BRIEFING - October 2024

Batteries on wheels

The untapped potential of EVs

Summary

EVs are virtual power plants

As Europe transitions to clean energy and zero-emission transport, electric vehicles (EVs) are emerging as 'batteries on wheels' with the potential to revolutionise our energy system. A new study by the Fraunhofer Institute reveals how bidirectional charging could transform EVs into 'virtual power plants', delivering substantial economic benefits.

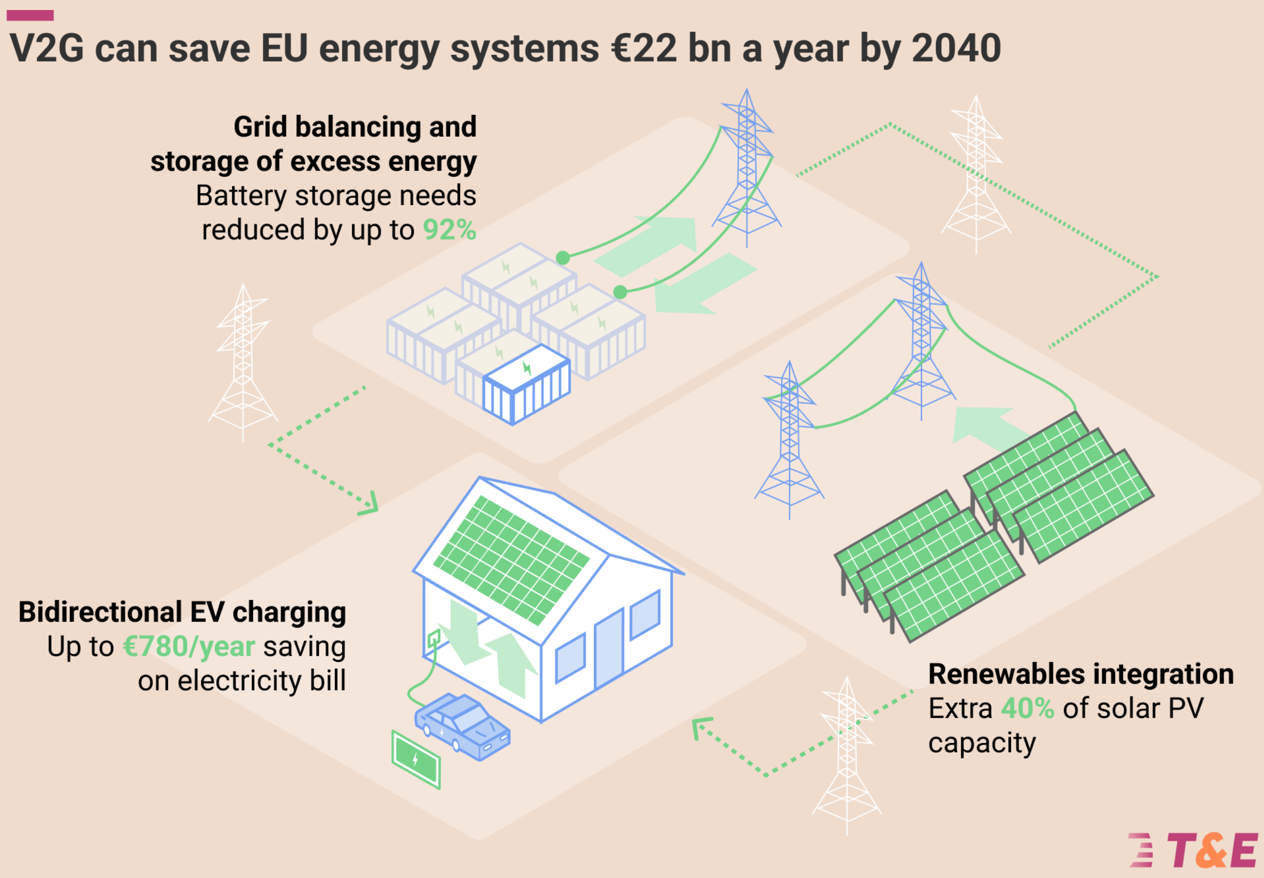

Figure 1: Total energy system cost savings

Key Findings:

1. Massive energy system savings: By 2040, widespread adoption of bidirectional charging could **reduce annual energy system costs** across the EU, by **8.6%**, amounting to **€22.2 billion** in savings per year. Even by 2030, savings of 5.5% or €9.7 billion annually are projected. **Total savings** between 2030 and 2040 could amount

to **€175.45 billion** - which is almost the entire EU budget for 2023[1]. Those saving stem from a reduction of generation capacity, reduction of curtailment as well as reduced fuel consumption.

2. EVs as a major power resource by 2040: EVs could **contribute** up to **9% of Europe's annual power supply**, becoming the **4th largest power supplier**. During peak demand periods, EVs could supply **15-20% of instantaneous electricity demand**, acting as a massive, distributed virtual power plant.
3. Boosting renewable energy integration: bidirectional charging could enable an additional **430 GW of solar PV capacity by 2040**, nearly doubling the current EU capacity.
4. Reduced storage needs: the need for **stationary battery storage could be cut** by up **92% in 2040**, while **backup power plant capacity** could be **reduced by 126 GW**.
5. EV drivers could save between **4-52% on annual electricity bills**, with savings ranging from **€31 to €780 per year**, depending on factors such as location, solar PV ownership, and vehicle battery size - this does not even include V2G services.
6. Grid impact: while bidirectional charging offers **positive effects** on the low voltage grid, the impact is modest. Potential **savings in grid expansion costs** could reach **€9.8 billion by 2040**, but this technology should not be seen as a substitute for necessary grid reinforcement and expansion.
7. Battery life considerations contrary to common concerns, **bidirectional charging can extend EV battery lifetime by up to 9%** compared to standard charging practices.

