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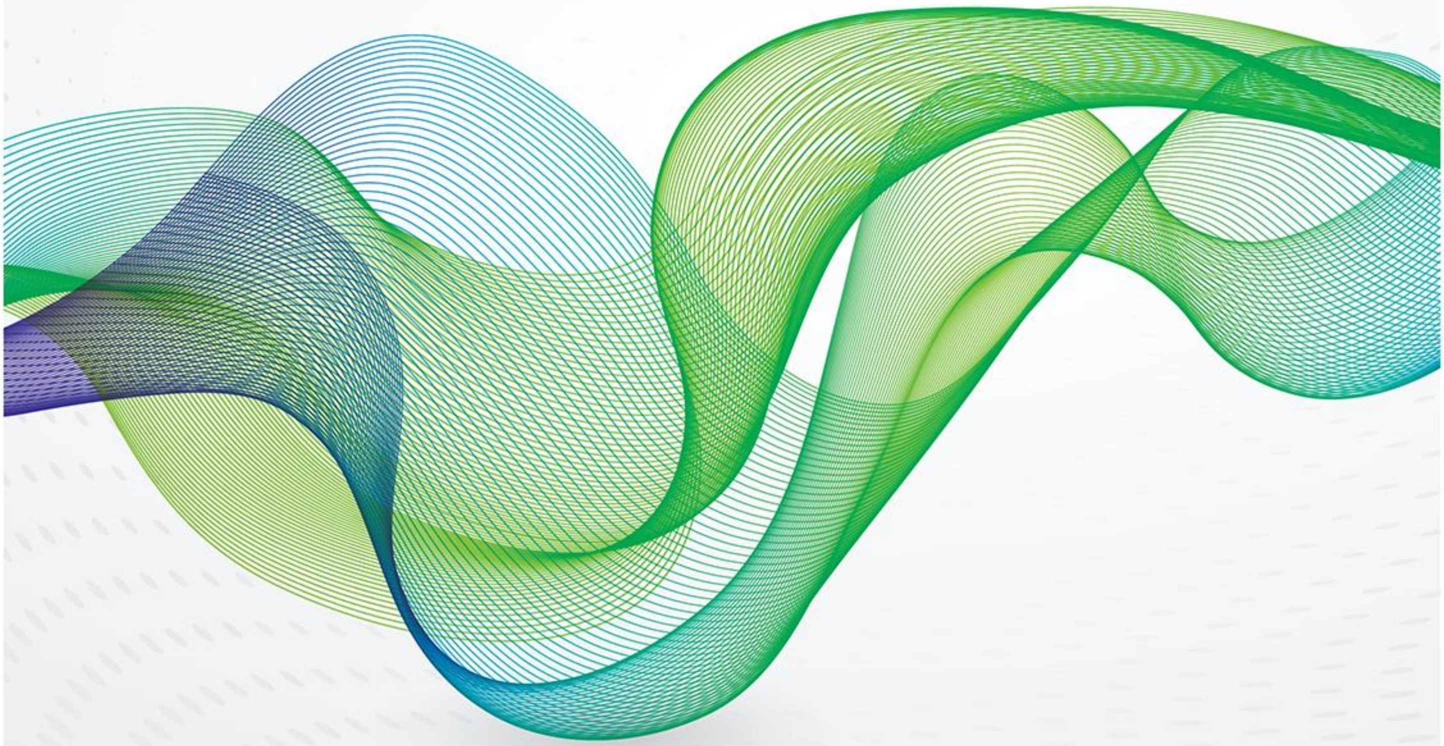
Electricity, Electric Vehicles, And Public Policy:

Eight Key Takeaways



The Oxford Institute for Energy Studies held its second workshop on the impact of disruptive change in the transport sector, titled 'Electricity, Electric Vehicles and Public Policy'. Participants included experts from the electricity, oil, auto, mobility, finance and technology sectors.[1] The workshop focused on investigating the prospects for deep EV penetration. The focus was on specific urban transport modes (light passenger and small freight vehicles) and within the timeframe 2040–50. The workshop recognised the essential role of electricity in enabling deep penetration of EVs, while emphasizing that various public policies, new technologies, and changing social habits are the main drivers of that penetration.

The workshop resulted in eight key takeaways:

1. ***Globally, EV penetration is primarily being driven by its use in cities.***
2. ***The inefficient integration of EVs into the electricity sector could be a potential barrier to rapidly achieving high levels of EV penetration.***
3. ***Consumer perceptions about the adequacy of charging infrastructure are key to the success of EV uptake.***
4. ***The EV transition could raise issues around equity of access to electricity that will need to be addressed.***
5. ***Business models to enable EV uptake will adapt differently to different markets and geographies.***
6. ***Non-rational factors and traditions are important influences on consumer decisions around EV adoption.***
7. ***The supply chain for batteries could face short-term obstacles, but the industry will adapt.***
8. ***Auto manufacturers face strategic choices between EV technologies.***

The discussions reflected the consolidation of some of the trends identified in the last workshop. For instance, it is becoming clearer that emerging markets such as China are pursuing distinctive strategies in a bid to scale up EVs, by relating them to wider goals on industrialisation and energy security. Second, we also see the emergence of new business models based on technological advancements in Vehicle Grid Integration, offering consumers new commercial value propositions to encourage EV uptake – these business models offer opportunities for collaboration between various players in the EV and energy industry, opening up new revenue streams. Third, the supply chain for battery raw materials is likely to follow a cyclical path in the medium term, with periods of price volatility, until the chain matures – but the industry will continue to ride this cycle, with suppliers potentially hedging against price volatility using financial markets. Fourth, auto manufacturers' business models will be determined, to a large extent, by the strategic choices they make on EV technologies. The discussions from the second workshop also revealed fresh challenges facing EV transition, and potential options to resolve them.

The following paragraphs summarise eight key takeaways from the workshop discussions.

