with the OEM.

- Installation of wallboxes in customer premises can be handled, or at least coordinated, by the utilities.

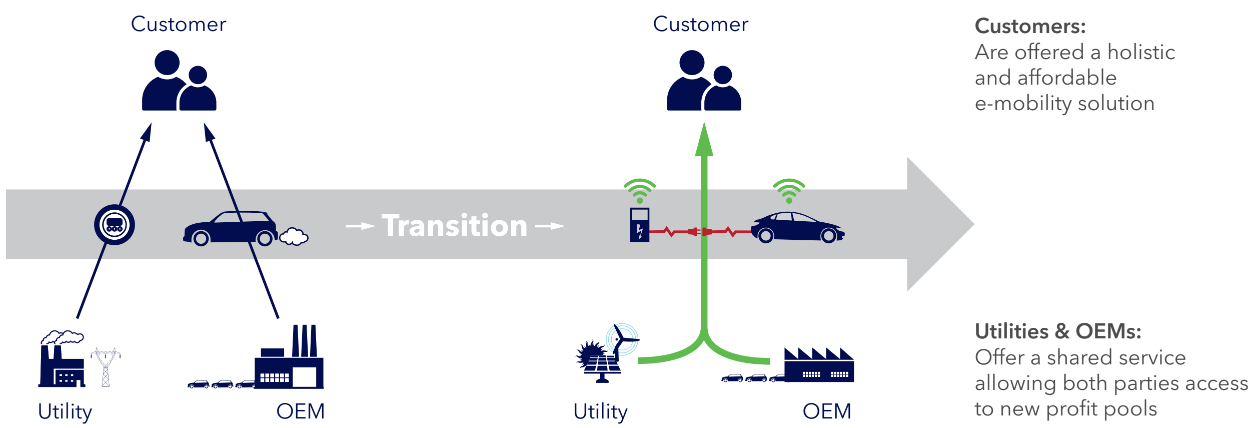


Figure 12. Business model transition.

- The customer's energy contract will include access to roaming agreements with several national or even transnational utilities, allowing the EV owner to charge in public and semi-public locations more easily.

- Offering a dense network of charging stations will be a key element for EV adoption. With the EV batteries owned by the utility, they are then incentivized to establish more charging stations to access the batteries' capacity during every hour of the day as the business case to install chargers improves.

Benefits for the customer

A joint OEM-utility service proposition will provide customers with a comprehensive 'one-stop shop' e-mobility solution. Such an offering is not only economically enticing, but also eliminates many of the reservations facing prospective EV buyers today.

Not only will customers benefit financially from a lower upfront cost for the EV itself, but a battery-leasing contract will ensure that they pay only for their fair share of usage costs. The battery-leasing contract itself can be just one component within a more comprehensive energy contract. Such an energy contract could also incorporate financial rewards for making alternative use available (with rewards varying depending on the amount of flexibility offered by the consumer). It is not inconceivable that customers could also benefit from a discount on the retail price for the electricity supply to their household premises should they choose the aggregator to be their electricity supplier as well.

Both public and private charging will be hassle-free. The installation of an appropriate wallbox at home could be included as part of the package, with the (rental or purchase) cost of the wallbox itself being paid for as part of the energy contract. With roaming agreements in place as part of the same contract, and expected developments in standardization of payment processes amongst different suppliers, the customer would benefit from a simple, uniform payment process, regardless of where they charge. Further financial benefits could result from charging at charging stations operated by the customer's electricity supplier of choice.

Benefits for the utility

Electric mobility will be the major contributor towards countering declining energy sales. Moreover, e-mobility provides a utility with ample possibilities for developing an energy service portfolio. An energy service contract would not only encompass an energy contract for the home connection, but also a lease contract for the battery. The energy provider will be able to lock customers effectively into contracts for energy delivery for the duration of the battery's automotive lifecycle. In addition, an energy service can be provided by (dis)charging the battery according to the customer's demands. This would remove the need for feed-in tariffs, although some legal obstructions may exist for this concept.

If the second use application involves the battery being within a customer's home, this would further extend the energy service offering. The homeowner could lease a storage facility for their PV-produced energy, but still allow the utility to exploit the battery for alternative uses. This concept allows the utility company to provide services to customers, even if they are largely self-sufficient in their energy needs.

Through this model, the supplier is also able to offer grid support to the DSO, a concept that is common practice in, for example, the USA. As stipulated by the new EU directive on electricity market design, it is expected that this concept will be stimulated by individual Member States by 2022. Through this model, the supplier is also able to participate in a future national capacity market, a concept that is widely discussed in the EU and one that has already been implemented in a few EU countries.

A portfolio of EVs and grid-connected second use batteries is likely to have significant value on this market. In the long-term, EVs might be able to offset substantial investment costs in the grid infrastructure for utilities.