However, while the benefits are huge the potential is not fully captured today. Not all electric vehicles are V2X capable. Crucially, there are important **interoperability challenges** as current focus on either AC or DC bidirectional charging by different manufacturers poses a significant barrier to widespread adoption. Ensuring interoperability between all EVs and chargers - by mandating bidirectional capability as a standard at EU level - is crucial for realizing the full potential of bidirectional charging technology.

By leveraging the full potential of electric vehicles as 'batteries on wheels', Europe can significantly reduce energy system costs, enhance grid stability, and accelerate the transition to renewable energy. This approach aligns perfectly with the EU's climate and energy goals, offering a win-win solution for consumers, the energy sector, and the environment.

[1]Council of the EU (2023). EU budget for 2023. Retrieved from Link.

1. Introduction

As Europe accelerates its transition to clean energy and zero-emission transport, a powerful enabler is parked in our driveways. Electric vehicles are not just the cleaner way to travel - they are 'batteries on wheels' with the potential to revolutionise Europe's energy system.

The key to this is to enable all EVs to charge in a smart way - shifting charging times to times when power generation is high - and to make sure they can discharge the stored energy in their batteries to power apartments, entire buildings and eventually feeding power back to the grid to compensate for peak loads.

Transport & Environment commissioned the Fraunhofer Institute for Solar Energy Systems (ISE) along with the Fraunhofer Institute for Systems and Innovation Research (ISI) to examine how bidirectional charging of vehicles could transform EVs into 'virtual power plants', accelerating our renewable energy transition and saving billions of Euros for consumers and companies alike.

2. Bidirectional charging and the power system

The study reveals substantial cost saving potentials for the European power system through the widespread adoption[2] of bidirectional charging technology. A power system reference scenario for the EU and the UK for 2030 and 2040 was modeled with EVs (cars, vans, trucks and buses) only as consumers: merely charging electricity, not functioning as a storage, nor feeding electricity back to homes or the grid. The model was then used to analyse how the reference power system would change, if bidirectional charging is widely adopted and a significant part of the EV fleet is capable of participating in V2X applications. The effects and cost saving potentials are significant.

Changes to the power system

These savings stem from various improvements and efficiencies to the reference scenario as the model swaps EVs for other costlier options. For example: the need for stationary battery storage could be reduced by up to 142 GWh compared to the reference scenario, while the required capacity of backup power plants could be cut by 126 GW. Furthermore, bidirectional charging enables more effective integration of variable renewable energy sources, particularly solar PV as the more cost effective option. By 2030 the additional installed PV capacity could amount to 121 GW, by 2040 the additional PV capacity could increase to 430 GW - this is almost twice the installed total PV capacity in the EU today[3]. In addition, while Europe needs to still massively increase its onshore wind power generation capacity, the free storage provided by

[2] This briefing only refers to the most ambitious scenario analysed where 72% of the energy demand for electric cars can be charged in a smart way and 50% in a bidirectional way. For vans, truck and busses the shares are 55% and 55% respectively.
[3] Solar Power Europe (2024). The Rise of Solar PV in the EU - key facts. Retrieved from: Link.

EVs could reduce that needed increase by more than 100 GW. The study also indicates more efficient use of existing power generation assets, leading to reduced system operational costs. Overall, a full EV integration into the EU's power system allows for a more efficient and thus cost effective power system compared to the reference scenario.