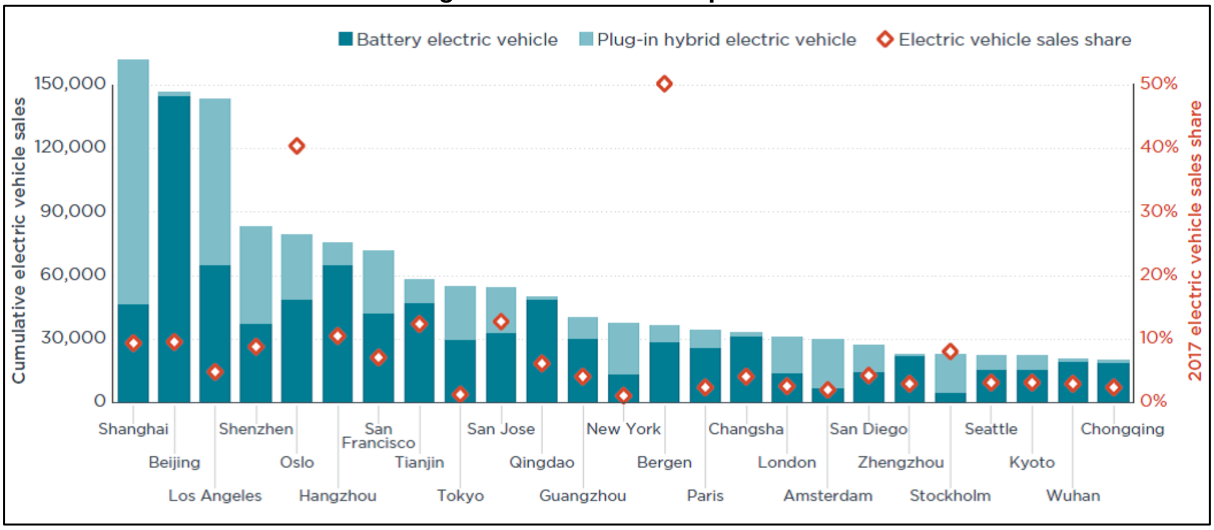
[1] ***OIES is grateful to the speakers and participants for bringing valuable insights to the debate. The key takeaways from 2017 can be found <u>here</u>. Takeaways compiled by Anupama Sen, Senior Research Fellow, OIES.***

1. Globally, EV penetration is primarily being driven by its use in cities.

The rapid growth in EVs seen over the last few years (approximately four million light duty EVs on the road globally, as of late 2018)[2] is being driven primarily by the promotion of their use in city environments (city being defined as greater metropolitan areas surrounding an urban core) - EV uptake has also tended to vary significantly across different cities even within the same country. According to the International Council for Clean Transportation (ICCT)[3] 97 per cent of EV sales are concentrated in four countries or regions: China, the US, Europe and Japan. However, within these, the growth of markets for EVs has been concentrated within specific cities, with 25 of these '*EV capitals*' accounting for 44 per cent of global EV sales. Among them, Shanghai, Beijing and Los Angeles account for the highest cumulative electric vehicle sales (see Figure 1). In the US, the highest EV penetration in terms of the share of EVs in total vehicle sales has been in San Jose, California, at 13 per cent (compared for instance with a US average of 1 per cent) (Hall et al., 2018).

Experience from these global EV markets (i.e. cities) has shown that the key barriers to EV penetration in urban settings tend to be cost, model availability, convenience (e.g. charging infrastructure) and consumer understanding and awareness. The leading global EV markets have a full package of policies, comprising a combination of 'carrots' and 'sticks', aimed at overcoming prevailing barriers to EVs. The ability, at city level (or metropolitan area), to overcome these barriers appears to have accelerated EV uptake from the 'bottom-up'[4], and could be indicative of a pattern with regards to future EV penetration. This is highly significant for future EV penetration with nearly 70 per cent of the world's population predicted to be concentrated in cities by 2050.[5]

Figure 1: World "EV Capitals"



Source: *Hall, Cui, & Lutsey, 2018.* http://www.theicct.org/publications/EV-capitals-of-the-world-2018

For example, EV owners in the San Jose (USA) market benefit from a federal incentive (approximately $7,500 per vehicle) in addition to a rebate provided by the state of California. Apart from such federal and state purchasing incentives, valuable local-level perks for EV drivers in San

[2] A recent *Financial Times* blog estimated the total number of plug-in EVs on the road at 5.4 million; this was 0.4 per cent of the total global light vehicle fleet (see Crooks, E. (2019) 'A look ahead to 2019', *FT Energy Source*, 5 January).
[3] Hall, H., Cui, H. and Lutsey, N. (2018) 'Electric Vehicle Capitals: Accelerating the Global Transition to Electric Drive', *the International Council on Clean Transportation.*
[4] The Nordic countries, where EV growth has been driven by 'top-down' policies, appear to be an exception.
[5] UN estimates.

Jose include access to carpool lanes and free parking. While some European cities have instituted congestion charging, some of the more aggressive EV policies are arguably seen in Chinese cities and provinces, which utilise vehicle registration quotas or allocation auctions that favour consumers who purchase EVs. Almost all these cities also have EV-ready building codes, and most have policies which require that car parking facilities, over time, have an increasing number of designated spaces for EVs. Increasingly, more city and state governments are putting policy plans for an EV transition in place – for instance, 8 US states and 2 Canadian provinces have stated that they want to achieve 100 per cent zero emission vehicles by 2050. There is however uncertainty over the renewal of government support policies for EVs post 2020, and the potential dampening impact of any withdrawal of incentives on EV sales; this again will be dependent on government priorities in different regions.

2. The inefficient integration of EVs into the electricity sector may be a potential barrier to rapidly achieving high levels of EV penetration.

