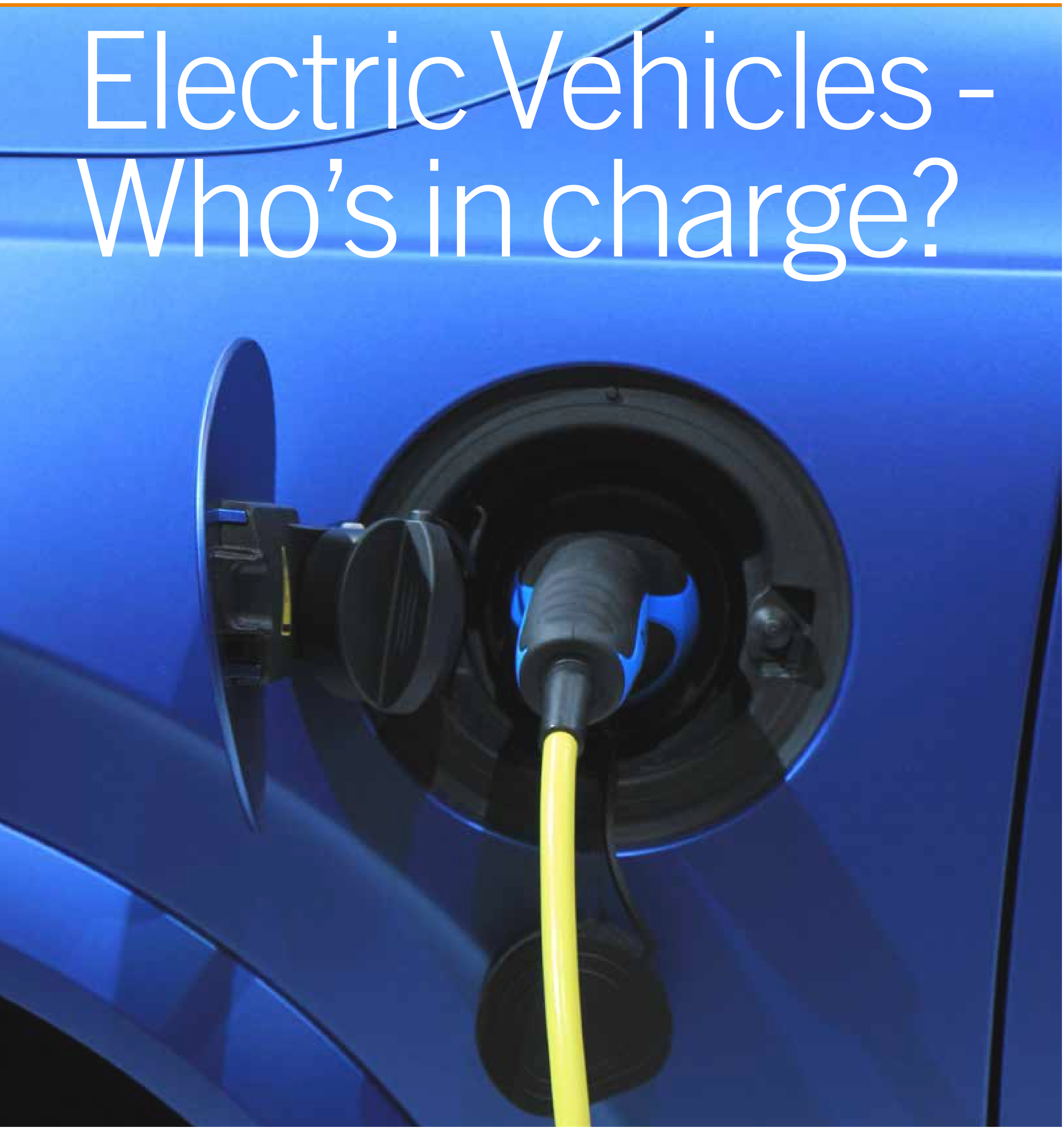
PÖYRY POINT OF VIEW - DECEMBER 2017

Electric Vehicles - Who's in charge?



What impact will EVs have?