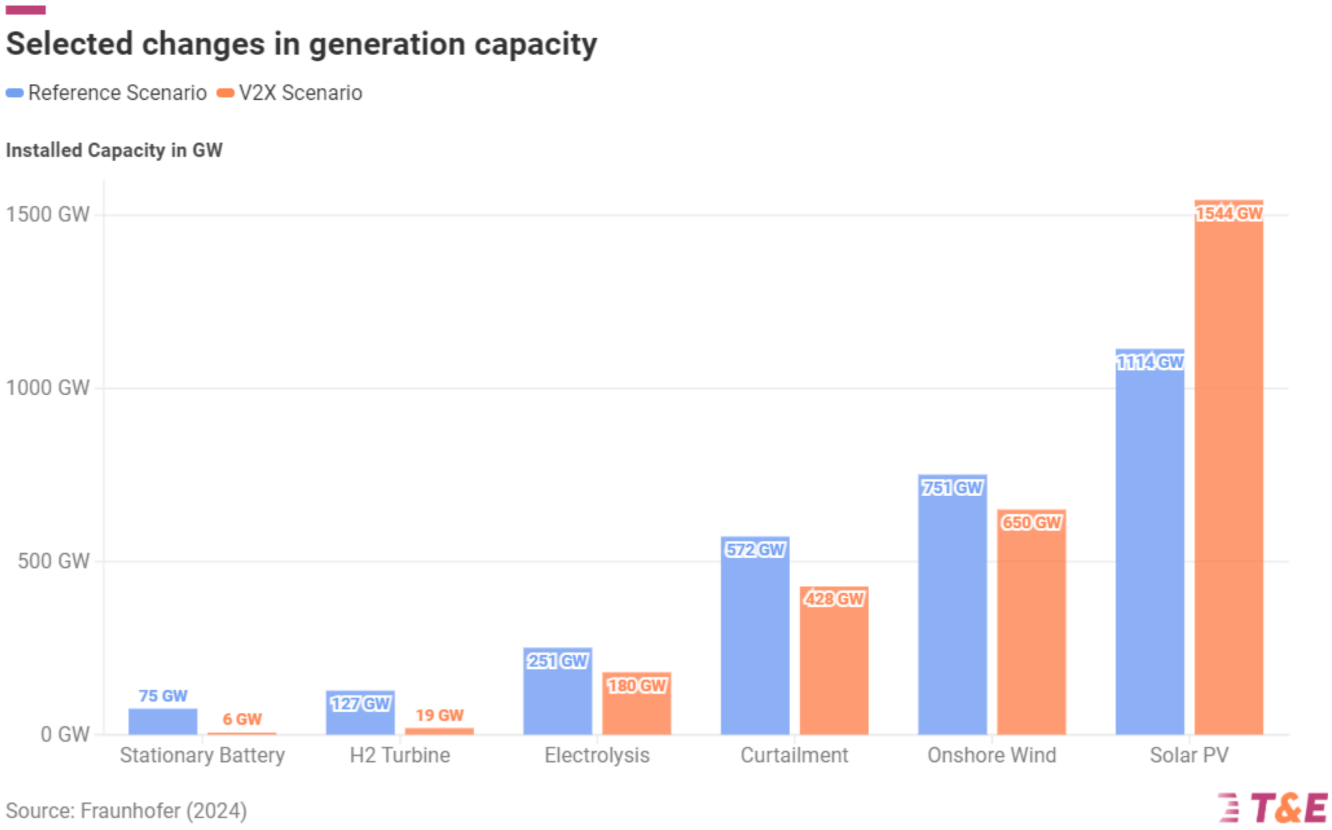

Figure 2: Selected changes in generation capacity in 2040

To illustrate what these changes in generation capacity could result in, it's interesting to look at the projected energy demand and supply. By 2040, the European electric vehicle fleet is projected to become one of the main power resources for the electricity system. Based on the study's findings, assuming widespread adoption of bidirectional charging technology, the EV fleet, through feeding energy back to the system, could potentially contribute up to 9% of the annual power supply in Europe - this would catapult EVs to become the 4th biggest overall power 'supplier'. In practical terms, this means that EVs could feed back hundreds of terawatt-hours of electricity to the grid annually, acting as a massive, distributed virtual power plant. During peak demand periods, the contribution could be even higher, potentially supplying 15-20% of the instantaneous electricity demand.

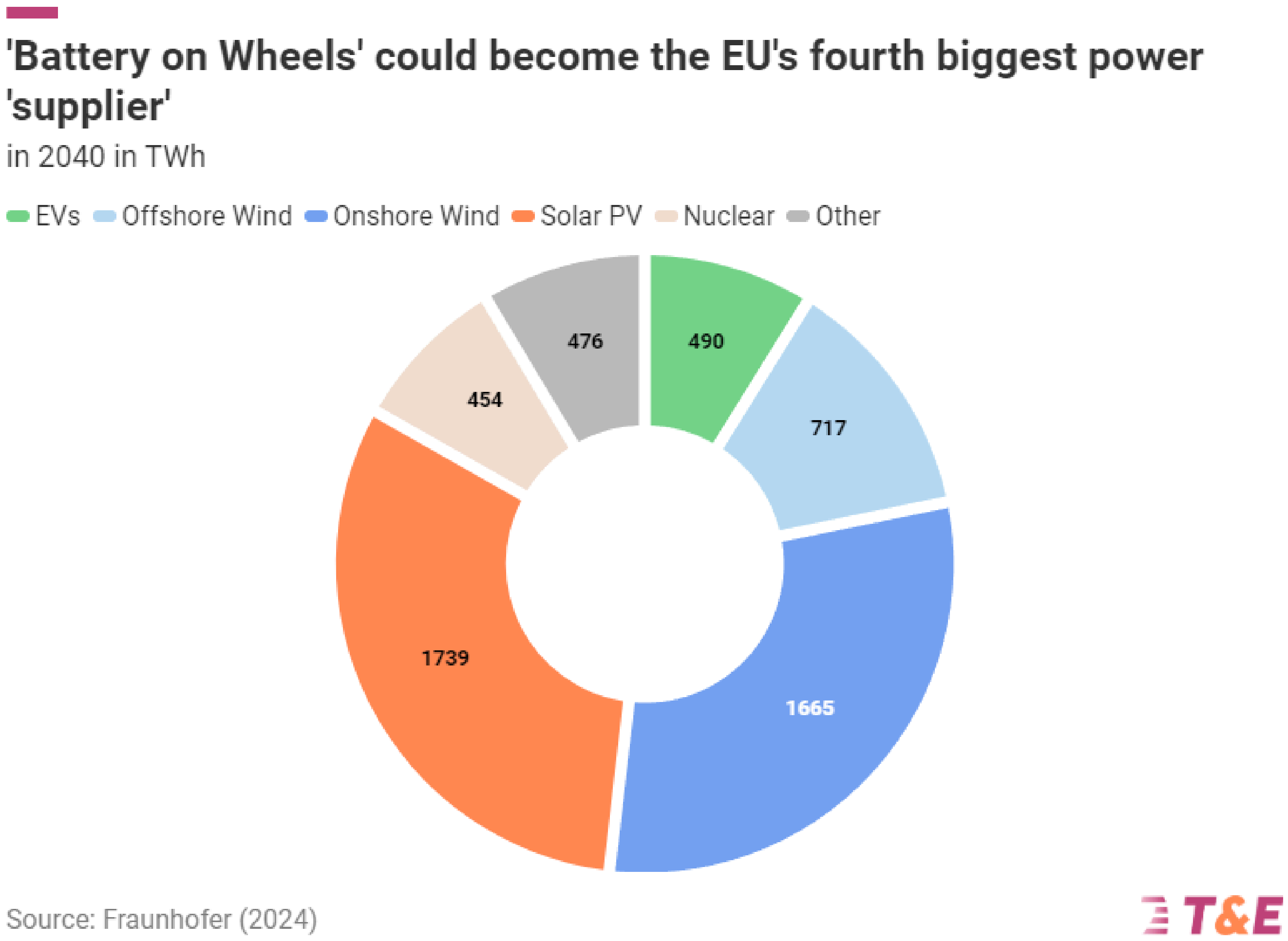

Figure 3: Power supply EVs in 2040 EU

Cost savings

These transformative changes in the generation capacity but also in terms of power supply, translate into a significant cost saving potential: in 2030 the total annual cost of the EU's power system could be reduced by 5.5% or €9.7 billion, rising to €22.2 billion in annual savings by 2040 or 8.6%. For the entire period between 2030 and 2040 this could amount to €175.54 billion which is almost equivalent to the EU's total budget in 2023.

