EV NETWORK INTEGRATION

GREEN PAPER

Vector

OBJECTIVE

This Green Paper represents Vector's contribution to the evolving discussion around electric vehicle (EV) adoption in New Zealand.

As a large energy network business, Vector wishes to share its insights, informed by a detailed understanding of the electricity network closest to customers, (i.e. the local low-voltage network, which is utilised for EV charging), robust engineering modelling, and research into emerging global trends and changing consumer behaviour.

The objective of the Green Paper is to:

- examine the potential long-term network impact of widespread EV charging;
- identify options that both Government and industry could consider to minimise significant infrastructure investment implications; and
- ensure all stakeholders can make informed decisions to enable customer choice in the uptake of EVs in New Zealand in the short and the longer term.

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EXECUTIVE SUMMARY (1/2)

A key aspect of the discussion on EV uptake is future proofing, informed by customer behaviour, technology advancements and international trends.

Vector is seeing clear trends of longer range vehicles, requiring larger capacity batteries, and customer behaviour that suggests a trend towards faster charging times and clustering of chargers in some areas on the network. These trends necessitate the need for a strategy on EV charging for New Zealand that is future-proof. The perception that networks can absorb the uptake of EV charging is only true for the short term while batteries have a short-range capability, customers are satisfied with long charging times and chargers are evenly distributed across the network. In Vector's view, this will change in the longer term as the uptake of EVs increases.

The potential network impacts of changing customer behaviour or battery technology are most pronounced at the street level. This is where electricity networks have traditionally been sized according to the number of houses on a street, with little spare capacity. The local electricity network was not designed for, or envisaged, any significant uptake of EVs and the consequential demand for charging at home.

The network issues are brought forward when understood in the context of emerging EV manufacturer roadmaps, which have much longer range and larger battery EVs entering the market in the next few years. These larger batteries, combined with customer demand for shorter charging times and increased affordability of high capacity chargers, mean a single EV household has the potential to increase its electricity capacity needs between 100% for very slow trickle charging, and 2000% for rapid charging. This is essentially adding between one and 20 additional 'homes' in terms of network capacity.

These potential street level impacts are magnified by emerging research showing the extent to which EV take-up is commonly 'clustered' in suburbs, bringing forward constraints on existing network investments. Should households purchase more than one EV, the problems magnify further.

As a business, we are technology-agnostic and wish to continue to be a key enabler of customer choice and the adoption of all new distributed energy technologies in New Zealand, including EVs. As such, we have already invested in public charging stations, which has helped mitigate the well-publicised "range anxiety" deterrent to early EV uptake.

However, as battery technology costs continue to fall, car battery sizes increase, and customer demand for longer-range EVs grow, the current model of public charging stations cannot be assumed to be the default charging infrastructure of choice beyond early adopters. Unlike five minute petrol refuelling stops consumers are historically used to, electric charging – even with rapid fast chargers – will test customers' patience.

EXECUTIVE SUMMARY (2/2)

In parallel, as demand and consumer options grow for suitable at home charging technologies, the same larger size/range battery developments will also challenge the assumed viability for at-home overnight "trickle charging". For example, trickle charging Audi's Q6 e-ton (due to market in 2018/2019) will take two full days.

Vector has examined likely EV uptake scenarios from a customer behaviour, engineering, and investment perspective. Even at low EV penetration (10-20% on a network feeder or neighbourhood), low-voltage capacity constraints can occur if charging during peak time and/or using faster charging options. If 7kW chargers are deployed, low-voltage network expansion cost can range from $100 million for 10% to $530 million for 40% penetration.

As with any rapidly changing technology, consumer behaviours can change quickly. As such, and to avoid any chance of network constraints undermining EV uptake or customer choice for charging options, Vector wishes to ensure that all stakeholders carefully consider the infrastructure, regulatory, and software coordination solutions that will best serve New Zealand consumers well in the long term.

Left unaddressed, tipping points for significant network upgrade investment can be expected to have either large cost implications for consumers or eventuate in physical constraints preventing customers from charging their EVs at home. Vector believes that neither scenario will be acceptable from a customer, government or industry perspective. As such, we hope this paper prompts an early and forward-looking conversation that explores initiatives and potential interventions that can avoid either outcome.

While time-of-use tariffs may provide short-term cushioning for network impacts at today's low levels of uptake, longer range/larger battery size EVs, combined with the reducing costs of EV fast chargers, will undermine pricing alone as a credible means to avoid peak capacity levels being breached. Pricing alone fails to recognise the value of dynamic scheduling, which through greater coordination of individual chargers, fully utilises network capacity throughout the day. "Smarter" charging has an added customer benefit of enabling EV users to become market participants whereby, for example, the aggregated, dynamic EV battery load can supplement the generation mix and add to community resilience.

Finally, potential energy inequity issues can arise where network investment is required to accommodate EVs, as the related costs would be carried by all network-connected customers. With the advent of 'internet of energy' network technology and the use of advanced data analytics to dynamically manage EV charging, there are exciting possibilities emerging to help deliver a fairer, more consumer-controlled energy future that serves to minimise such inequities.

We look forward to continuing to participate in this discussion as it evolves, and we welcome feedback on this paper.

CUSTOMER CHOICE

CUSTOMER CHOICE

EVs are perceived positively in New Zealand (NZ). A recent customer survey found that 60% of New Zealanders would consider buying an EV, as opposed to 54% in the United Kingdom (UK). This high interest is distributed evenly throughout the country and across all demographic groups. Customer research is showing that EV interest goes beyond ecological concerns. Therefore, based on customer-interest, a high uptake of EVs is probable in the near future as the current main market barriers are lowered. Currently the three main barriers for customers are the high upfront price, range anxiety, and the time to charge (Figure 1).

EVs are expected to reach cost parity with conventional cars between 2021[3] and 2025[4]. However, the lower operational and maintenance cost and superior driving performance of EVs (e.g. quick acceleration, low noise) means that for most customers, the value proposition of an EV could surpass conventional cars even earlier. This indicates that EVs have reached a tipping point where they will fully disrupt new car sales and lead to strong exponential market penetration. These rapid EV developments are even more remarkable given that oil prices have been low for the last three years. It indicates that car manufacturers believe customer interest in EVs is high for reasons beyond cost-competitiveness alone.

Figure 1: Customer utility increase by improving different EV attributes[2]

The main EV adoption barriers for New Zealanders are high purchase price, range anxiety and charging time. These are all short term in nature. We are already seeing affordable, new technology reducing these barriers.

[1] Ford, R., Stephenson, J., Scott, M., Williams, J., Rees, D. & Wooliscroft, B. (2015). Keen on EVs: Kiwi perspectives on electric vehicles, and opportunities to stimulate uptake, University of Otago
[2] See 1
[3] Arbib, J., and Seba, T. (2017), Rethinking Transportation 2020-2030
[4] Bloomberg New Energy Finance:

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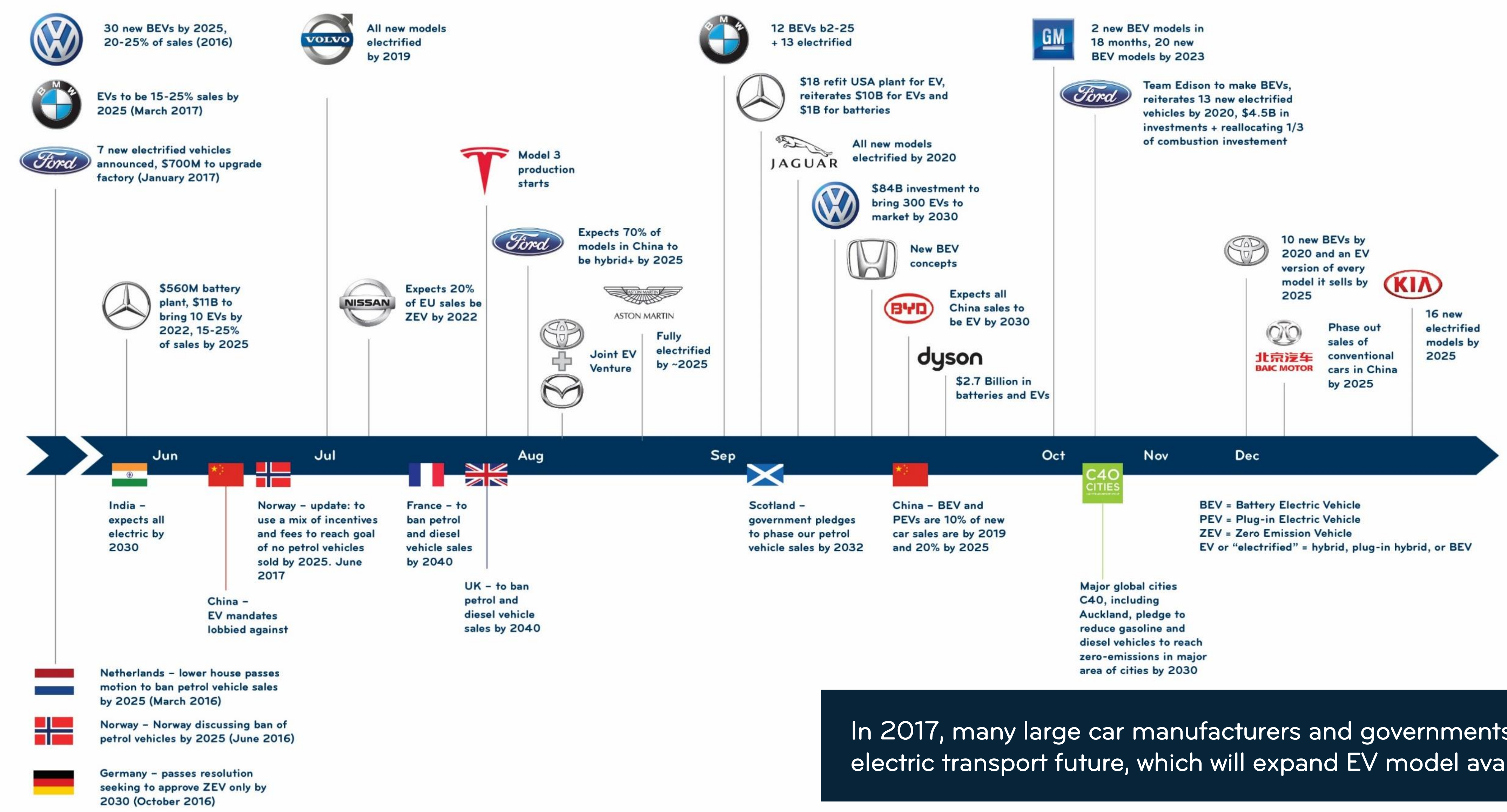
GLOBAL MOMENTUM FOR VEHICLE ELECTRIFICATION

Figure 2: Announcements from major car manufacturers in 2017[5]



In 2017, many large car manufacturers and governments committed to an electric transport future, which will expand EV model availability.

[5] Adapted and updated from https://www.teslarati.com/automakers-come-acceptance-ev-revolution-begun/

EV INTEGRATION IN LOW VOLTAGE NETWORKS

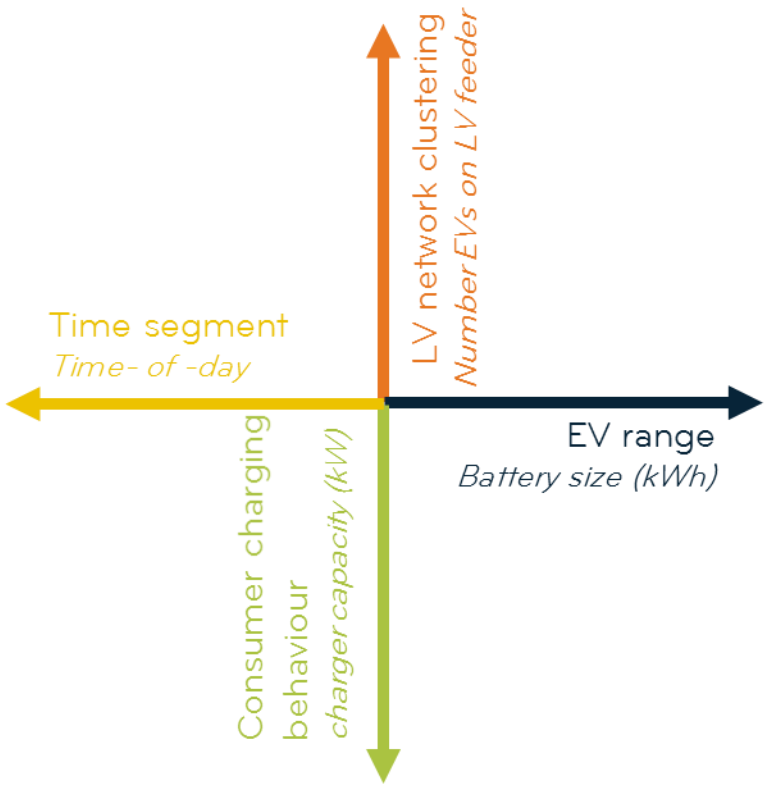
INVESTMENT UNCERTAINTIES

Customer-driven technology disruption is leading to a paradigm shift in electricity networks and markets. The part of the network that empowers the customer, the low voltage network, is becoming increasingly important. As a result, future network investment will increasingly shift away from higher distribution and transmission voltage levels, as consumers exercise choice and change behaviours. This will also create a new, localised electricity market as opposed to the traditional centralised generation and transmission dominated market.

The network impact of EV network integration will depend on four main uncertainties (Figure 3) that will be discussed in more detail on the next slides:

- Uncertainty 1: EV uptake and network clustering
- Uncertainty 2: EV range and battery size
- Uncertainty 3: Consumer charging behaviour (charge anxiety and charger capacity)
- Uncertainty 4: Customer choice around the time of charging

Figure 3: EV-driven uncertainties for network investment



The 4 main uncertainties for EV network integration are network clustering, EV range, customer charge anxiety and charging timing

UNCERTAINTY 1: EV UPTAKE AND NETWORK CLUSTERING (1/2)

Based on early NZ and international experience, EV growth is characterised as being exponential, urban and clustered in individual neighbourhoods.

The number of EVs on NZ roads is currently low (6160 EVs were registered as at 31 December 2017), but uptake is expected to increase exponentially, achieving the government target of 64 000 EVs (2% of current car fleet) by 2021, or even more if the current growth rate continues. International experience on EV adoption also reflects strong exponential growth (Figure 4).

EV adoption is likely follow an exponential growth curve.