2017 was a major year for announcements on electric vehicles (EVs) (see box 1). While there are still hurdles to be overcome (see box 2), it seems that EVs have already won the battle for the future of transport.

BOX 1: MAJOR ANNOUNCEMENTS

In 2016 and 2017 there were many announcements on EVs from a wide range of car manufacturers. Mercedes-Benz will invest $1 billion in an Alabama plant to produce all-electric SUVs; Nissan-Renault is targeting 1.5 million cumulative sales of electric cars by 2020; and Mitsubishi plans to release 12 all-electric models by 2022. Moreover, it was announced in November 2017 that Ford, Daimler, BMW and Volkswagen will develop a pan-European electric vehicle charging network called IONITY. IONITY will operate about 400 fast charging stations across major European thoroughfares by 2020.

0.1 million electric car sales in 2017 and 15-25% of the BMW group's sales by 2025	30 thousand annual electric car sales by 2017	4.52 million annual electric car sales by 2020
0.1 million annual electric car sales by 2020	13 new EV models by 2020	Two-thirds of the 2030 sales to be electrified vehicles (including hybrids, PHEVs, BEVs and FCEVs)
1.5 million cumulative sales of electric cars by 2020	0.5 million annual electric car sales by 2018; 1 million annual electric car sales by 2020	2-3 million annual electric car sales by 2025
1 million cumulative electric car sales by 2025	20 all-electric vehicles by 2023	$1.6 billion plant by 2021, to produce electric and hybrid vehicles
Electrify the entire vehicle line-up by 2020	Release two fully electric models in 2019	80% of models will be offered with electrified powertrain by 2023

Several governments announced future bans on internal combustion engine (ICE) vehicles. France and the UK are planning to ban the sales of new diesel and petrol cars and vans from 2040. Germany's federal council has passed a resolution calling for a ban on combustion engine cars by 2030. Similarly, the Dutch government wants all new cars in the Netherlands to be emission free by 2030. Sweden is committed to become carbon neutral by 2045 (see our Point of View article **EV charging challenging the grid,** published January 2018). Norway is committed to sell 100% electric vehicles by 2025, and it does not seem unrealistic, since 37% of new vehicle registrations between Q1 and Q3 2017 were EVs. The Indian government also announced its intention to only sell electric cars by 2030; however it later qualified the target as "aspirational" and that "Ultimately the logic of markets will prevail". As for China, the country with the largest fleet of EVs, they are also looking at plans to ban petrol and diesel cars. China is currently the largest market for EVs, accounting for more than 40% of the world's electric car sales in 2016.

BOX 2: WHY THE EV REVOLUTION HAS NOT HAPPENED YET

While steadily growing, the current market share of electric vehicles is still low. Beyond cost there are other factors. Limited knowledge about their own behaviour makes drivers overestimate the required range. Limited familiarity with the technology sometimes contributes to the perception that electric vehicles are expensive, have limited range and that charging infrastructure is insufficient. Limited variety makes it less exciting for consumers to shop for a new car. All of these factors contribute to electric vehicles not even being on the radar of many potential new customers. However, most of these issues are being addressed. Indeed in some countries, through city hire schemes, familiarity with the technology is growing.

Naturally at Pöyry we don't rule out the possibility of natural gas, hydrogen and fuel cells playing their part, but in this Pöyry Point of View we consider only an 'all electric' future.

Imagine that by 2030 EVs have taken over as the vehicle of choice and rapid EV take-up has transformed our streets making them quieter and with much reduced local air pollution. Still a major uncertainty exists - when and where will people charge their EVs? What behaviour will we see?

Added to this uncertainty is the transformation of the electricity system that is ongoing – decarbonisation, decentralisation and digitalisation. We expect increasing amounts of non-dispatchable renewable generation in the form of wind and solar, and for new technology and innovation to allow for much greater levels of consumer participation in the electricity market.

So the key question we address here is 'what impact may EVs have on the generation and distribution of electricity?'

FROM OIL PRODUCTS TO ELECTRICITY GENERATION

In a future with 50% of all cars, buses and motorcycles 'all electric' across the EU28, the demand for liquid transport fuels is 68 mtoe p.a. lower (or 24% of the 2016 total) and annual electricity demand is 330TWh higher, which is 11% of EU28 final demand in 2016[1].