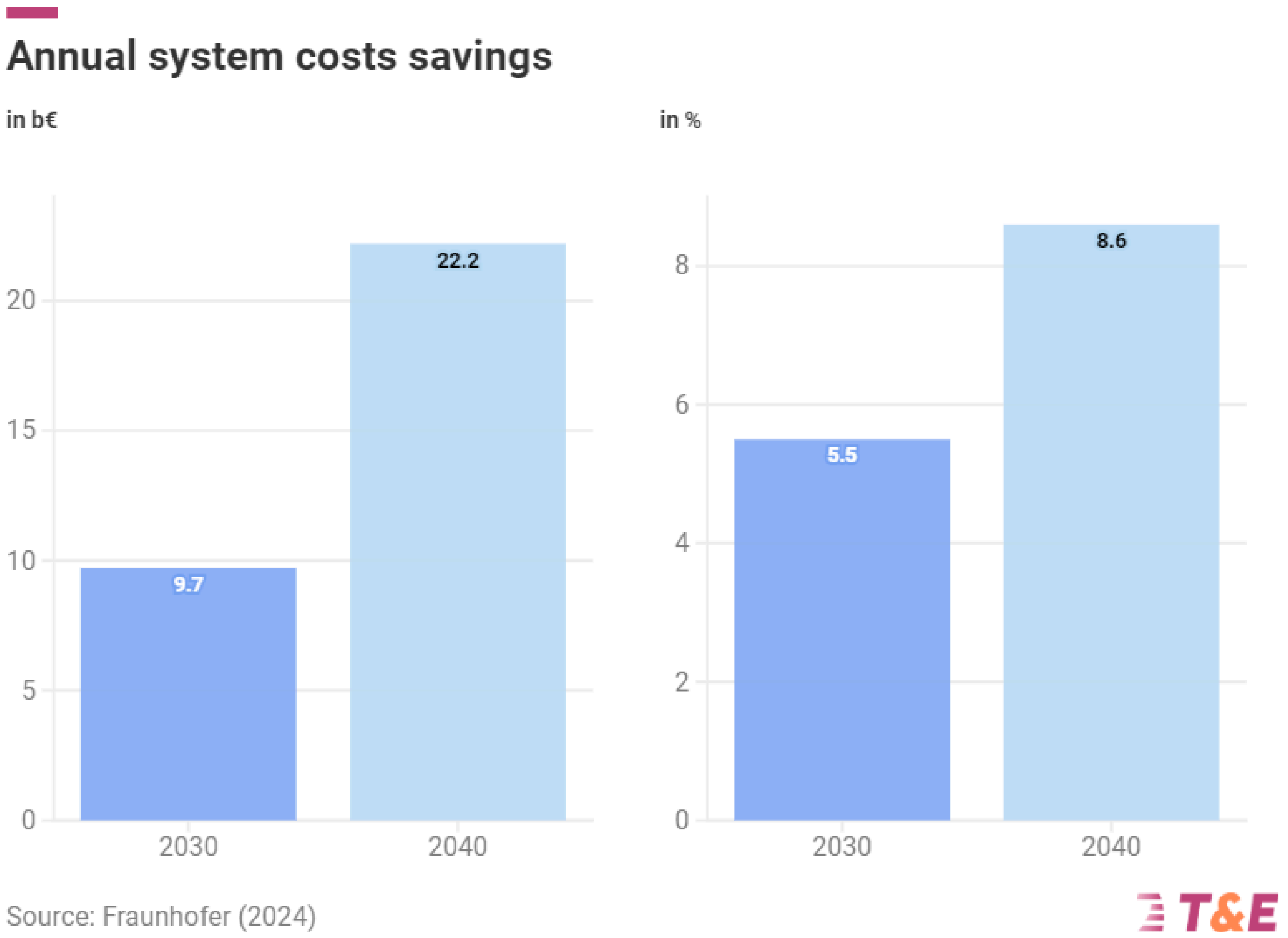

Figure 4: Annual energy system cost savings

Regional variations

The potential savings vary across Europe based on factors such as the existing power mix, renewable potential, and population density. Our study analysed the effects for Germany, France, the UK, Italy, Spain and Poland in more detail. Italy and Spain would see the highest relative profits from integration of EVs into their power systems with EVs feeding energy back to the system that could amount to 17 and 18% of the total annual electricity demand.

For Germany and France the contribution is 'only' 6% respectively; for the UK and Poland it is 3%. While not as pronounced as for countries with a very high solar PV potential, these numbers are still astonishing and cost saving estimates for all 6 countries range in the billions.