Benefits for the OEM

The automotive industry (especially OEMs) will also profit from alternative and second use. Selling more EVs will play a vital role regarding compliance with CO_2 fleet targets enacted by governments in most countries. In the automotive industry, the fleet targets cannot be achieved without a partial (plug-in hybrid) or full electrification of the vehicle's drivetrain. Increased EV sales will lower overall fleet consumption, which is mandatory by 2020. A possibility would be to accept monetary penalties for each ICE vehicle sold. OEMs can increase their brand value through establishing a green image when offering EVs, and strengthen their role as an innovative company in the automotive industry.

SUMMARY AND CONCLUSION – A NEED FOR CLOSER COLLABORATION

It is apparent, that the automotive and the energy industry are confronted with disruptive trends, that will over the next decade change the business models in both industries significantly.

Whilst the energy industry's major trend is decentralization, a major trend in the automotive sector is electrification. As shown in this paper, both trends merge at the end customer whose energy storage capabilities will grow significantly when EVs will be mature enough to serve the mass markets.

Both trends are currently still in their beginning but in the mid-term, they will change the way OEMS and utilities will be able to generate business. As we tried to show in this paper, cooperation between utilities and OEMs can be beneficial for both sides in order to manage the transition smoothly and use the core competences of both partners in the most effective and efficient way.

In that sense, we have explored in this paper several aspects concerning alternative and second use for EV batteries. According to our calculations, alternative use proves promising and the technical barriers to overcome are surmountable.

There is no way around smart charging. The current and future electricity infrastructure will be unable to bear the load of charging hundreds of thousands of EVs if not managed, but this will not be an issue if smart charging strategies are in place. And with smart charging unavoidable, why not reap the benefits of discharging, if the technology and infrastructure are already implemented?

Our calculations show that the corresponding values are sufficiently interesting that this opportunity should be pursued further. When discharging functionality is present, individual alternative use case benefits vary between 100 and 700 €/year, with minimal impact on battery degradation for the majority of use cases. Our calculations also show that a positive business case can be created when the batteries are deployed in a second use application, which will increase the residual value of batteries after their first use – thus improving the TCO of the EV.

It should be noted that these values have been calculated specifically for the German situation; the optimal smart charging strategy is likely to be country-specific (and even region-specific).

In addition to alternative use, the utilization of the residual value of second use batteries could be an interesting business opportunity for utilities. No question there will be a market for stationary battery storage, especially at households and small and medium sized enterprise with PV installations. According to our calculations, second use batteries could very well compete with new battery systems. However, due to the long time until a second use market would materialize (one vehicle generation lifetime) and the multitude of influencing factors that could make or break the business case, the potential for second use batteries remains uncertain. In conjunction with alternative use and battery ownership by the utilities, it makes sense to invest in second use to retain the option to pursue this concept once the market emerges.

Recommended action

The relatively low number of EV owners at present means that a business model based on utilizing EVs to offer flexibility to different markets is currently of limited interest to OEMs and utilities alike. For utilities, low EV numbers also imply little potential for additional revenues arising from the supply of energy to these EVs. Consequently, it is easy to dismiss the ideas proposed in this paper as something to consider in the future. This should not be the case.

Many European countries have ambitious targets for EV adoption, with various incentives in place to encourage sales.

This is spurring the market development and we already observe a growing share of EVs being delivered to the customers. Also with regard to the energy market, although the value of flexibility may still be low today and varying per country, it is set to rise in the coming years as countries install increasing amounts of variable renewable generation.

We therefore recommend:

- To evaluate the depicted trends thoroughly with regard to their effect on the individual business model
- To act proactively and investigate how cross industrial partnerships could improve the individual position in a changing environment

Effective collaboration between market parties today will be vital in order to reap maximum benefits in the future.

It will be essential to be able to offer customers a comprehensive service and this can only be achieved by some form of alliance being created between the OEM and the utility. Instead of selling EVs and energy contracts separately to individuals, partnerships between OEMs and utilities could better serve customer demands by offering a service that neither of them could provide alone.

Ready? The road ahead

In the competitive worlds of energy retail and automotive industry, companies are keen to develop strong and commercially attractive propositions. In such a competitive environment, cross-divisional product combinations are a proven concept in e.g. telecom sector and known to generate fair margins. The key aspect is to setup commercial configurations that can swiftly be implemented.

In this new business model, OEMs and utilities must determine how exactly they will earn their revenue, incur their cost and manage the associated risk. They should evaluate the depicted trends thoroughly with regard to their effect on the individual business model. OEMs and utilities must act proactively and investigate how cross industrial partnerships could improve the individual position in a changing environment.

The question for future successes is not whether there will be a market for EV storage, but rather who will be in a position to capitalize on the new opportunities that will arise with a large number of EVs in the power system.

Having an overarching vision on the specifics of such a product and its implications, the combination of DNV GL and accilium is geared to guide parties in this direction.

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