Technical or capacity constraints in the electricity sector are unlikely to seriously slow widespread EV penetration. For instance, studies show that electricity investment requirements for projected EV demand are within historic range. The International Energy Agency's (IEA) '2-degree' scenario suggests that the additional generation required to meet EV demand will amount to just 1.5 per cent of total electricity demand in 2030. Similarly, Bloomberg New Energy Finance's (BNEF) scenario for 2040 concludes that electricity consumption by EVs will represent just 5 per cent of projected global power in 2040. This is also largely the case regarding meeting peak demand. In Europe, for example, distribution networks currently run at below full potential, and underutilized capacity can potentially meet increases in demand from EVs. In terms of capacity, there is no reason why the existing energy demand, currently delivered through petrol stations, cannot be transferred onto the electricity system, without the need for a massive amount of investment. As the electricity system moves towards a decarbonized and decentralized scenario, from matching supply with demand to matching demand with supply, in theory EVs can provide flexibility to the system in order to support renewable penetration, by storing excess renewable energy to prevent curtailment, and discharging it to the grid[6] when additional supplies are required. EVs are therefore technically compatible with the existing (and potential future) decarbonized electricity system.

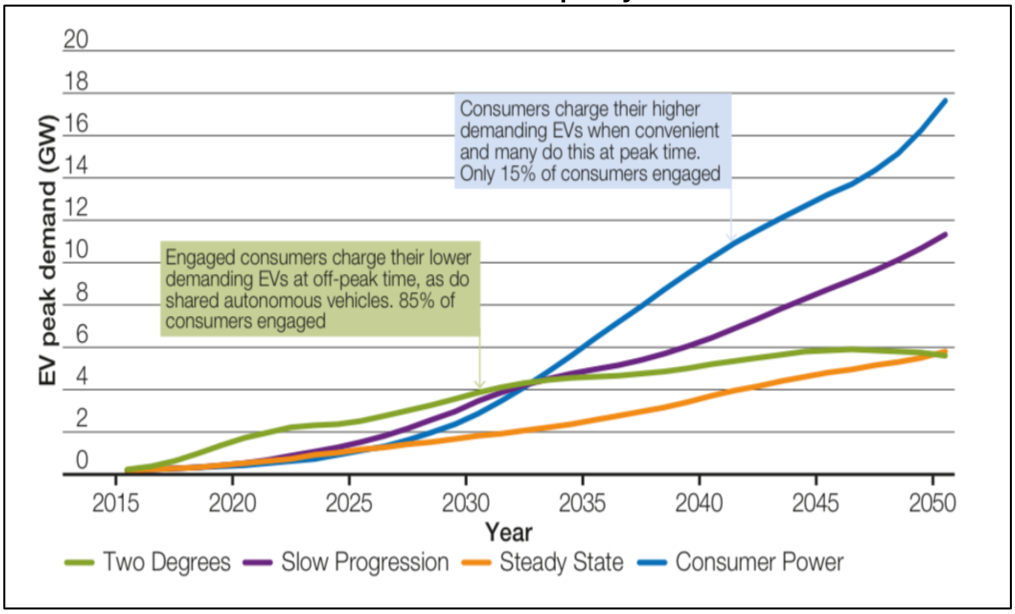
However, electricity networks rely on a significant amount of diversity in demand, and higher EV penetration is likely to change assumptions about diversity significantly. As opposed to their technical integration, therefore, the lack of *economic integration* of EVs could pose a barrier to their rapid penetration. Economic integration refers to the design of markets, regulation, and appropriate incentive structures to ensure that the operation of EVs is in line with the efficient operation of the electricity system. For instance, by putting in place incentives to ensure 'smart' charging by consumers (promoting charging when there is excess generation in the system, and alleviating network constraints by shifting charging to times when there is also sufficient network capacity).[7] The successful economic integration of EVs can in fact ensure their successful technical integration by managing the load on the electricity system and limiting the need for further investments. To illustrate, Figure 2 depicts National Grid's *Future Energy Scenarios*, which shows that economic incentives encouraging 'smart' EV charging in the UK could engage a larger number of consumers and aid in successfully managing peak load without the need for further capacity investments. The economic

[6] Discharging to the grid requires commercial Vehicle-to-Grid (VtoG) technologies which are currently being developed.
[7] See Ofgem (2018) 'Implications of the transition to Electric Vehicles', *Future Insights Series.* https://www.ofgem.gov.uk/ofgem-publications/136142

integration of EVs in the context of decarbonized and decentralized electricity systems (such as those based on liberalized electricity markets in OECD countries) requires the appropriate design of distribution network tariffs, as well as reassessing the organizational structure of the distribution network and the role of network operators.

These challenges are analogous, in many respects, with integrating renewables into the electricity system, as EVs similarly represent a random injection of energy into the system. In the case of renewables, government intervention has been utilized to create the regulation and policies which are needed to facilitate their efficient integration. Given the experience with renewables, there is no reason why similar incentives cannot be established for EVs.

Figure 2: UK Incremental Peak Electricity Demand for EVs Scenarios – Smart Charging Off-Peak Limits the Need for Capacity Investments.



Source: National Grid 'Future Energy Scenarios' (2017, 43) http://fes.nationalgrid.com/media/1253/final-fes-2017-updated-interactive-pdf-44-amended.pdf