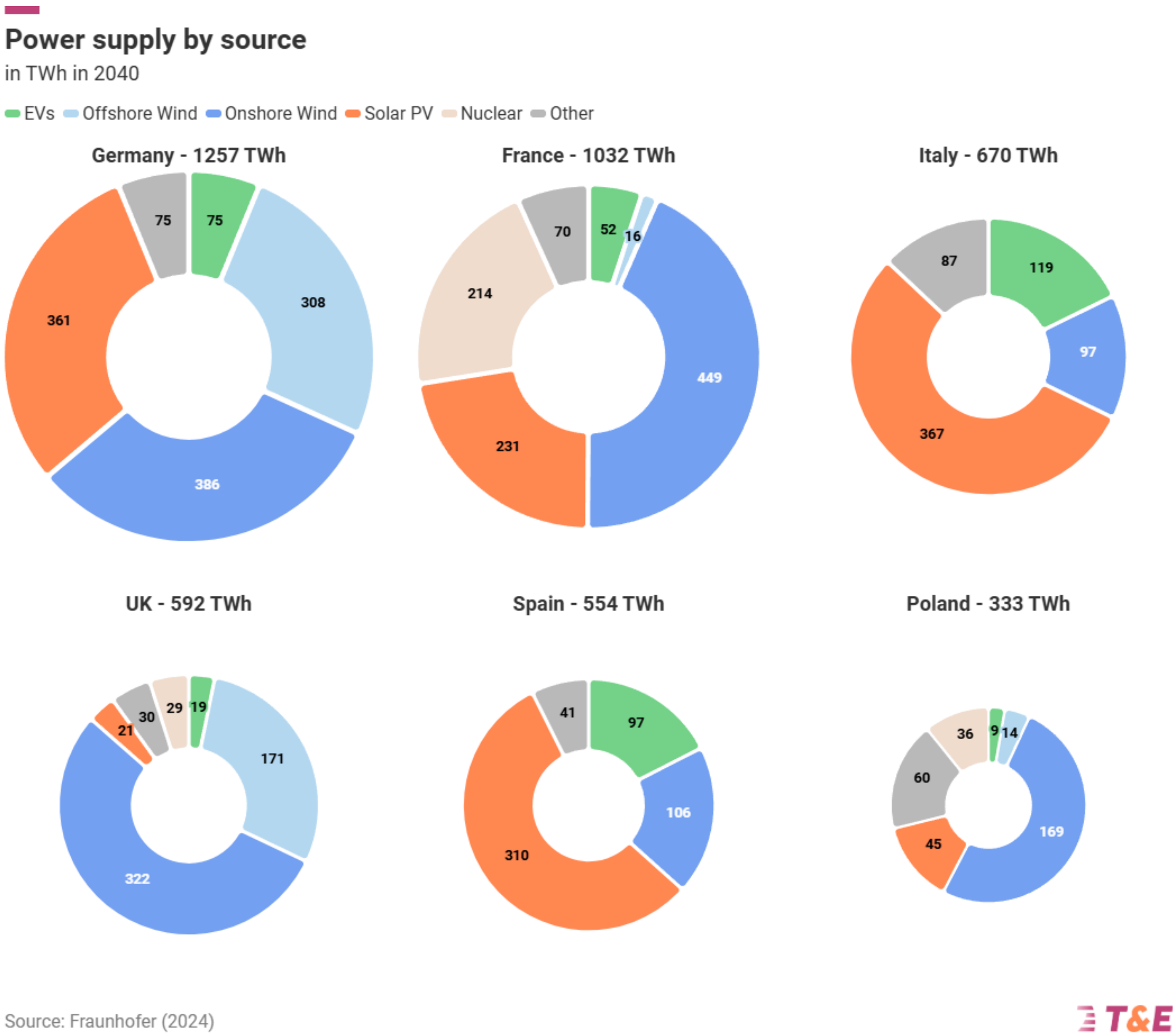

Figure 5: Power supply EVs country level in 2040

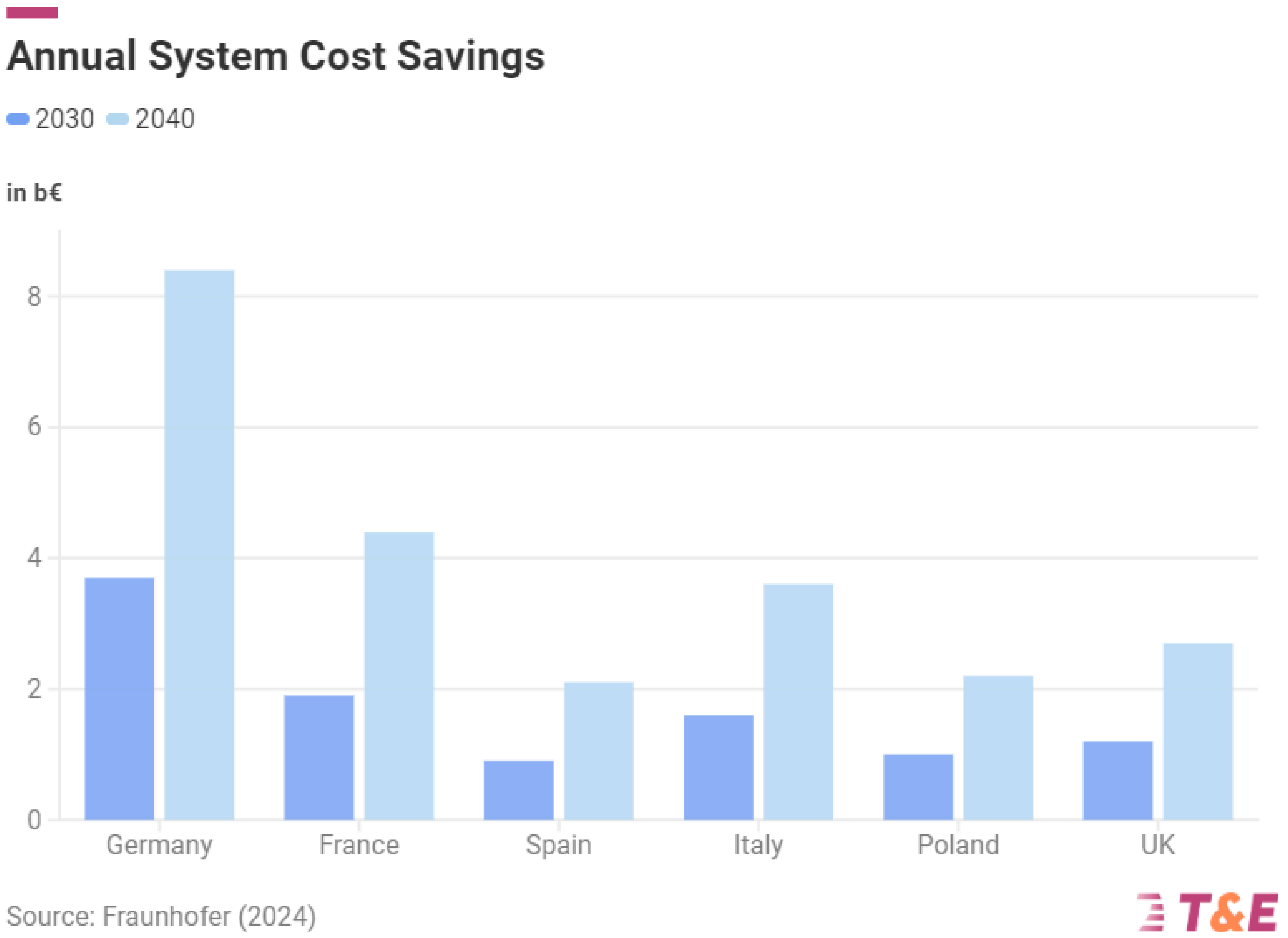

Figure 6: Annual energy system cost savings per country in 2040

3. Reduced energy bills

Through the significantly reduced cost of the energy system, bidirectional charging has the potential to lower not only the costs of utilities, but indirectly for the end consumers, whether they are big companies or small households. On top of that, smart- and bidirectional charging can reduce the final energy bill of households that have access to a private wallbox quite dramatically - even when the vehicle's battery is only used for the optimisation of own consumption and without feeding anything back to the grid - something that has been out of the scope of the study.

While virtually every EV-driver with a private wallbox will profit from using their car as a 'battery on wheels' the actual total savings are subject to the individual situation, e.g. the domestic electricity prices, the number of people in a household, or how much hours per day the EV is actually parked and plugged into the charger, whether the household has solar PV or not, and last but not the least the size of the EV's battery.