To some this may not seem much but it is equivalent to adding a country the size of Italy to the electricity demand of the EU28. One reason why the impact is not larger is that EVs are efficient in turning energy into km travelled when compared to reciprocating engines.

It is important though to consider how the electricity is generated and compare primary energy use per passenger km to ensure a like-for-like comparison.

What does this 330TWh mean in terms of additional capacity – how many gigawatts of new plant may be needed as a result of this increased electricity demand? If the 330TWh was considered on a standalone basis, it would require 45GW of baseload plant which is equivalent to 14 Hinkley Point Cs, or 125GW of onshore wind capacity which is almost 3 times the current total onshore wind capacity of Germany.

But what does it mean for investment needs when considered in the existing electricity system? The answer to this question is not at all straightforward, as it depends on how, when and where EV owners choose to charge.

1 These figures are taken from our Transport model **MOVE** developed as part of our Future Role of Gas multi-client study. For more information please contact us (details on back page).

When will EVs charge?

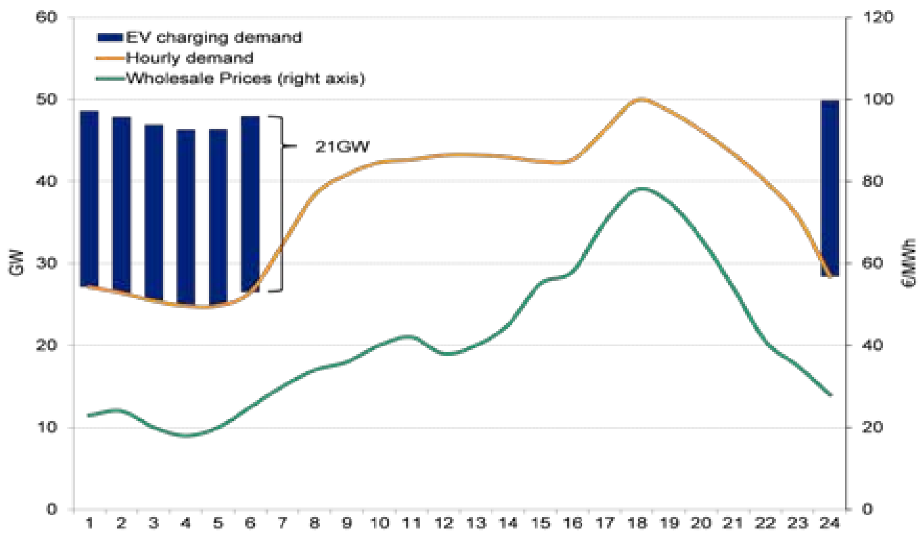
ENERGY VERSUS CAPACITY

Electricity demand varies across the day and across the year, and storing electricity is currently costly. As a result, traditionally electricity systems have plants that run in baseload, mid merit and peaking duty. In addition, they hold reserve capacity to deal with unexpected peaks in demand. So a peaking plant may only run for a small number of hours over the year. In addition, the wires that distribute electricity also have to cope with peaks in demand and be sized appropriately.

With spare capacity on the system, additional energy demand could in theory be accommodated without the need for new capacity.

We use Great Britain (GB) and a simple scenario to demonstrate this. In GB, peak demand currently occurs in the winter at around 18:00 due to the combination of heating, lighting and cooking demand. Figure 1 shows demand on a winter's day together with wholesale prices. Imagine all cars (that are charging) slow charge at the same time overnight in a seven hour period starting at 23:00. In this example, it would be possible to accommodate over 21GW of charging demand before a new peak demand period is

FIGURE 1 - FILLING THE OVERNIGHT TROUGH - A WINTER DAY



created. However if charging began earlier in the evening, say at 21:00, then around 4GW of charging demand creates a new peak. If charging starts when people return home from work, at say 18:00, then the impact is direct and new capacity is required immediately.

Assuming a 50% penetration of EVs in GB, the demand from charging over these seven hours translates to 20GW[2] and so can in theory be accommodated within the existing generating capacity.