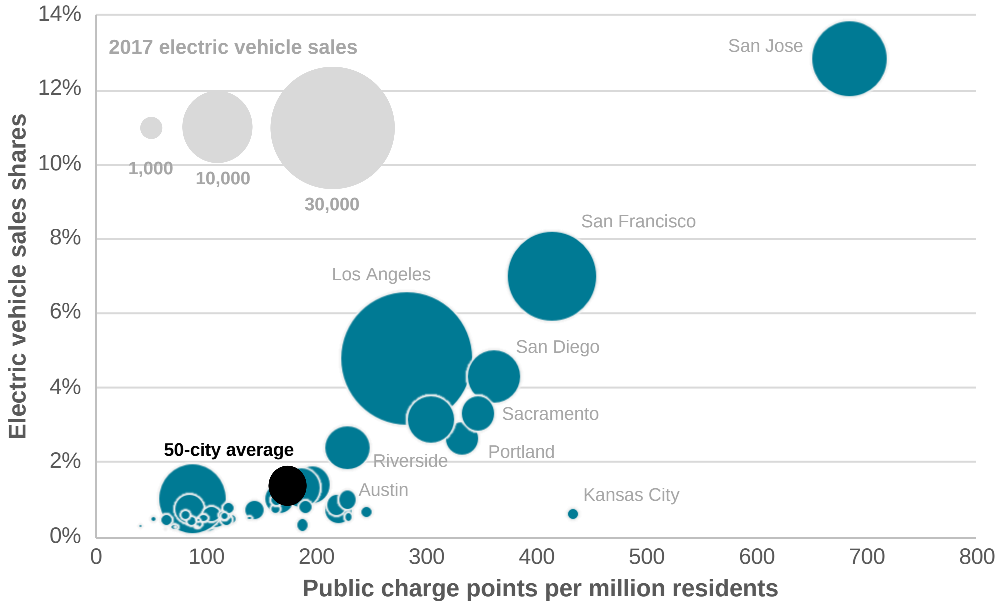
3. Consumer perceptions about the adequacy of charging infrastructure are key to the success of EV uptake.

Experience from the leading global EV markets shows that the availability of charging infrastructure stands out as a key driving factor in EV uptake among consumers. The ICCT study[8] for instance observes a strong correlation between EV sales shares and the number of public charging points per million residents. Accordingly, San Jose (USA), which is a leading EV market, has the highest charging per capita (see Figure 3). The data suggests that the causality goes both ways: the higher the number of EVs on the road, the higher the demand for charging, which increases the amount of charging infrastructure, which in turn reinforces the confidence of prospective EV buyers in their decision to purchase EVs.

[8] Hall et al. (2018).

Consumer concerns over the adequacy of charging infrastructure for EVs[9] are arguably, to a great extent, perceived rather than real. This is largely because EV charging infrastructure, although present, is less visible relative to conventional petrol and diesel filling stations or forecourts. For this reason, the installation of charging infrastructure *within* conventional filling station forecourts is a logical step. Yet, it is unlikely to be sufficient on its own in enabling deep EV penetration. This is because the EV transition implies going from a world in which nearly the entire fleet of passenger vehicles is fuelled through a traditional filling station forecourt, to one in which the majority of charging is likely to occur at home (overnight) and in workplaces.

Figure 3: EV Uptake and Charging Infrastructure in US 'EV Capitals'



Source: Slowik & Lutsey (2018). The continued transition to electric vehicles in U.S. cities. https://www.theicct.org/publications/continued-EV-transition-us-cities-2018

Government pronouncements around a willingness to invest in charging infrastructure can send strong signals of policy commitment to the EV industry, potentially enabling EV uptake. For example, China's stated target to provide 4.8 million charging points by 2020 to nearly equal their target for the total number of EVs (resulting in a 1:1 ratio) may be ambitious but provides a strong signal on policy direction to businesses (e.g. auto manufacturers), which then orient their strategies to align with these goals. The ICCT[10] study points to an increasing alignment between government support and ambitions on achieving all-electric transport and announcements by major automakers (OEMs) on EV investments.[11]

[9] Referred to as 'range anxiety'.
[10] Hall et al. (2018).
[11] Ibid. Reportedly amounting to 15 million EVs per year by 2025.

4. The EV transition could raise issues around equity of access to electricity that will need to be addressed.

Access to electricity is considered a universal human right, and therefore, accommodating EVs in the electricity system is not just a technical, but also a social and economic issue. In the transition period to low carbon and renewable energy technologies, it is likely that the electricity system will not just have to cope with increases in demand from EVs, but also the electrification of other sectors, such as heating. During this transition, the efficient outcome for the system may not necessarily be the outcome desired by consumers. Consumers may want access to electricity at low prices and on demand, but in order for EVs to operate efficiently in line with the system, there may be times at which it could be prohibitively expensive to charge EVs, essentially restricting consumer access.

At the same time, transferring energy use from the oil market into the electricity market might bring with it expectations related to Universal Service Obligations, which might clash with the efficient system outcome. The design of incentives to deal with EV integration into electricity networks could involve policies such as congestion charging in order to allocate capacity on the network at times of heavy use, and these policies will need to be made consistent with peoples' expectations of electricity as an essential service. People expect that part of their right as citizens is to have good access to essential services (including electricity), and if the arrangements put in place to enable EV integration deny some people this access or prioritise certain consumers over others, this could pose a potential barrier to deep EV penetration.

This raises three issues around equity of access to electricity in the presence of a significant number of EVs on the electricity system.

- First, any restriction of people's access to their private vehicles would need to be counterbalanced by the provision of alternative sustainable mobility solutions (such as public transportation systems).
- Second, it raises the issue of 'who pays' for the fixed costs of the system, and government levies related to aiding EV integration. If EV penetration leads to changes in the cost structure of an electricity system such that it does not match with the structure of retail tariffs, then there will be a cross-subsidy among end users based on their level of consumption.
- Third, it raises issues around connections for charging points, locations, and the cost of connections – for example, whether charging infrastructure should be sited according to the convenience of EV users, or in locations where it contributes to the efficiency of the network.

Having said that, most European utilities appear to be confident that capacity and grid competency will be sufficiently developed in the near future to handle a large scale injection of EVs. But equity issues need to be considered early in the design of electricity markets and network tariffs, as the higher the level of EV penetration among consumers, the higher the likelihood of consumer reactions to perceived inequities, and the more difficult it may be to address equity issues later in the process. Optimal solutions to EV integration may need to go beyond the electricity system and consider, in totality, the creation of a transport and mobility system which meets the needs of consumers, businesses and society at a cost that is affordable, and which does so within the necessary environmental limits to meet the wider goal of decarbonization.