The study looked at a number of different scenarios and settings and the relative savings ranges from as little as 4% savings on the annual electricity bill for a teleworker in Spain without own solar PV and a car with a small battery (40 kWh) to as much as 52% for a teleworker in France owning a car with a big battery (100 kWh) as well as solar PV.

The total annual savings range from a minimum of roughly €31 for a teleworker in Spain owning a car with a small battery and who has no own PV to €780 for a family of four in Italy optimising their own consumption with their own solar PV and according to varying electricity prices.

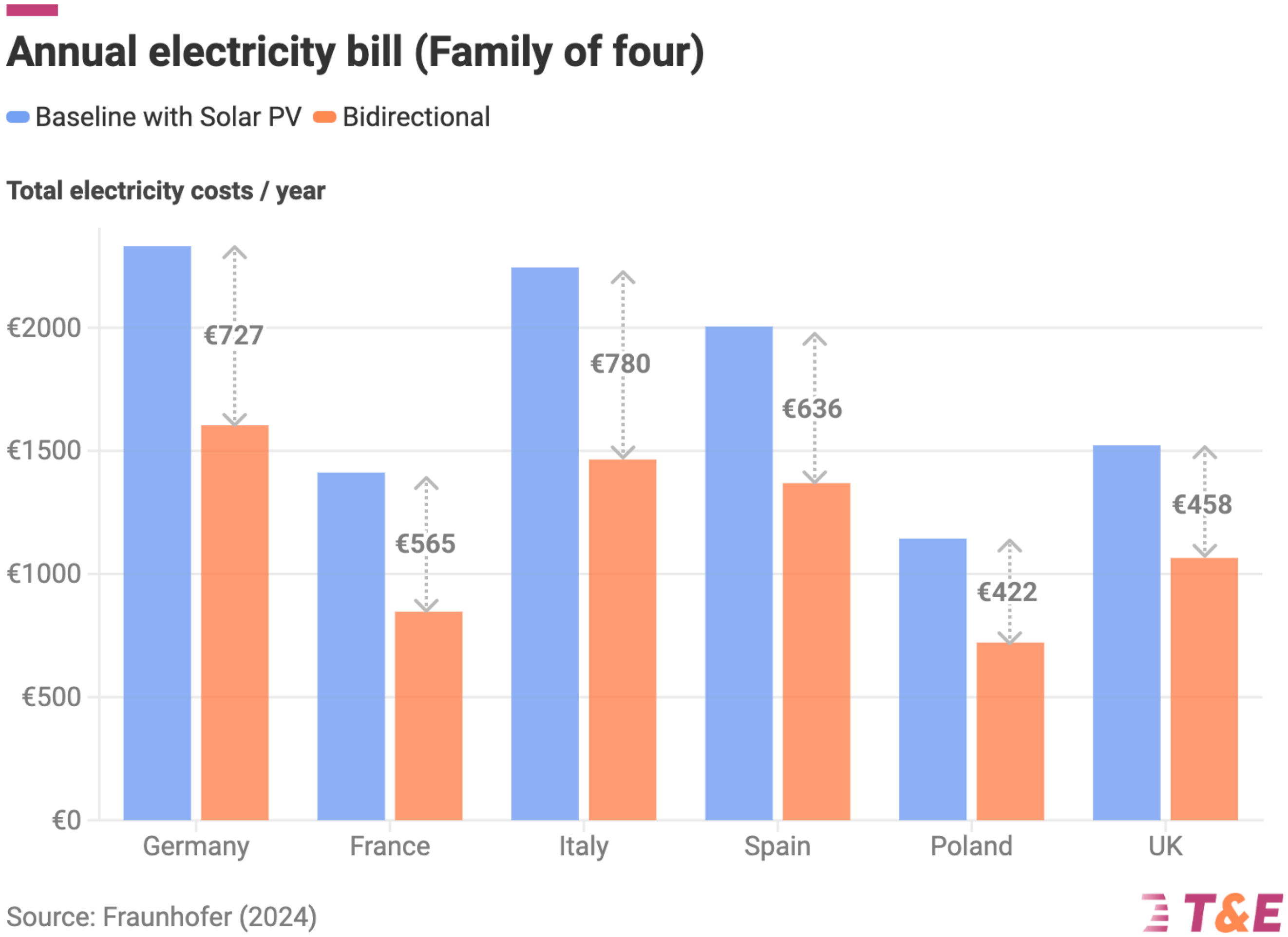

Figure 7: Annual electricity bill changes, family of four, EV with 100 kWh battery

The study did not simulate real V2G cases e.g. where cars feed electricity back to the power grid, functions as a backup storage or is engaged in frequency services. In those cases numbers of up to €1,500 savings per car and per year can be realised according to existing studies and stakeholders active in this field.