Figure 4a: Number of EVs in national fleets internationally[6]

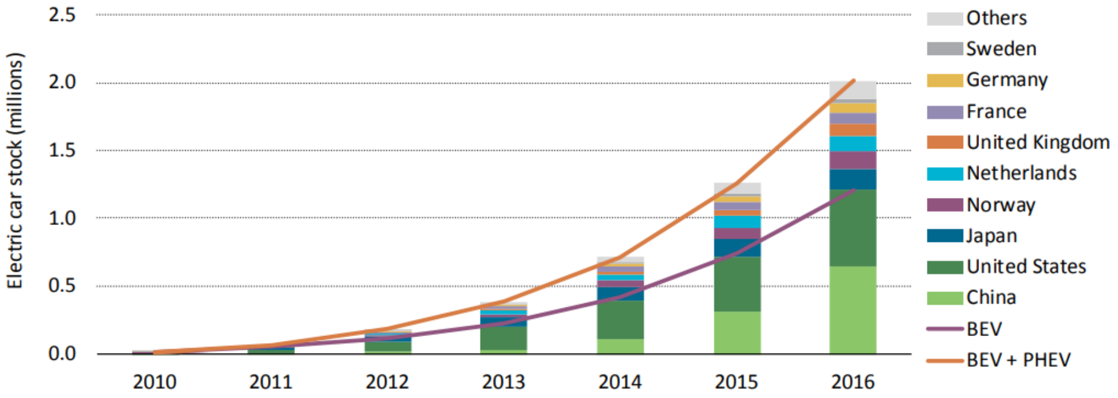
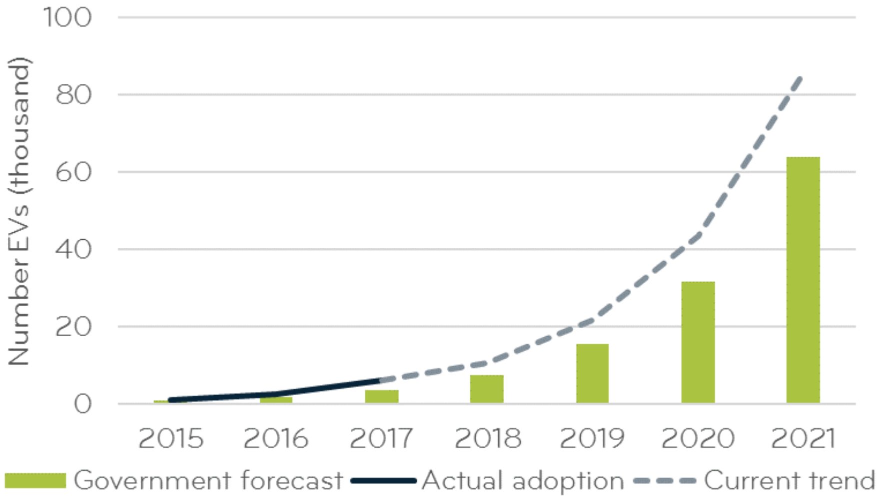


Figure 4b: Number of EVs in national fleet in New Zealand



[6] International Energy Agency (IEA) (2017), Global EV Outlook

UNCERTAINTY 1: EV UPTAKE AND NETWORK CLUSTERING (2/2)

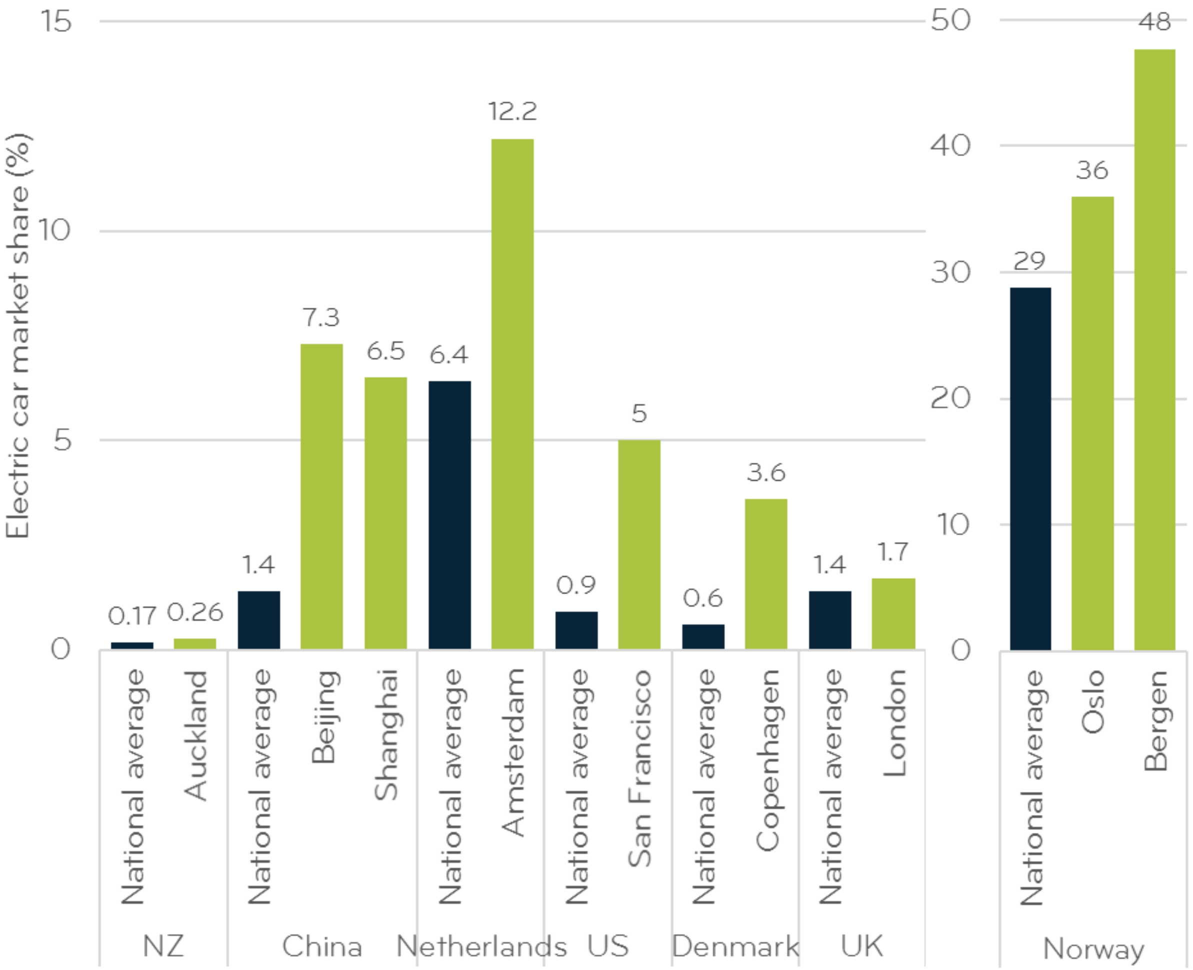
Due to the shorter ranges of EVs as opposed to conventional cars, EV growth in major cities is higher than national averages. Auckland is the hub of EVs in NZ, with one out of two EVs registered in Auckland (while only one in three New Zealanders live in Auckland). If this trend continues, we could see one in 15 households in Auckland with an EV by 2021. This is also in line with international experience (Figure 5). For example, market share in Amsterdam and San Francisco is twice and five times the Dutch and United States (US) national average.

Within cities, EV penetration is not evenly spread and growth is higher in certain neighbourhoods, where EVs cluster due to peer influencing, higher income level, infrastructure availability, and other factors which encourage early adoption. An analysis of Christchurch for example, has identified a neighbourhood clustering of hybrid cars[7].

Exponential EV adoption, exponential EV purchase price reductions, and superior driving performance means that EV sales could disrupt the conventional car market in the short term and exceed most adoption forecasts post 2020. Preparing the network today to accommodate for a high EV penetration is therefore a priority for Vector, especially given that clustering requires active engagement with consumers to manage EV integration into the network.

EV growth is stronger in cities than national averages.