5. Business models to enable EV uptake will adapt differently to different markets and geographies.

Business models to enable EV uptake are evolving to adapt to different markets and geographies, and there is unlikely to be a 'one-size-fits-all' approach. For instance, EVs represent different products to consumers in developed markets versus those in emerging or developing markets. In Europe and the US, most consumers purchasing EVs will be doing so to replace their existing vehicles and associated technologies. In emerging markets such as China or India on the other hand, potential consumers are likely to be first-time buyers of cars, encountering the choice between EVs and ICEVs. Therefore, different factors drive consumers' EV (or car) purchase decisions in the two types of markets.

Many countries with 'top down' regulations on EV penetration rely on traditional auto industry intermediaries such as independently-owned car dealerships to promote EV uptake among consumers.[12] However, evidence[13] from the Nordic countries shows that dealers could in fact be a barrier to EV penetration, at the point of sale. Research shows that this may be because car dealerships face significant disincentives, such as: EVs typically take longer to sell, dealers face more questions from consumers, and there is less potential revenue to be made from after-sales services and maintenance (an estimated 80 per cent of dealerships' revenues cme from these services). Sole EV manufacturers such as Tesla have attempted to bypass this intermediary model through owning their dealerships.

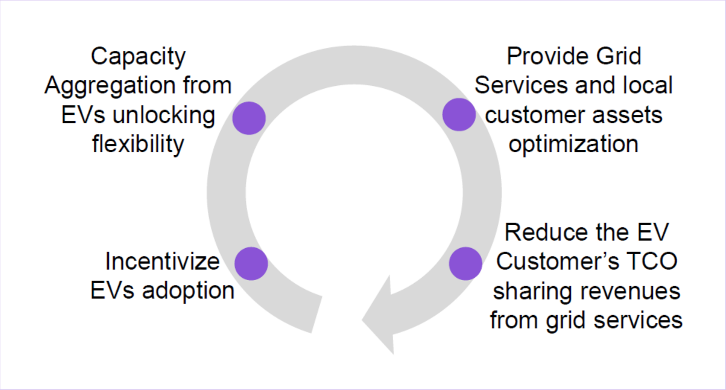
In developing countries, business models to enable EV uptake may also be integrated with broader goals on economy, energy, and the environment. For instance, EVs in China are being considered primarily as a future storage option, with a forecast for 100 million EVs by 2030 potentially offering 5 Terawatt-hours (TWh) of additional storage. Specifically, using smart charging, battery swaps and 'retired' batteries, storage provided through EVs could be a solution to prevent the curtailment of renewable energy[14] from the electricity system during periods of abundant availability of renewables, thereby also offering energy security as a by-product. This model may also incentivise 'indigenous' companies to actively participate in the full EV supply chain.

New business models to enable rapid EV penetration may require offering innovative new commercial propositions to EV users that depart from the traditional mode of electricity supply – this may entail bringing new players into the market that can provide these propositions without strictly having to go through the electricity supplier interface. Two emerging business models in this regard are Vehicle Grid Integration (VGI) and Vehicle-to-Grid (VtoG). VGI is the process by which EV batteries can be aggregated and integrated with the energy system in order to provide a service to the electricity system – VGI models are based on unidirectional flow[15] and the ability to stop, start and modulate the level of charging. VtoG models can additionally discharge energy from the EV battery to the grid.

[12] Dealerships serve as a 'buffer' against misalignment between supply and demand in the car distribution chain.
[13] Source: Zarazua de Rubens, Gerardo, L Noel, and BK Sovacool. "Dismissive and deceptive car dealerships create barriers to electric vehicle adoption at the point of sale," *Nature Energy* 3 (June 2018), pp. 501-507.
[14] China has faced high (double-digit) rates of curtailment of wind and solar energy due to system inflexibility and transmission bottlenecks. See https://www.greentechmedia.com/articles/read/china-faces-uphill-renewable-energy-curtailment-challenge#gs.NA7QesrL
[15] There is no energy being fed from the EV battery into the grid.

VGI and VtoG based business models involve the aggregation of EVs (essentially acting as batteries or storage) and utilising them to provide 'flexibility' services to the electricity system[16] by modulating the amount and the times of EV charging to relieve 'stress points' and enable an efficient outcome for the electricity system. This could be done via participation in electricity markets – for instance in markets for grid balancing or ancillary services, with the value of 'flexibility' determined by the level of dependence placed on it by the energy system.

Figure 4: Vehicle Grid Integration (VGI) Models



Source: Enel-X

EV users that participate in these services can be remunerated by the aggregating entity – for instance through a monthly fixed payment or sharing a portion of the revenues earned from the market, or credits allocated towards the purchase of EV services (e.g. charging). These models rely heavily on the use of algorithms to ensure that although customers effectively 'give up' a level of control over their EV charging, they are offered commercial propositions that remain convenient and do not require any substantial deviation from their preferred habits or lifestyles. Such models are currently in operation or being piloted in several countries around the world including the USA (California) and Europe. Figure 4 illustrates the operation of VGI-based EV business models, the end-point of which is to reduce the customer's Total Cost of Ownership, and encourage EV uptake.

As these business models mature, there could be increased customer segmentation, as they imply drawing on a heterogeneous fleet of cars and consumers, requiring commercial value propositions tailored to target these different types. The future of VGI and VtoG based business models could involve collaboration between the providers/enablers of aggregated EV 'flexibility' services and auto manufacturers, utilities, and energy companies looking for new revenue streams. In this future, the EV essentially becomes the main incubator of data on consumer behaviour, charging patterns, and interface with the electricity system.