THE ENERGY TRANSITION

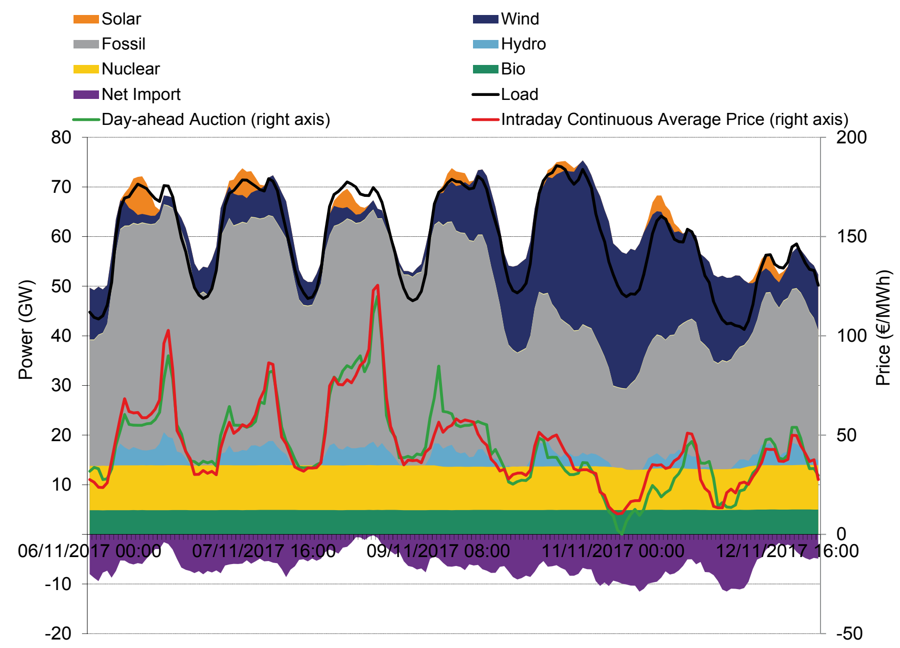
However, the situation both today (in some countries) and in the future is not well represented by the above characterisation for a number of reasons, not least:

- the continuing increase in non-dispatchable generation such as solar and wind; and
- the growing potential of flexible demand from appliances and EVs, to balance supply and demand in a future smart, digitalised, decentralised energy system.

As the amount of wind and solar grows in the electricity system (whether centralised or decentralised) the shape of electricity demand will no longer be the main driver for when to charge an EV, as low electricity prices will not necessarily coincide with periods of low demand overnight.

Rather than charging overnight, it will make sense for EVs to charge (and for other flexible loads to run) during a sunny or windy period. Assuming that the average EV user charges once a week, then as shown in Figure 2 the best day to charge in Germany during Week 45 2017 is the 10th November.

FIGURE 2 - GERMANY GENERATION AND PRICES FOR WEEK 45, 2017



Sources: 50 Hertz, Amprion, Tennet, TransnetBW, EEX, EPEX

The price of electrical energy on, say, a 15-minute[3] dynamic basis, can provide the right signal about when best to charge an EV. Consumers will, if so enabled by technology in the future, respond to the price signal, increase aggregate demand and reduce the level of curtailment on zero or negatively priced renewable generation. Therefore flexible demand will allow for more wind and solar to be built on a profitable basis as a result. Consumers will set their preferences and the EV will do the rest. Such preferences may be that they never want less than 40% charge in their EV and are willing to pay a maximum amount per day for their electricity.

In addition to EVs, large controllable loads in the home (washing machines, tumble dryers, immersion heaters) will also be programmed to switch on at such times. These interactions will likely be automated through a home hub system rather than requiring any human intervention.

The pricing of electricity will also need to be dynamic so that as demand increases, prices respond and additional demand sees its impact on price levels.

For this to work, of course, consumers will need smart meters that can record demand on this 15-minute basis and retail prices that reflect the changing value of electricity in each 15 minute period. In a world in which flexible demand responds to changes in the price of electrical energy, what implication will this have for the distribution of electricity?

2 This represents 20m vehicles and an energy demand of 50TWh.

3 We choose a 15 minute settlement period by way of example only.

Can EVs solve the grid problems they cause?