Does bidirectional charging degrade the battery more?

The short answer to that question is: no. The long answer is, that while bidirectional charging itself will inevitably add charging and discharging cycles to the EV's battery, the effects on the battery life time and capacity are negligible. Compared to how most cars are charged today however, bidirectional charging - on average - is likely to even extend battery lifetime.

For this the study looked at three different charging modes:

- Unidirectional charging (baseline): the EV is connected to the charger and is charged immediately;
- Unidirectional smart charging: the EV is charged in a smart way, responding to external signals like price, to store self generated solar power etc;
- Bidirectional charging: same as smart charging + the EV is feeding power back for own consumption and/or to the grid.

While unidirectional smart charging extends the battery lifetime by up to 11%, the positive effects of bidirectional charging is more modest, but can still extend the battery lifetime up to 9% compared to the baseline scenario. Hence, on average bidirectional charging has a positive effect on the battery lifetime.

The effects are dependent on various factors such as cell chemistry and the charging patterns. What harms the battery lifetime most is not the amount of charging cycles but is highly dependent on the state of charge (SOC). The gravest effect on battery lifetime can be expected if a vehicle's battery is repeatedly charged to 100% of its capacity - which is way within the boundaries of what OEMs today have to guarantee in terms of battery lifetime. In those cases the battery lifetime is seriously impaired. If however, the battery is only charged to a SOC of 80% the life time is extended on average by an astonishing 40%.

When it comes to the effects on the batteries capacity the study also shows that light and even strong bidirectional charging has on average a very limited effect on the battery's capacity and in many cases the capacity loss is lower than if a vehicle is charged without any charging strategy - as it is the case for the vast majority of EVs today.

4. Impacts on the grid

Bidirectional charging is often touted to be a major solution to reduce the increasing strain the energy transition is going to put on the European power grids as well as reducing the need for grid expansions and reinforcements.

Our study has thus analysed how much a bidirectional charging EV fleet could reduce the need for grid expansion at the level of the low voltage grid - the grid that connects most end consumers with the medium voltage grid. Representative grid structure clusters from Germany were used to analyse the effects on the low voltage grid and those effects were then scaled up to the entire low voltage grid network in the EU.

Grid friendly bidirectional charging has the potential to reduce grid expansion needs in the EU's low voltage grid. By 2040 the needed investment in expansion could be reduced by €9.8 bln.

While these savings are noticeable they appear rather modest when comparing them to the cost reduction potential at the energy system level.

The analysis thus shows that while bidirectional charging has a positive impact on the low voltage grid it is most likely not a substitute to ramp up grid investment and accelerate the speed of grid reinforcement and expansion.