Figure 5: EV penetration in major cities and national averages[8]



[7] Grenier, A., Page, S. (2012), The impact of electrified transport on local grid infrastructure: A comparison between electric cars and light rail, In Energy Policy, Volume 49, 2012
[8] see 6

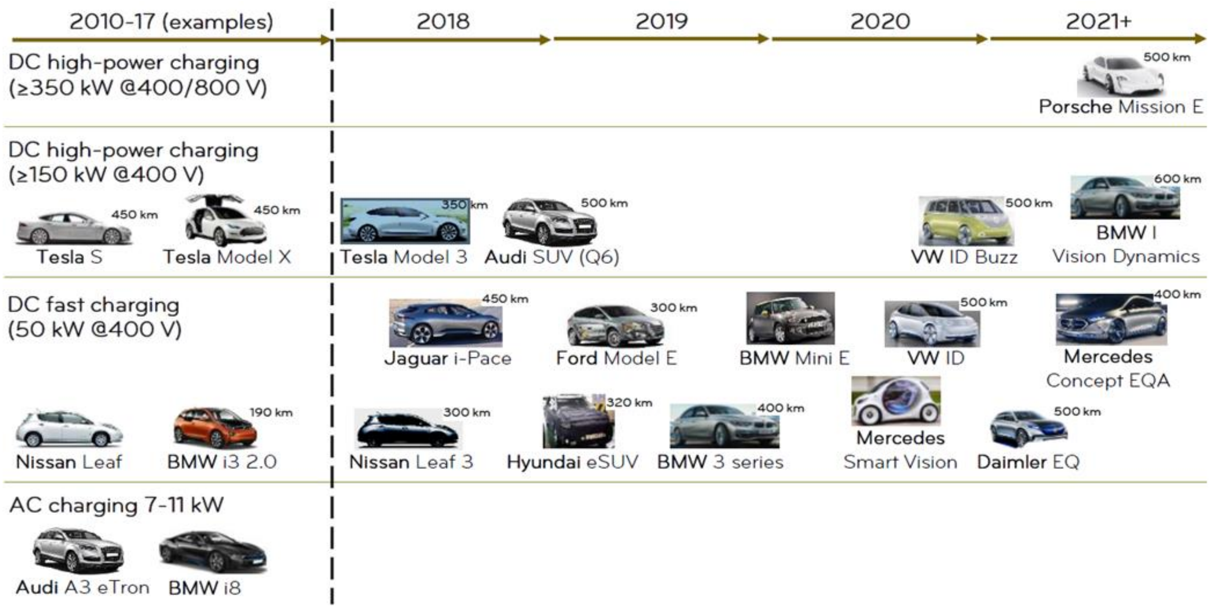
UNCERTAINTY 2: EV RANGE AND BATTERY SIZE

The EV fleet in NZ comprises a variety of vehicle types, battery sizes, ranges and charging requirements, largely because the majority of vehicles are second-hand. Based on data from Vector's rapid charging stations, 92% of EVs in Auckland currently have battery capacities with between 10kWh and 30kWh, which corresponds to an electric range of roughly 50 to 150 km. As a comparison, a second generation Nissan Leaf has a 28kWh battery and 150km range. Today, only 4% of EVs have battery sizes over 50kWh.

However, in the next couple of years, the market share of EVs with longer electric ranges (and battery sizes) is expected to grow. As shown in Figure 6, new EV models will have an average range of 350-500km. The long-range cars shown in Figure 6 will have batteries of up to 100kWh. As a point of reference, a standard Tesla Model 3 has a range of 350km with a battery size of 50kWh, and the third-generation Nissan Leaf 2018 has a range of 250-400km with a battery size of 40-60kWh.

Larger batteries take longer to charge and might even make over-night charging practically unfeasible unless faster charging technologies are adopted.

Figure 6: EV models in New Zealand market and compatibility for different charging technologies[9]



New EV models have the potential to charge at increasingly higher capacity levels.

[9] Adapted from ABB presentation

UNCERTAINTY 3: CONSUMER CHARGING BEHAVIOUR

Larger battery sizes will compound the need for faster charging capabilities to reduce charging duration. Figure 7 shows the difference in the time required to charge a short-range battery (135 km) and a long-range battery (500 km) based on different charger types.

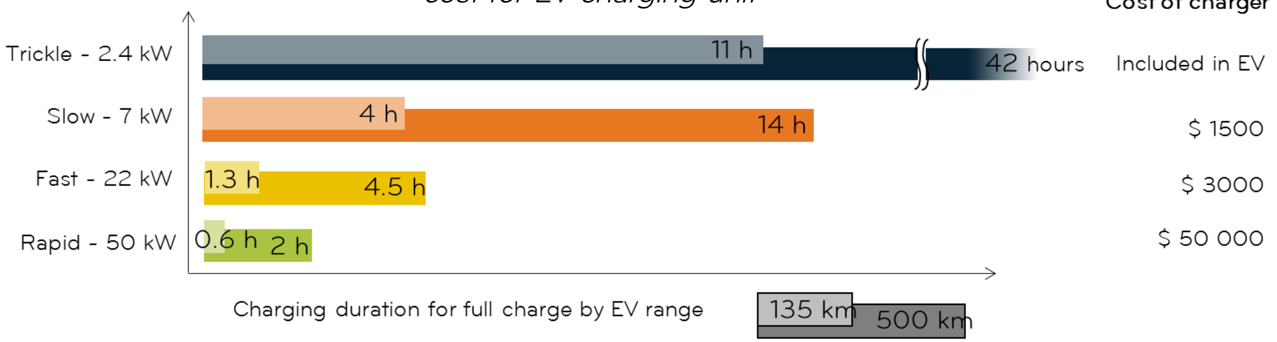
EV chargers put a large electrical load on the network, with a capacity that varies between 2.4 kW and 50 kW based on current technologies. Upcoming super-fast charging technology that will be available in NZ late 2018, will be capable of charging loads between 150-350 kW.

An average house has a load impact of 2.5 kW, which means that every EV trickle charger (2.4 kW) effectively adds another home to the network. Given the long charging times associated with trickle charging, Vector expects customers to opt at least for the 7kW slow charger whenever financially possible. Adding a 7kW charger equates to the equivalent of 2.8 homes being connected to the local network. A fast (22kW) and rapid (50kW) charger equals to 8.8 and 20 new houses being added to the local network (Figure 8).

With longer EV ranges, the customer value for higher capacity chargers and shorter charging duration increases. Faster chargers may therefore be necessary to avoid "charge anxiety," that may limit the potential for EV mass market adoption.

Depending on charging technology, connecting one EV is equivalent to an additional one to 20 new homes on the electricity network.

Figure 7: Time duration to full charge for different charging technologies and cost for EV charging unit



Notes:

i) A range of 135 and 500 km is equivalent to 28 kWh (e.g. Nissan Leaf) and 100 kWh battery (e.g. Audi Q6 e-tron) capacity;

ii) All charger costs are based on Vector market research and exclude any network or customer premise upgrade costs.

Figure 8: Capacity of different charger types compared to average household connection capacity

UNCERTAINTY 4: TIME OF CHARGING

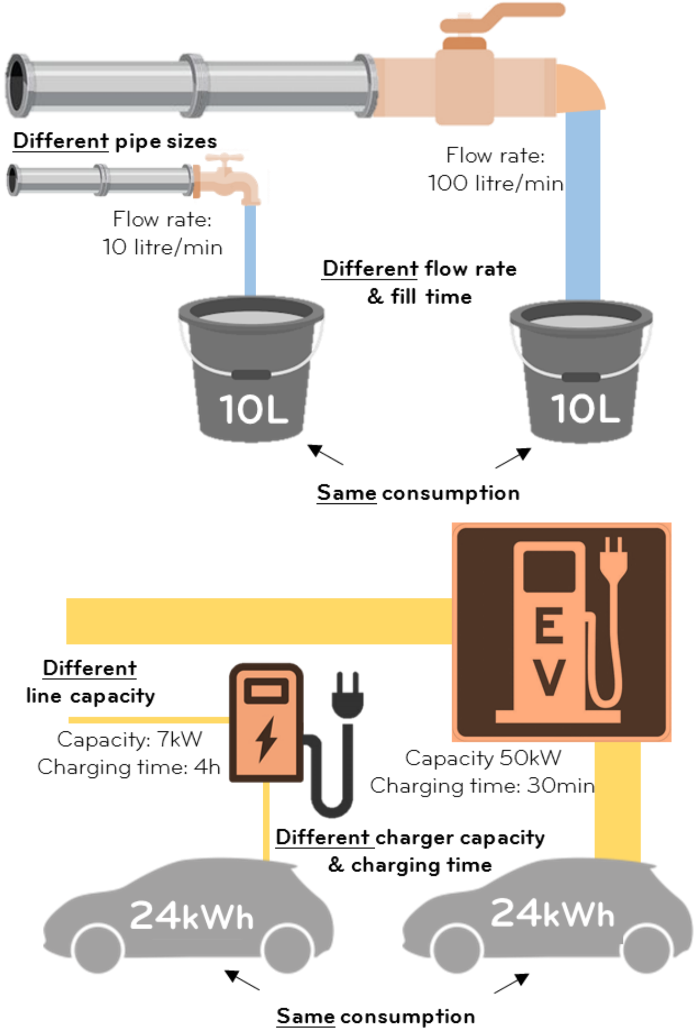
In NZ, 90% of travel by light vehicle is less than 100km a day, and the average daily distance travelled is 29km. This means that the average residential customer would only need to charge every third day for two hours at home. However, driven by range anxiety and probably a preference for routine and convenience, EV drivers currently prefer to charge where possible and top up to 100%.