DISTRIBUTION AND DIVERSITY

In practice, our electricity systems rely on diversity of demand to hold down costs. The fact that people use electricity at different times means that the capacity of the system is lower than it would need to be if they used it at the same time.

If everyone in a street put their electric ovens on at the same time, then the low voltage fuse at the street substation would blow and supply would be lost to everyone on the street. If people were willing to pay more so they could all have their ovens on at the same time and not lose supply, the distribution company could come and put in a bigger cable and potentially a bigger transformer at quite a significant cost (tens of thousands of Euros per street).

By dint of natural diversity, the cost of distributing electricity to consumers is kept lower when we share assets. With non-smart systems it doesn't matter to the residential consumer when their electricity demand occurs as settlements are based on half-hourly or hourly profiles rather than on actual demand.

In a 50% EV penetration scenario, if all the EVs in a city street slow-charged at the same time, major investments in the electricity distribution system would be required.

In a world in which flexible demand is chasing low electricity prices, there is an incentive for consumers to charge their vehicles at the same time. Natural diversity will reduce and distribution systems will need even greater levels of investment. The cost of distributing electricity will be low most of the time and then increase significantly when grid capacity grows scarce. There will exist at times a tension between the cost of electrical energy and the cost of distribution. The cost of delivered electricity will vary significantly with time and location.

The impact that this has on the electricity system will depend on the underlying characteristics of the system. In systems with high levels of hydro storage, the variation in electricity prices driven by wind and solar will be low. The incentive to all charge at the same time will be reduced. In systems built to cope with mainly electric heating, home-based slow-charging demand is proportionally less important as the distribution system is already built for larger loads (as long as one avoids having the heating on at the same time as the EV is charging).

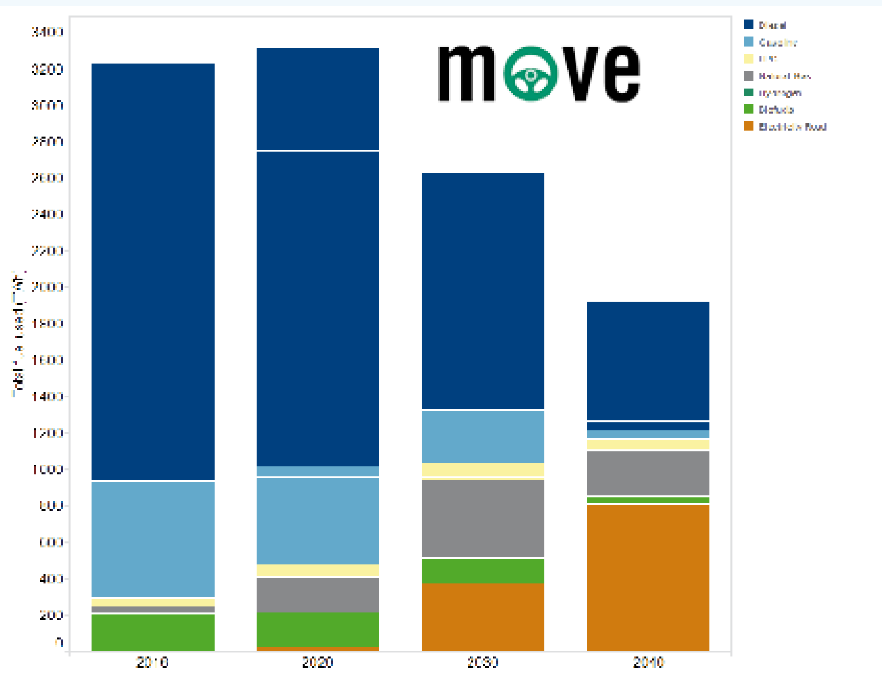
One solution is a system of dynamic pricing that reflects the cost of electricity at a specific location. The pricing option could be a variation on nodal pricing, common in many electricity markets, but which is extended down to the local distribution level, even to a price at the top of a city street. Whatever the form, the key will be reflecting the cost of electrical energy and the cost of distributing electricity to an appropriate degree of temporal and geographic resolution.