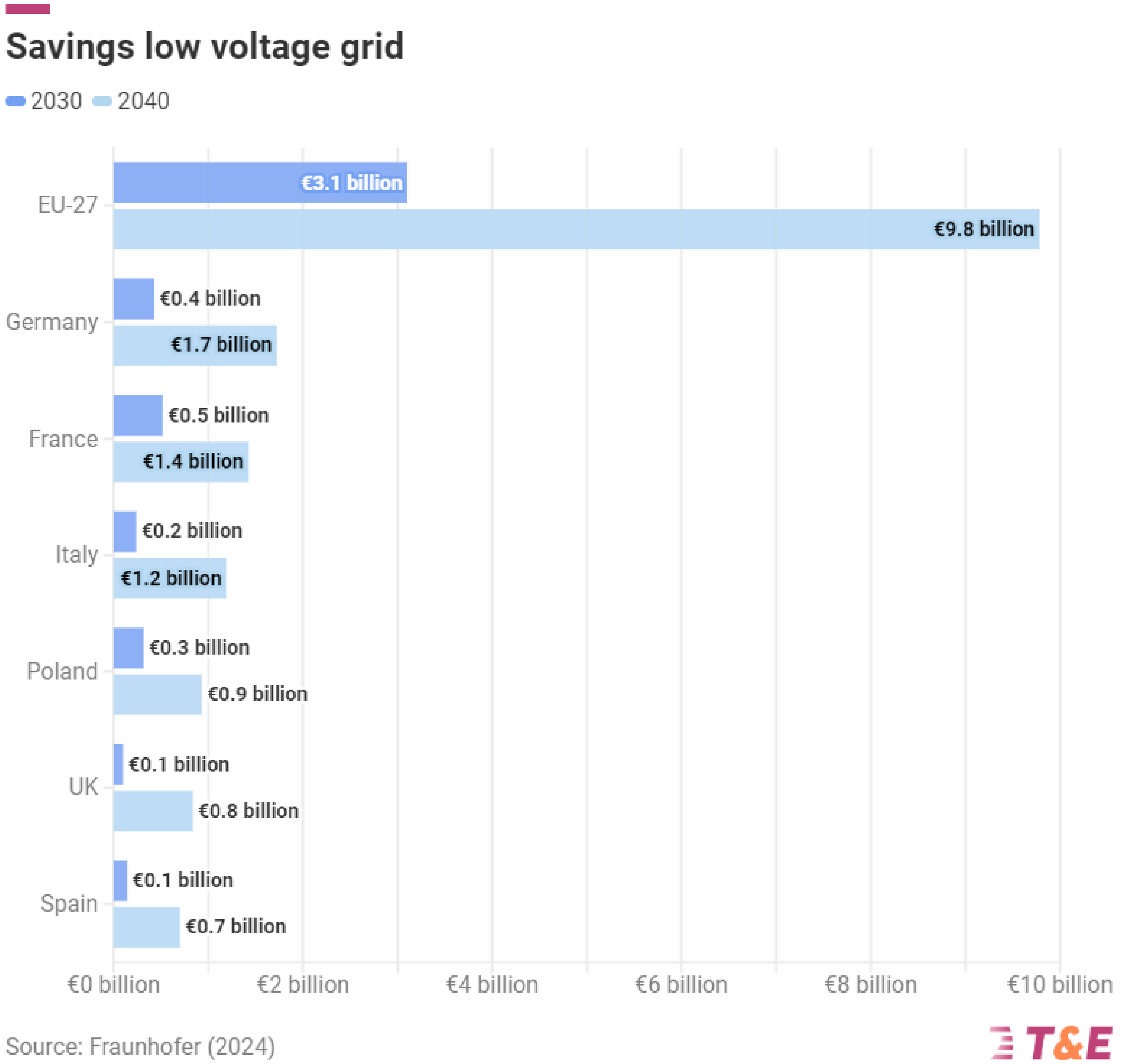

Figure 8: Potential total savings in low voltage grid expansion

5. The AC-DC question - how to ensure interoperability?

Bidirectional charging today can be realised through AC or DC chargers. AC chargers are typically used for low charging speed and almost all residential or private chargers are AC. DC chargers are today mostly used for fast charging applications and are mostly found at public fast charging hubs. The main difference is that for AC charging the alternating current (from the grid) is converted to direct current inside the EV in the onboard charger while for DC the conversion happens within the charger.

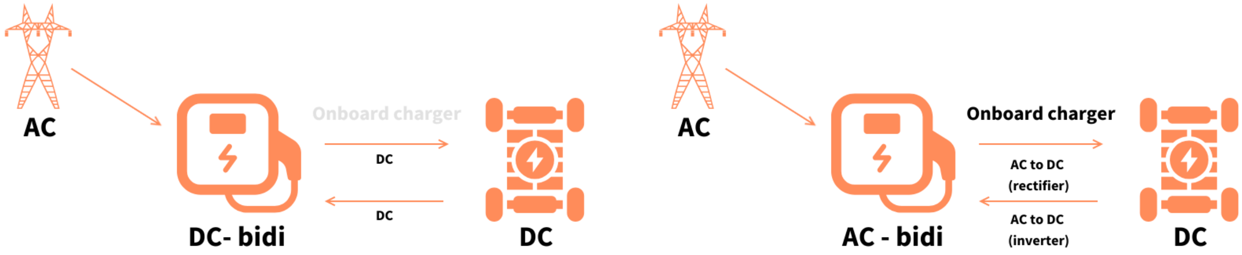

Figure 9: AC and DC bidirectional charging

DC bidirectional charging does not require any (hardware) changes to the vehicle. It requires, however, a DC bidirectional charging point that, according to our study, is likely to remain almost three times more expensive than an AC bidirectional charger. Our study further finds that adapting an EVs onboard charger to make it bidirectional is relatively easy from a technical point of view, and would only modestly increase the cost of the onboard charger by around 10%. The cost of a bidirectional AC charging point / wallbox would increase by a modest €100 per charger. Comparing this to the expected economic benefits outlined above, most bidirectional AC chargers would amortise within a couple of months of usage.

The prevailing problem remains interoperability, as different OEMs today are currently focusing on either AC or DC bidirectional charging solutions. However, while an EV with a bidirectional capable onboard charger is, from a hardware point of view, able to charge bidirectionally via a DC or AC bidirectional charger, this is not possible for an EV without an adapted onboard charger.

This could represent a major barrier for many EV drivers to actually use their EV as 'battery on wheel'. On a system wide scale, it could furthermore drastically reduce the overall potential of EVs as virtual power plants. In order to ensure interoperability, the bidirectional charging capability of the onboard charger of every new EV should be the default option.

6. Policy recommendations

Bidirectional charging promises massive cost savings on an individual and economy wide level. Savings that come at almost no additional costs. To realise it however, EU and national regulatory frameworks need to set some minimum requirements, or the significant potential of 'battery on wheels' could be seriously reduced.

The regulatory framework in the EU and its member states, and in light of the EU's work on a new framework on European Grids, the Electrification Action Plan and the Citizens Energy

Package as outlined in the letter of new designated Energy Commissioner, should take the following points into account:

Make onboard chargers mandatory and bidirectional

To make sure that the onboard charger of every new EV is capable of bidirectionality, the Commission should propose a targeted change in the type approval regulation, making the onboard charger a mandatory feature for all new EVs and ensure that it is capable of charging and discharging.

Make sure charging infrastructure is bidirectional

To enable most EVs to charge bidirectionally, chargers must be capable of doing so. It is sensible to change the Alternative Fuel Infrastructure Regulation (AFIR) and make at least all public slow chargers (≤ 22 kW) bidirectional. These chargers have the highest potential for bidirectional charging, because they are typically in use for several hours or overnight.

For private chargers the Commission should, via a targeted change of the Energy Performance of Buildings Directive, make sure all charging points falling under the scope of the directive are capable of charging both ways.

In both cases technological neutrality should apply, meaning that Charge Point Operators and owners of buildings should be free to decide whether they deploy AC or DC bidirectional chargers.

Fast implementation of Energy Market Design (EMD)

The recent revision of the EU's EMD should be implemented as fast as possible at member state level. Notably the parts that are crucial to enable and incentivise V2X applications.

- in particular the shift from a purely CAPEX focused to a CAPEX + OPEX focused (TOTEX) grid planning and;
- lower bid-sizes for day ahead and intraday markets to 100 kW to incentivise small scale demand-side flexibility;
- Widespread introduction of time of use tariffs.

Adapt network codes to allow on board charger to work in distribution grids

Network codes should be adapted to allow on board chargers to work in distribution grids operated by different DSOs. This is crucial to allow an EV to engage in V2X services whenever it is connected to a bidirectional charger, whether this would be at work at a public slow charger or at home.

Further information

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