Home-charging EVs, which represents 95% of residential customers, are plugging in every night, even if a charge is not required to fulfil the next day's driving needs. International experience confirms this trend for both full battery EVs and plug-in hybrid EVs[10].

The network loading varies across the day and year. The electricity network is dimensioned by power capacity (and peak demand), not by energy consumption. As the analogy with water in Figure 9 illustrates, filling up the same battery in a shorter time at a higher charging rate, will require a 'thicker' power line (as well as related equipment such as transformer and protection gear) to provide this capacity.

It is not the battery size, but the capacity of the charger, which defines power line capacity and investment requirements.

Figure 9: Analogy between water and electricity infrastructure to illustrate the difference between power and energy



[10] see 6

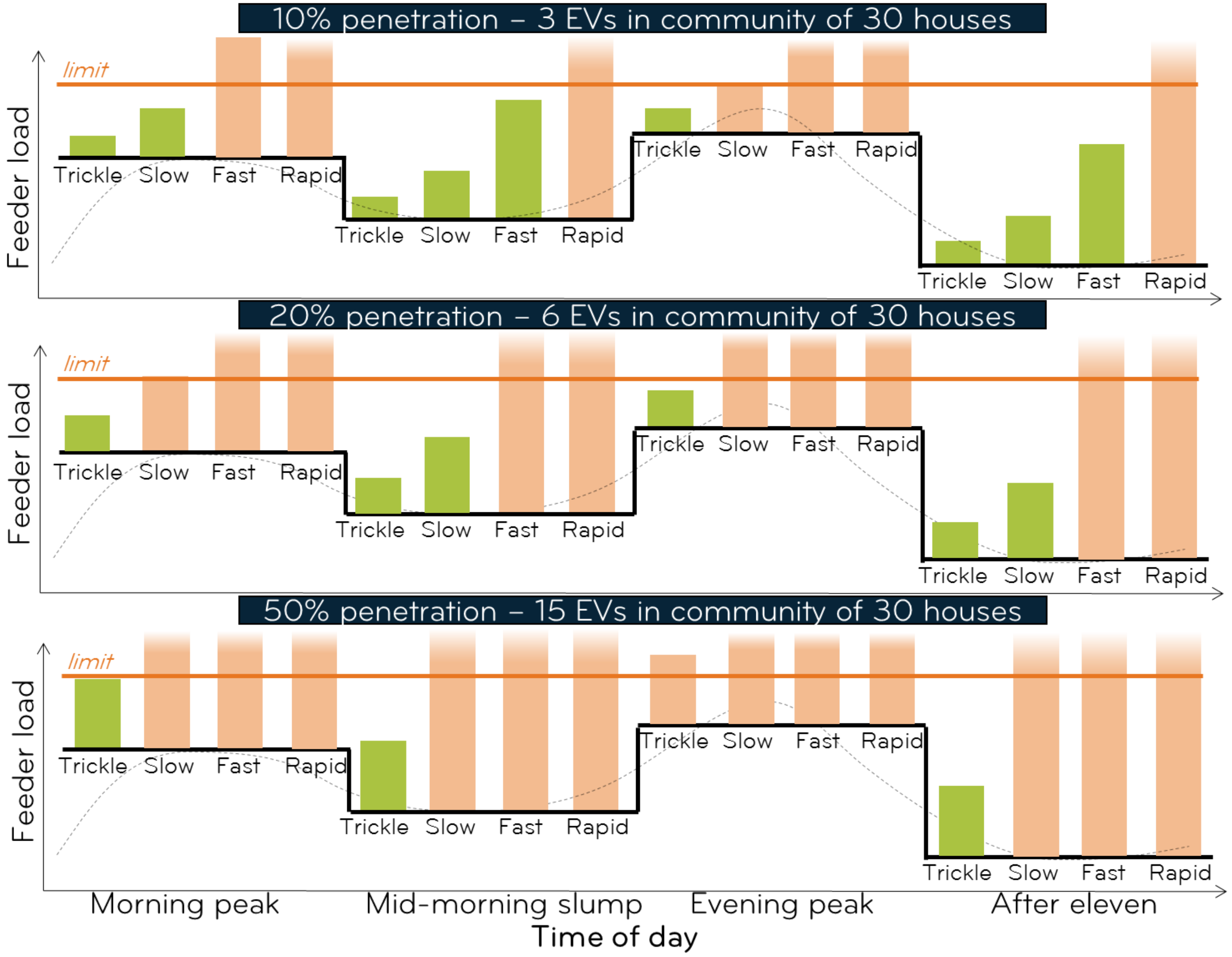
EV NETWORK INTEGRATION CAPACITY (1/2)

Exponential growth, combined with local clustering in urban areas, especially Auckland, means that the impact of EVs on the electricity system will be primarily on low-voltage distribution networks. Apart from the adoption/diffusion of EVs, which depends on the consumer's decision to buy an EV, the network impact depends on the EV battery characteristics, charging technology, location of charging, and time of charging.

Vector has assessed the capability of the existing network to accommodate EVs based on different penetration rates, battery sizes, charging capacities and across different part of the day. Figure 10 illustrates the impact of different charging scenarios for a typical low-voltage feeder of 100kW and 30 customer connections. The analysis highlights that the connection of fast and rapid chargers will stress or surpass the network capacity even at penetrations as low as 10%. The network headroom for trickle and fast chargers is larger, especially during parts of the day when demand is low. However, charging duration may be the limiting factor for customers for these chargers.

Even at 10% EV penetration, low-voltage capacity constraints can occur if charging during peak time and/or using faster charging options.

Figure 10: Low-voltage network capacity limits for different EV penetration and charger types



EV NETWORK INTEGRATION CAPACITY (2/2)

There is a trade-off between higher capacity chargers and charging duration in terms of low-voltage network integration. The adoption of high capacity chargers with shorter charging duration will reach existing network limits even at very low penetration (<10%) and when charged during the night (off-peak). Slower chargers can accommodate higher penetration, especially off-peak, but require longer charging durations that reduce the potential of overnight charging.

Figure 11: EV connections possible (%) on a typical low-voltage feeder across different times of the day for different chargers.