There is a view that a widespread uptake of EV usage based on ride-sharing and carpooling (or Mobility-as-a-Service), requiring a greater number of hours spent 'on the road' by vehicles, could be a potential barrier to VGI or VtoG, as it leaves less time for interface with the grid. This is unlikely to be a long-term impediment with advancements in charging and grid integration. While both developed and emerging markets are considering VGI and VtoG based business models, they are likely to evolve over time in different geographies, and require the achievement of a minimum scale – for instance in China most EV charging stations currently lie below the market minimum requirements to

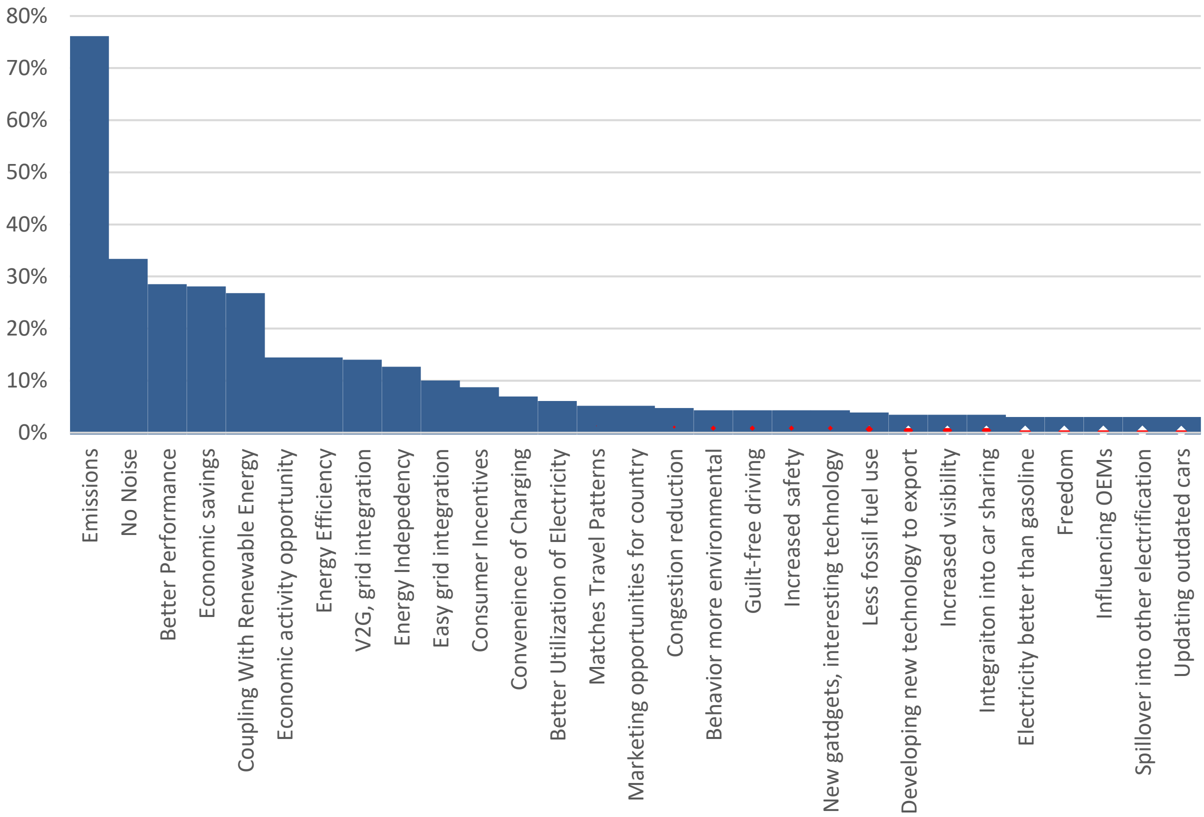
[16] Future decarbonized energy markets with high penetration of renewables may open up new markets for providing short-term backup to the intermittency of renewable (e.g. solar and wind) supplies. EVs essentially represent 'batteries on wheels' which can participate in these new markets.

participate in electricity markets.[17] Finally, early adopters of VGI or VtoG models may get a bigger share of the ancillary services market, but as the level of adoption increases, the 'pie' is likely to get smaller, implying that these business models will need to continue to evolve to operate in a more competitive environment.

6. Non-rational factors and traditions are important influences on consumer decisions around EV adoption.

Government policies to promote EV uptake among consumers assume that consumers make economically rational choices and respond primarily to economic incentives. These policies are therefore aimed at providing incentives around EV pricing, charging infrastructure, and model availability. However, decision-making on EV adoption is arguably at its most rational in regard to vehicle fleets and fleet management. For individual consumers, the decision to purchase EVs is beset by a whole host of non-rational factors and traditions that are emerging as strong influences on their adoption of EVs. The experience of auto mobility for individual consumers is strongly linked to habitual behaviours around travel and driving.

Figure 5: Co-Benefits of EVs Identified in Interviews with Nordic Consumers



Source: Noel, L, G Zarazua de Rubens, J Kester, and BK Sovacool. "Beyond Emissions and Economics: Rethinking the co-benefits of Electric Vehicles (EVs) and Vehicle-To-Grid (V2G)," *Transport Policy* 71 (November 2018), pp. 130-137.

[17] The minimum threshold for participation in the energy services market in China is 10 GWh/year, whereas an EV charging station with 20 DC chargers amounts to 1 GWh.

It has been argued that to understand EV adoption and uptake, it is necessary to look beyond the notion of automobiles as merely functional technologies. Sovacool and Axsen (2018)[18] for instance qualify automobiles and auto mobility in a non-rational context, as follows:

> "They are a means of identification; items of conspicuous consumption; possible abodes of privacy, solitude, and ritual; instruments of aggression and skill; ceremonial initiations into adulthood; and potential hobbies. Passenger vehicles are polysemiotic, that is, they signify multiple ideas. The development of particular modes of transport are thus deeply altered and affected by social and cultural patterns of courtship, residence, socialization, work habits, education, leisure, and suburbanization. Cars provide status and emotional affect through their speed, security, safety, link to sexuality and career achievement, and facilitation of freedom."