Unless customers see the cost of their actions through locational dynamic pricing of electricity, it is likely that very significant investments in electricity distribution infrastructure will be made unnecessarily. In the interim, a system of pricing distribution use on a kW capacity rather than kWh energy basis to reduce individual consumer peaks may alleviate the issue. Some trials of command and control by distribution companies, in which the distribution company controls the charging time, have taken place but it is difficult to see how this is consistent with a smart energy future.

DID YOU KNOW...

Pöyry uses its **MO**tor **V**ehicle **E**nergy (**MOVE**) model to investigate the energy use in the European road transport sector. **MOVE** is a bottom-up model that uses the current stock of motor vehicles in Europe as a starting point. The future transport mix – split into motorcycles, cars, vans and trucks of different sizes – can be determined by the model itself using optimisation criteria such as capital and fuel cost and carbon emissions; or alternatively, constraints to the future energy mix can be pre-determined by the user. Depicting the transport sector on an annual basis until 2050 or beyond, inputs include; costs and efficiencies of vehicles, scrapping rates of existing vehicles, supply chain constraints to produce new vehicles, fuel costs in different countries, and political targets. Outputs include; numbers of vehicles, travelled distances, fuels usage, carbon emissions and costs (see Figure 3).

FIGURE 3 - SAMPLE MODEL OUTPUT: TRANSPORT FUEL CONSUMPTION IN AN ELECTRICITY-DRIVEN DECARBONISATION SCENARIO



EVOLUTION

One of the key questions that remain with EVs is their ability to inject energy back into the grid economically. With current technology the received wisdom is that cycling of the EV battery has too great a cost (in reduced battery performance and early replacement) for injecting back into the grid to be economic for much of the time. But if the scarcity of the wires were priced accurately, the economics will change. In addition, as the number of EVs increases, this will lead to more periods of grid scarcity with greater value.

Battery technology for EVs will no doubt improve over time and, if re-injecting from an EV creates a value that can be captured, then developments will likely lead to a lower cost of re-injecting.

Alternatively, static batteries in the home or in the local grid may be the answer to reducing congestion on the local distribution wires. Evidence from Norway suggests that avoiding grid capacity fees is a major driver of residential battery deployment.

The economics of EVs reinjecting electricity into the system could end up being based on the cost of storing energy in, and re-injecting energy from, an EV (or static) battery versus the cost of grid reinforcement. So when you want to charge your EV at a specific time and there is local grid congestion you will charge from other EVs that are discharging energy in your local street or area.

The available re-injection capacity from EV batteries will be limited by the connection to the grid and by the ability of the grid to distribute electrical energy. An EV battery can deliver a large amount of power to the motor by comparison to its grid connection.

Even with this limit, the GW of capacity that could be delivered by a 50% penetration of docked EVs is large and this could lead the way to an electricity system premised on renewables and EV battery storage (as long as the issue of rate of change of frequency can be addressed).

So we may find that the problems that EVs cause in the future are actually solved by EVs themselves (either directly or indirectly through advancement in battery technology in static battery applications)[4].

This will be the case as long as the correct price signals are seen. And this may mean having a new electricity market design fit for the future that prices not only the electrical energy dynamically within day, but also the grid congestion on the same basis down to a local level. It is uncertain exactly how EVs may develop and given this uncertainty a flexible pricing system may be the best solution to make the most of the flexibility they will bring.

The truth is that EVs will fundamentally challenge the whole of the electricity industry – from the approach and remit of regulators, to the licences that define the activities of companies, as well as the settlement processes. It will also impact business models across the industry as we move behind the meter and allow for multiple suppliers to supply each home. Developments are already being seen in some markets but a huge amount of work remains to be done.

If we are too slow to bring about these changes, we risk making generating capacity and grid investments in the shorter term that become unnecessary in the long-term and that burden consumers with higher costs for years to come.

4 Further, with autonomous EVs it may even be that some vehicles charge themselves at a higher voltage location in the network and transport electricity back into the local grid by docking at home. And even further, car ownership may fall dramatically in cities, as fleets of autonomous taxis provide for our transport needs. These possibilities could themselves drastically alter the impact of EVs.

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