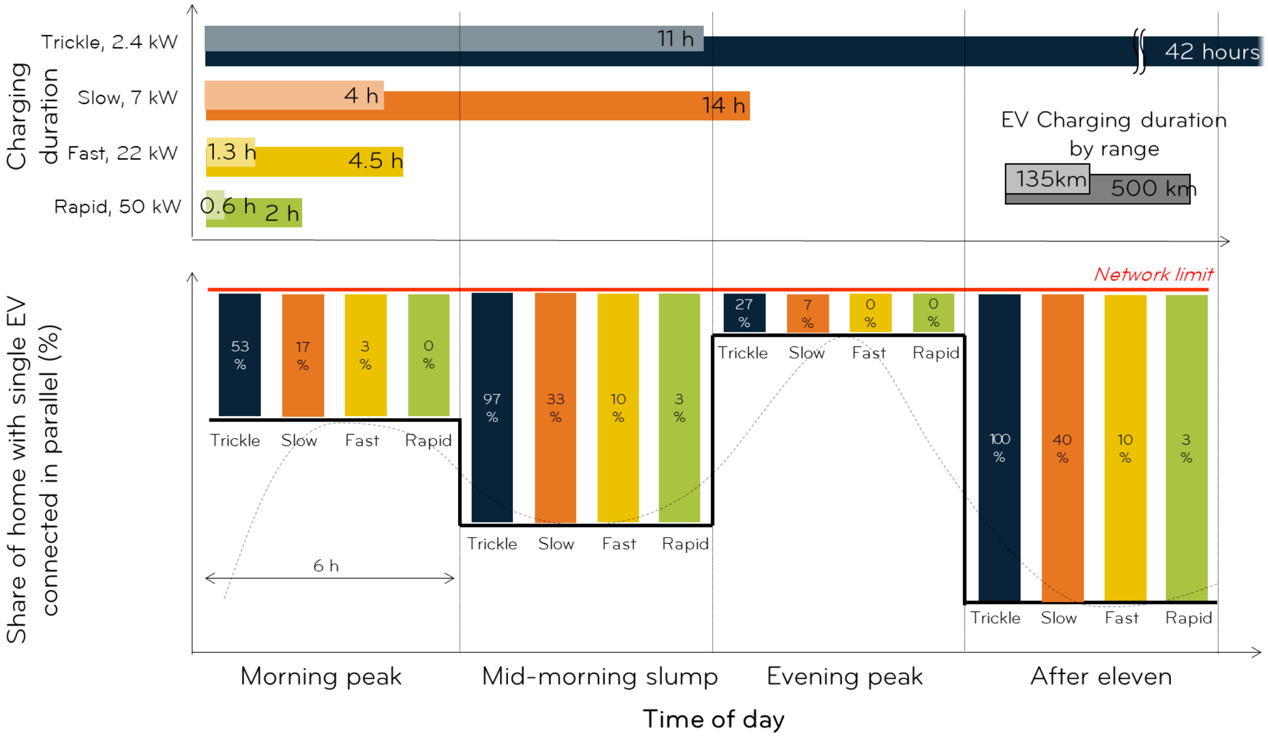
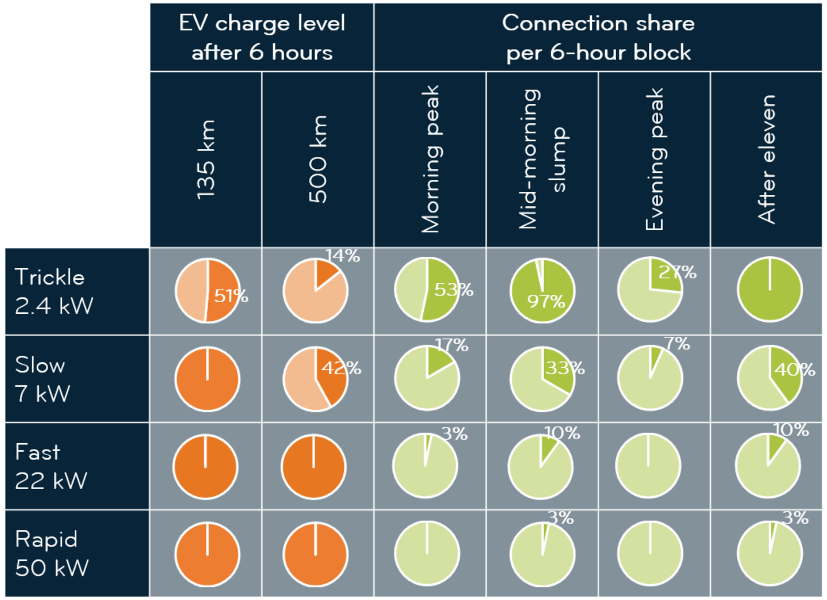


Figure 11 shows the share of homes with a single EV that can be connected in parallel to a typical low-voltage network for different charger types, while also indicating the duration that the EVs would need to be connected in order to be fully charged. Clearly, even if overnight charging allows for a high number of connections, it cannot fully charge a long-range EV during that time.

The network integration of EVs will depend on both the capability to accommodate different charger capacities and the capability to provide sufficient battery energy within the time connected. Figure 12 illustrates the EV battery charge during a six-hour block and the network headroom for parallel connections.

Figure 12: EV charge and connection in different 6-hour blocks across the day



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INVESTMENTS FOR EV NETWORK INTEGRATION

As discussed in a previous slide, the additional load from EV charging could result in the overloading of local networks, depending on the extent to which these chargers are clustered on the same circuit. This in turn will require network reinforcement to avoid overloading of assets.

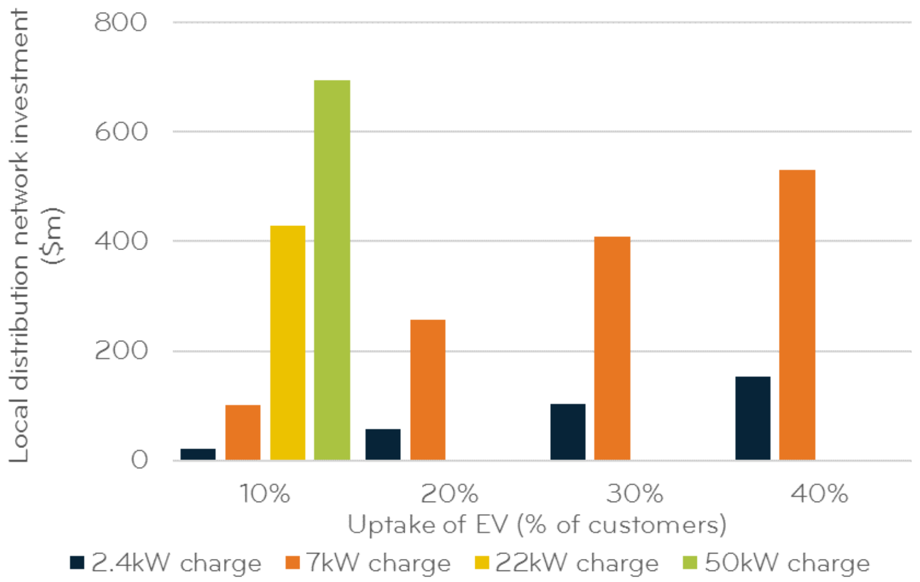
A UK study[11] estimates that 32% of the low-voltage feeders (i.e. 312,000 circuits) will require reinforcement by 2050 to cope with clustered EV uptake. This has a price tag of GBP 2.2 billion by 2050 (based on 40-70% of customers having an EV charging at 3.5 kW). This impact on the network will be exacerbated if customers opt for higher capacity chargers. These findings are supported by a recent report from the Sacramento Municipal Utility District (SMUD), which forecasts that EV-related overloads could necessitate replacing 17% of its transformers by 2030 at an estimated cost of USD 89 million[12].

In a similar investment analysis, Vector assessed the investment requirements to integrate EV charging at home for four different EV penetration levels (10, 20, 30 and 40%) and different charger capacities (Figure 13). The level of investment that would be required to reinforce the local network in order to accommodate 2.4 kW-trickle charging could range between $22 million - $154 million depending on the EV penetration. If 7kW chargers are adopted, the level of investment that would be required to reinforce the local network would be substantially higher and could range between $100 million - $530 million.