Research shows that conventional auto mobility fulfils different dimensions of these non-rational, cultural, and habitual factors (for instance, see Sovacool and Axsen, 2018 again). Therefore, any substitutes (e.g. EVs) should fulfil the same needs (beyond those of a 'functional technology') in order for consumers of auto mobility to adopt them. Research also shows that many of the benefits that consumers attach to EVs (see Figure 5), particularly in developed-country markets, are non-monetary, and include factors related to emissions reduction, noise reduction, 'guilt-free' driving, and 'freedom' (see Sovacool et al., 2018). Evidence from Nordic countries shows that these factors also vary based on demographic groups (e.g. such as gender, age, education, urban-rural divide, occupation).[19] All of the above exert an influence on consumers' preferences, purchase patterns, and expectations.

7. The supply chain for batteries could face short-term obstacles, but the industry will adapt.

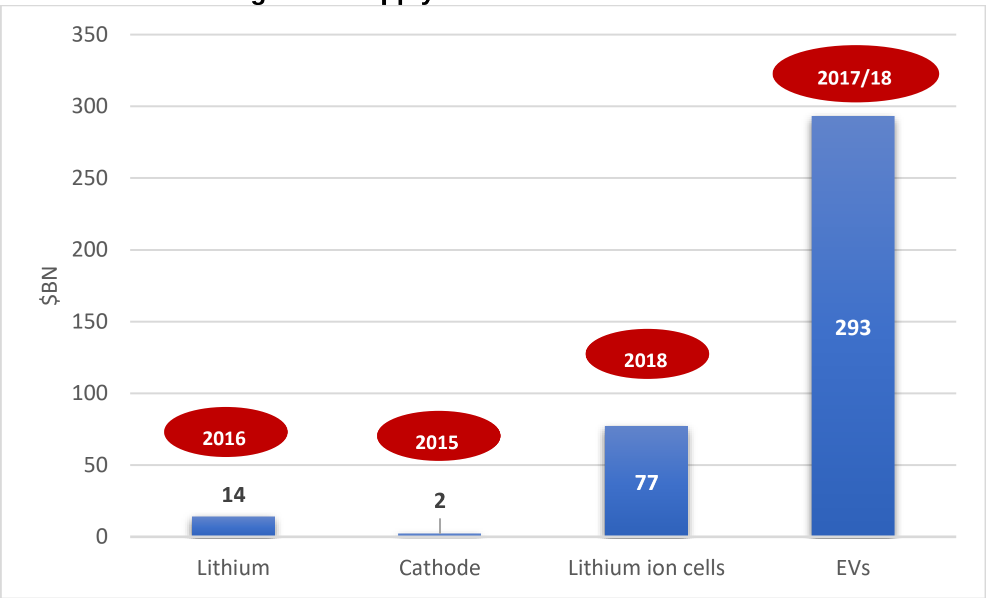
The vast majority of EV batteries are lithium ion-based, with variations in the chemistries of the raw materials or core ingredients that go into the battery cells – the latter include lithium, cobalt, graphite anode and nickel. A distinctive characteristic of the battery supply chain is that battery grade raw material does not represent a *commodity*, but a *specialty*, as it needs to be subjected to chemical processing procedures, between mining and delivery to market, that make the material useable to the end consumer. Raw material produced from different mines is also heterogeneous and cannot be uniformly used across all batteries. Each step of the supply chain from the raw material, to the chemical, to the cathode and battery cell therefore must produce a product that is qualified by the end user. Typically (and especially prior to the recent spike in demand for battery raw materials from the EV industry), these separate components of the supply chain have tended to operate as disconnected from each other. No organisation/company provides the entire supply chain (including processing) 'in house'. As a result of these disconnections and complexities in the supply chain, investments across various components have not been uniform (see Figure 6), constituting a short-term hurdle to scaling up the supply chain in response to growing demand.

The last three years have seen a spike in the price of battery raw materials, driven by rising demand from EVs. This was first sparked by the announcement of lithium ion battery mega-factories (e.g. by Tesla in 2014), and soon followed in 2015 by announcements on competing battery plants, driven by

[18] Sovacool, B.K. and Axsen, J. 'Functional, symbolic and societal frames for auto mobility: Implications for sustainability transitions', *Transportation Research A*, 118 (2018), pp.730-46.
[19] Sovacool, B.K., Kester, J., Noel, L. and Zarazua de Rubens, G. "The demographics of decarbonizing transport: The influence of gender, education, occupation, age, and household size on electric mobility preferences in the Nordic region," *Global Environmental Change* 52 (September 2018), pp. 86-100.

rising demand for EVs. As a result, battery mega-factories are predicted to go from a capacity of nearly 150 Gigawatt-hours (GWh) in 2017, to 1.45 Terawatt-hours (TWh) in 2028, representing roughly 20-22 million EVs annually by that date. Raw material supplies would need to grow exponentially in order to support this capacity. Lithium and graphite anode production would need to increase by roughly nine times their 2017 production levels by 2028, cobalt by five times, and nickel by far more, in order to meet 1.45 TWh of capacity by 2028 (see Figure 7).