Figure 13 summarises the impact of the uptake of EVs on Vector's distribution networks for the adoption of both 2.4kW and 7kW chargers at different EV penetration levels. As a reminder, the trickle and slow chargers represent the load of 1 new and 2.8 new houses, respectively.

As the previous analysis (Figures 10-12) for typical feeders has indicated, the very large capacity of fast and rapid chargers, which represent 8.8 households and 20 households, can only accommodate very small penetrations (<10%) even if used in the middle of the night when demand is typically low. The large capacity of these chargers would lead to very high level of low-voltage network reinforcements, which would also trigger investment further upstream in the electricity system. Investment cost requirements for penetrations of 22 and 50kW chargers higher than 10% are therefore not assessed in Figure 13.

Figure 13: Investment impact of the uptake of EV on low-voltage distribution networks



[11] Electric Avenue (http://myelectricavenue.info) and ICF (2016), Overview of the Electric Vehicle market and the potential of charge points for demand response
[12] SEPA and Black & Veatch (2017), Planning-for the distributed energy future Vol II: A case study of integrated DER planning by Sacramento Municipal Utility District

COST ALLOCATION AND EQUITY POLICY FOR NETWORK REINFORCEMENT

The integration of EVs into the electricity network and the potential impact on infrastructure investment needs to be carefully considered to avoid overloading and excessive peaks that could jeopardise physical reliability as well as customer equity.

Network reinforcements could create an equity issue between EV and non-EV owners. Network investments due to EV penetration would most likely be subsidised by non-EV owners under today's regulation. This could be perceived as adequate due to the wider societal benefits of EV adoption, such as CO2 reduction and energy security improvements. However, public perception may judge that differently. The desire of some EV owners to acquire fast chargers will considerably accentuate investment needs for all network customers, with largely private benefits by reducing charging durations for individual EV owners.

An equity issue might also develop among EV owners. Network investments on a low-voltage feeder are triggered by the connection request that would breach the existing network capacity. However, the EV owner that causes the network reinforcement can not be expected to cover the full cost. All previously and future-connected EV owners would otherwise benefit from a free-rider bonus and share the cost for the benefit they incur from the network. A cost allocation policy will need to be prepared to manage equitable grid access.

Vector views EV integration as a priority to deliver an equitable, cost-effective and resilient network that provides customers with choice on how they power their transport needs and at the same time realises the social value proposition of EVs for NZ.

Network reinforcements could create an equity issue between EV and non-EV owners.

INTERNATIONAL APPROACHES

An international review provides a set of different approaches to deal with efficient network integration of EVs.

EV REGISTRATION AND TARIFFS

Registration

Registration of EV connections and charger types by EV owners would facilitate coordination of electricity distribution planning and operation. EV registration data and/or consumption data from smart meters can provide information on charging behaviour. This data can support the forecasting of loads and the planning of electricity networks, in particular at low-voltage level where little data is available.

In the UK, the parliament is currently considering a bill that would require all EV chargers, for both domestic and public applications, to have smart meter capabilities to interact with the grid[13].

Tariffs

A special EV tariff with lower prices during off-peak times can incentivise EV charging off-peak.

The US behavioural trial "EV project" [14] found that charging can be impacted by different tariff structures. The project involved 4000 privately-owned EVs (90% Nissan Leafs and 10% Chevrolet Volts) across different stated in the US. In Nashville, where no Time-of-Use (ToU) tariff is in place, the EV charging demand coincided with the existing peak demand, while in California which has a ToU tariff with three prices for off-peak, partial peak and peak, the EV peak shifted to off-peak times around midnight. However, the project involved mostly early adopters of EVs that are more responsive to support EV integration.

Southern California Edison (SCE)[15] carried out a workplace charging pilot to reduce afternoon peaks and learn more about driver behaviour and responsiveness to pricing signals. The program included a high price option, allowing users to have no charging disruption; a medium price, allowing for peak demand curtailment from a fast charging to a slow charging rate; and a low price, allowing drivers to be entirely curtailed during peak demand. This study, as well as another SCE study focussing on peak rebates, confirmed that EV owners want the option to opt out if they need to charge at certain times, which highlights the need to give customers flexibility.

At high EV penetrations, tariffs may not be sufficient to account for the impact on local low-voltage networks as tariffs are based only on wholesale prices. A tariff is also a static price signal which does not reflect how EV owners respond to those price signals. These solutions are therefore only tenable at low EV adoption, but do not enable the transition to high levels of EVs without possible unintended consequences. In particular, all drivers receiving a static price signal could schedule charging to start at the moment rates drop and this would result in a 'timer peak' in which load ramps too sharply for the power system to effectively respond.

[13] Pratt, D. (2017), All electric vehicle chargers sold in the UK to be 'smart' under government plans, article on www.cleanenergynew.co.uk
[14] US DOE (2014), Evaluating EV Charging Impacts and Customer Charging Behaviours – Experiences from Six Smart Grid Investment Grant Projects
[15] SCE (2016), Southern California Edison Plug-in Electric Vehicle Workplace Charging Pilot

MANAGED CHARGING AND CONTROL

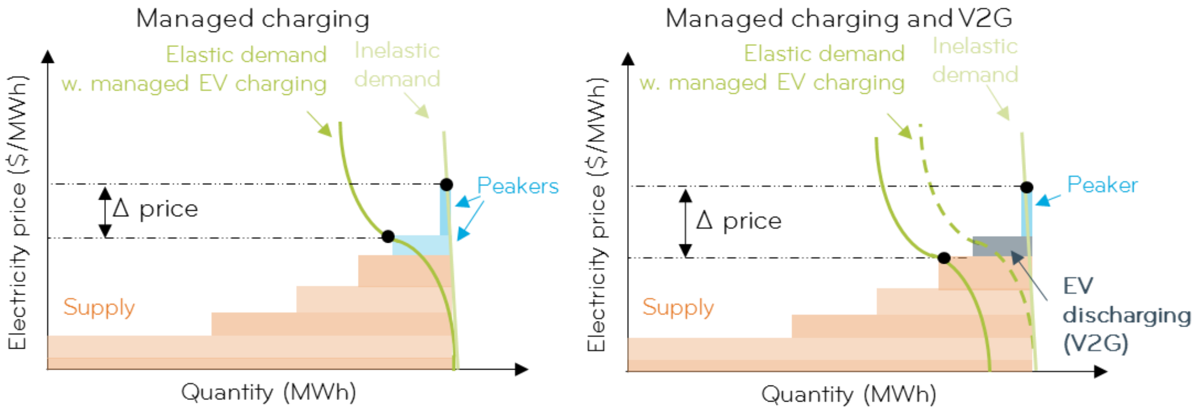
At high EV penetration levels, a dynamic or staggering charge algorithm can co-ordinate charging of the entire EV fleet based on a variety of variables, including but not limited to, charge status, EV owner's desired departure time, local network congestion and wholesale market price.

In the UK project 'Electric Avenue' for example, the aggregate EV demand can be shifted so that the peak occurs after midnight via managed charging. Under such a scenario, electricity system asset utilisation is increasing, and should reduce network charges for consumers. A study in California found that managed charging could reduce the costs of delivering electricity to an EV in California from USD 1,400 to less than USD 600, for a benefit of USD 850 per vehicle[17].

The IEA's "Digitalization and Energy" study[18] quantified the benefits of managed charging on a global level. The study finds that in a medium growth EV scenario where 150 million EVs are deployed by 2040, 140 GW of capacity is needed to meet standard EV charging needs. However, if managed charging is implemented, capacity requirements are reduced by nearly half (65 GW). In terms of financial benefits from capacity expansion alone, managed charging avoids USD 280 billion in transmission and distribution investments and USD 100 billion in new power generation capacity.

Managed charging empowers the customer to actively participate in the market at an aggregate level as customers will have the possibility to react to higher market prices by dynamically adapting their charging behaviour. This means that customer demand is becoming increasingly elastic through managed charging, which especially during peak times, can lead to substantial market price and carbon reductions by displacing expensive and polluting thermal peaking plants (Figure 14)

Figure 14: Supply and demand curve with price elasticity from managed EV charging (Adapted from [19] and [20])



Increasingly elastic demand from managed charging and EV discharging through V2G can reduce peak load prices, reduce carbon emissions, and increase customer benefits.

[17] ICT (2014), California Transportation Electrification Assessment Vol 2 – grid impacts
[18] International Energy Agency (IEA) (2017), Digitalization and Energy
[19] Regulatory Assistance Program(RAP) (2017), Unleashing Demand Response with Effective Supplier Compensation
[20] PJM (2017), Demand Response Strategy

VEHICLE TO GRID (V2G)

One of the most advanced and valuable forms of smart charging is vehicle-to-grid (V2G), or two-way charging. V2G allows electric vehicle batteries to discharge power back into the grid when needed, making the batteries an energy storage resource in addition to a mobility device. With full V2G capabilities, electric vehicles could be charged when power is cheapest and most abundant and fed back to the grid when the power is most valuable (i.e. during peak demand, Figure 14), providing financial benefits to customers. In most scenarios, a group of electric vehicles would be linked together to send power into the grid, forming a "virtual power plant".

The benefits of V2G for EV owners also include backup power for homes and businesses in the case of a fault or outage, which increases resilience. Additionally, if solar PV is available, EV owners can increase their self-consumption of solar PV given that solar supply is often exceeding demand during the sunniest parts of the day. For the electricity system, V2G provides an even stronger potential for demand response (DR) to further reduce peak load and increase asset utilisation of the network as well as increasing reliability and resilience of the local community and providing a variety of ancillary services including voltage control, frequency regulation and spinning reserve[21].

A Nissan-led V2G trial in Denmark revealed that EV owners could earn up to EUR 1300 per year by supporting grid balancing[22]. Nissan has conducted trials in other countries, but was only able to quantify the balancing benefits for Denmark given that it is the only market where EVs are able to earn money by feeding electricity back into the network.

The UK government is currently also offering up to GBP 20 million to carry out feasibility studies on V2G[23]. The US Department of Defence has trialled the potential of 42 EVs to provide capacity-based services, including spinning and non-spinning reserves, frequency regulation and peak power shaving, to the system operator CAISO. The economic benefits were estimated to range between USD 1 800 and 2 500 annually[24]. Table 1 summarises some other international V2G trials[25].

Table 1: International comparison of financial benefits for V2G

Service offered	Region	Est. annual value (NZD)	Source
DR	California	up to 1436	BMW USA, 2016
V2G regulation	US Mid-Atlantic	2520	Market et al. 2015
V2G regulation	California	3528	Gorguinpour, 2013
DR, V2G regulation (3.3kW)	Washington	1050	Markel et al., 2015
V2G regulation (1.3kW)	New York	388 – 1172	White & Zhang, 2011
V2G regulation (10kW)	New York	3080 – 3500	White & Zhang, 2011
DR	New York	109	MJ Bradley, 2015
V2G regulation (SRL)	Germany	1366	Schuller & Rieger, 2013
V2G regulation (3.7kW)	Germany	770	Raths et al., 2013
V2G regulation (SRL)	Germany	854 – 1099	Arnold et al., 2016
DR, load shifting	Spain	228	Madina et al., 2016
V1G regulation	Spain	392	Madina et al., 2017
CA LCFS credit sales	California	416	CARB, 2016

Based on trial *Based on model*

Notes: DR = demand response (on/off control); V1G = fully-controlled one-way charging; V2G = vehicle-to-grid (two-way) smart charging; SRL = secondary reserves; LCFS = Low Carbon Fuel Standard LCFS credit sales calculated assuming a 2016 Nissan Leaf with average U.S. driving habits, charged with electricity from the California power grid. The values shown in the third row reflect modeled values for a real trial project at the Los Angeles Air Force Base in California—final values are not publicly available. Converted from USD at 1.4 NZD/USD

V2G can provide financial benefits to EV customers.

21 Yilmaz, M., and Krein, P. (2012), Review of Benefits and Challenges of Vehicle-to-Grid Technology,IEEE Energy Conversion Congress and Exposition (ECCE)
22 Bloomberg (2017), Parked Electric Cars Earn $1,530 From Europe's Power Grids https://www.bloomberg.com/news/articles/2017-08-11/parked-electric-cars-earn-1-530-feeding-power-grids-in-europe
23 Innovate UK (2017), Innovation in vehicle-to-grid (V2G) systems: feasibility studies
24 EPRI (2016), Vehicle-to-Grid - State of the Technology, Markets, and Related Implementation
25 International Council on Clean Transportation (ICCT) (2017), Literature review on power utility best practices regarding electric vehicles

PUBLIC CHARGING AND FUTURE OF NON-OWNERSHIP

Public charging

The availability of public charging infrastructure supports the increased uptake of Evs as it enables the possibility to complete journeys beyond the battery range and reduces range anxiety. Offering public fast-chargers in proximity to residential neighbourhoods could also discourage customers from installing the more expensive fast and rapid chargers at home and therefore reduce low-voltage network impacts.

In order to harness the potential of analytics and digitalisation, communication and data exchange should be facilitated primarily to understand EV owner behaviour and the need to provide adequate charging infrastructure. Amsterdam, a city leader in EV uptake, has put in place a demand-led public charging expansion plan[26]. Under this plan, EV owners put in an online request for a new public charging location. The request is evaluated based on the walking distance to the nearest existing station, the occupancy rate of the nearest stations and previous requests for the location under consideration.

The city of Amsterdam is also collaborating with local universities to learn from data collected at the 2000 charging points and 48000 monthly charging sessions. Apart from building national research capabilities, this data has provided a deeper understanding of consumer behaviour and is expected to provide insights on how to influence behaviour and optimise the future roll-out strategy for EV charging infrastructure.

Future of non-ownership

The emergence of car-riding schemes such as Uber and Lyft are part of a global trend towards a sharing or on-demand economy. In such an economy, expensive assets with low utilisation, such as cars, are no longer owned by individuals since service providers are able to offer the same service at a lower cost by increasing utilisation of the assets, such as more trips per car. In the mobility sector, this is also referred to as 'Transport As A Service' (TAAS). Due to their lower operation and maintenance cost, EVs will strengthen the TAAS business model by lowering life-cycle cost compared to conventional cars. The penetration of autonomous drivers could further lower the cost of TAAS and mean society, at least in cities, could see a massive shift away from personal car ownership to fleet ownership in TAAS.

Such a future is possible within the next 10 years and would considerably change charging requirements and low-voltage network impacts. Fleets would be charged at a depot or public charging points that connect to the network at high-voltage level and does not stress the grid at local low-voltage level.

[26] Vertelman, B. and Bardok, D. (2016), Amsterdams demand-driven charging infrastructure

CHARGING AHEAD

NEXT STEPS TO SUPPORT EV UPTAKE

Effective electricity network integration is a key pillar of successful EV uptake. In order to ensure customer choice and support EV uptake in NZ, future network investment and integration risks need to be considered today while taking into account technical, regulatory, affordability and societal implications.

Even at today's low EV penetration – co-ordination and knowledge development are essential to enable the transition to high EV penetration and avoid duplication cost, ex-post interventions, as well as developing a positive public image of EVs and EV charging infrastructure.

Vector is looking to engage with leading stakeholders in NZ to collaborate in research and demonstration programs, exchange expertise and data, and develop a regulatory framework in which EVs can thrive and NZ can reap the societal benefits of EV uptake identified by the government.

CREATING A NEW ENERGY FUTURE

ENGAGE WITH US TO SUPPORT EV UPTAKE

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