Figure 6: Supply Chain Investment to Date

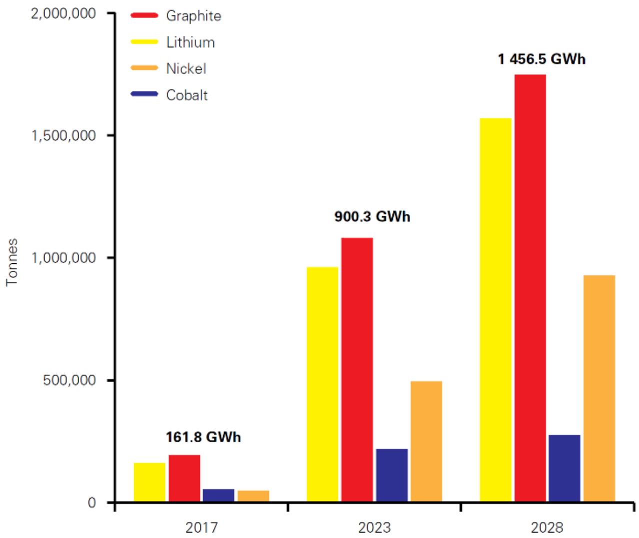


Source: Benchmark Mineral Intelligence

The increase in raw material prices, particularly lithium and cobalt, in the last three years triggered exploration, and financing for the same, and an ensuing expectation of oversupply on the market consequently lowered prices. The industry however faces other short-term constraints – for instance, the current geographic concentration of some resources in specific regions with weak regulatory standards (such as cobalt in the Democratic Republic of Congo where there are recorded exploitative labour practices; or political difficulties with lithium mining in Chile). While growing demand could spur new investments in mining in other regions, there will be a lag to market (e.g. it takes 5-7 years to build a lithium mine). Another factor that could slow the scaling up of the supply chain is an anticipated move to a different and more optimal battery chemistry: NCM 811 (8 parts nickel, 1 part cobalt and 1 part manganese) for which certain trade-offs (specifically, better energy density due to the higher proportion of nickel, versus higher safety risks due to a lower proportion of cobalt) have yet to be resolved. One the other hand, issues such as battery recycling which are perceived to be a barrier are unlikely to be a supply-chain constraint.

Price volatility is therefore likely to continue be a feature of the battery supply chain, until it matures, but there are no serious medium-term (5-year) risks. Essentially, the supply chain will scale in response to demand, but in a cyclical manner with periods of volatility alternating with periods of stability. In this regard, one of the benefits of lithium ion batteries, is that volatility will be shared across the four input materials (nickel, cobalt, graphite anode and lithium). Over the medium to longer-term, battery raw material price risks could potentially be hedged on financial markets (e.g. the London Metals Exchange), which could help mitigate the impact of price volatility.

Figure 7: Raw Material Demand vs Global Lithium Ion Cell/ Mega factory Capacity



MATERIAL	2017	2023	2028
LITHIUM	162,752	961,351	1,570,020
GRAPHITE ANODE	194,160	1,080,360	1,747,800
COBALT	54,354	219,679	276,401
NICKEL	48,584	494,774	928,018
TOTAL GWh	161.8	900.3	1,456.5

Source: Benchmark Mineral Intelligence

8. Auto manufacturers face strategic choices between EV technologies.

Auto manufacturers are at the heart of the EV transition, as they provide the interface between government regulations and ambitions on emissions reduction, and consumers' preferences and needs. Auto companies, particularly in Europe, face compliance with strict emissions targets to 2025.[20] The drive by governments to move away from the use of diesel over the next couple of decades (e.g. in many European countries) will further tighten compliance, forcing the electrification of the fleet. Emission targets and fuel economy regulations in the EU have been structured in a way that incentivises compliance, as the penalties (fines) for missed targets are set to be equivalent to the investment required per gram of CO_2 to comply with the regulations. An unintended consequence of improved fuel economy has however been that consumers have preferred to purchase 'bigger' cars, increasing the number of SUVs in the fleet.

As a result, the strategic choices that auto manufacturers face between EV technologies with regards to their business models, particularly between Plug-in Hybrid EVs (PHEVs) and Battery Electric Vehicles (BEVs), are becoming clearer. While PHEVs mitigate range anxiety among consumers, having two different power trains overcomplicates the manufacturing process[21] and increases the manufacturing cost (the cost of the combustion engine plus the cost of the small electric engine) of the car. According to one expert estimate, the average margin in Europe for ICEVs in the car industry is around 8 per cent, while margins for both PHEVs and BEVs are negative. One view is that while PHEVs will continue to remain unprofitable well into the 2020s, BEVs should achieve break-even by the early 2020s, potentially even beginning to compete on margins with ICEVs by 2025.[22] This will

[20] The European Commission (EC) 2021 target fleet average emissions for all new cars is 95 grams of CO_2 per km (gCO_2/km); in comparison, the average emissions level of a new car sold in 2017 was 118.5 gCO_2/km. EC proposals for 2025 state that average emissions of the EU fleet of new cars will have to be 15% lower than 2021, and 30% lower than 2021 for 2030.
[21] An analogy has been drawn with the 'steam ship with sails' i.e. where sails are perceived as a 'backup' but in fact entail additional (and potentially unnecessary) cost.
[22] Expert projections put the potential margin on BEVs at around 5% by 2025.

most likely be due to technological advancements and associated reductions in battery costs,[23] as well as lower assembly costs for BEVs (relative to PHEVs) since BEVs require fewer components and are easier to manufacture. On the other hand, a move to BEV-based business models implies the loss of revenues from after-sales services that are typical of ICEVs and even PHEVs, and potentially lower employment due to the simpler BEV manufacturing powertrain.

Government regulations in different markets will influence the choices faced by auto manufacturers to some extent. For instance, CO_2 regulations in the US are less strict comparative to other parts of the world, which implies that auto manufacturers could direct investments into improving the efficiency of the ICEV (also known as the 'high efficiency' powertrain). On the other hand, in China and the EU, regulations are much more aggressive and are likely to accelerate fleet electrification. Government regulations will also influence the rollout of EV models by manufacturers in specific markets – for instance, global auto manufacturing companies may tend towards selling EVs in the places where they obtain the most regulatory credits. Auto manufacturers may also vary in the strategies they adopt while moving towards electrification of their fleets – for instance, some companies (e.g. BMW) have opted for a 'modular' approach to manufacturing, whereas others (e.g. Tesla) prefer to go 'all out' in one direction by building brand new platforms tailored to EVs.[24] That said, most of the leading auto manufacturers are global companies, and if a particular strategy takes off significantly in one of their markets (e.g. Europe or China), the chances are that it may be adopted in other markets even where regulation isn't enforcing it (e.g. USA).

[23] To $100/kWh or below.
[24] There are tipping points and trade-offs involved in both strategies, with regards to costs and quality.