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**“Driving change” –  
Issues and options to maximise the  
opportunities from large-scale  
electric vehicle uptake in New  
Zealand**

**Prepared for Orion, Unison, and Powerco**

**7 March 2018**



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## Executive summary

### *What is this report about?*

Concept and the three network companies who have sponsored this report, think electric vehicles (EVs) have the potential to be a fantastic opportunity for New Zealand, both in terms of massive gains to the environment, and in terms of delivering genuinely cheaper transport services.

However, we believe that current electricity supply arrangements will frustrate realisation of these benefits – and will also result in EV uptake causing unnecessary costs.

There is the potential to change our electricity supply arrangements to maximise the good outcomes from EV uptake and minimise the bad. However, there are some real challenges to overcome before we get there, with some difficult choices and industry coordination challenges. Further, with mass EV uptake just around the corner and greenhouse reduction targets getting ever-more urgent, there is a real time imperative to resolving this issue.

We hope this report will be a useful contribution to the broader industry and consumer / political discussion about how we can make the changes to deliver the best outcomes for New Zealand.

### *A continuation of current electricity pricing approaches will result in higher costs and emissions*

Large-scale uptake of low emission vehicles is arguably the single most important element required to meet the government's target of net-zero greenhouse gas emissions by 2050. Further, it looks increasingly likely this need will be met by electric vehicles (EVs), as falling battery costs offer the prospect of genuinely cheaper transport compared to internal combustion engine (ICE) vehicles.

However, the current approach for charging for electricity – i.e. predominantly 'flat' \$/kWh prices which don't vary across the day<sup>1</sup> – will frustrate achievement of the benefits and also result in unnecessary costs being incurred:

- EV-owners will pay significantly more than they should for charging their vehicles. This will slow the rate of uptake of EVs, significantly increasing New Zealand's emissions and increasing overall economic costs.
- Those households who do purchase EVs will mostly adopt a 'passive' approach for re-charging their batteries: i.e. simply plugging-in and starting charging as soon as they get home. Unfortunately, the time most people get home – early evening after getting back from work – is also the time of peak electricity demand. The scale of demand from EVs is such that this will soon start to trigger expensive network capacity investments in many areas. Plus, additional fossil-fuelled generation will be required if charging is done at times of peak usage.

Overall, we estimate that a permanent continuation of current pricing approaches will result in unnecessary increased costs of approximately \$4bn (in present value terms, or \$14bn in future cost terms), and CO<sub>2</sub> emissions from internal combustion engine vehicles (ICEs) being over one-third greater in 2050.

These financial and environmental costs are avoidable with smarter, more cost-reflective electricity prices which encourage EV-owners to charge their vehicles smoothly overnight in off-peak periods. Such smarter pricing, working in tandem with the technology embedded in EVs and their chargers, will:

- make EV charging much cheaper – thereby facilitating EV uptake; and

<sup>1</sup> We estimate that over 95% of New Zealand households are on flat rate pricing

- avoid causing a material increase in peak power demand and associated costs and emissions.

***Electricity pricing options which apply to the whole of a household will likely be inadequate to meet the special challenges of EVs***

However, identifying and transitioning to smarter electricity prices will itself have some challenges:

- ‘Time-of-use’ (TOU) pricing (e.g. having a simple peak / off-peak pricing structure based on pre-set times) might be appropriate for most household electricity demand, but will not deliver good long-term outcomes in relation to EV demand. TOU pricing will likely create new demand spikes with a majority of EVs simultaneously charging from the start of the off-peak period.

While such issues won’t matter for very low-levels of EV uptake, our analysis suggests for EV penetrations of 15-20% and above (i.e. approximately 1-in-6 households owning an EV), the peak demand arising from everyone following a TOU pricing approach would be *greater* than if everyone had continued to follow a ‘passive’ charging approach and the peak period will shift to 9pm, from nearer 6pm now. Aside from not avoiding the need for expensive network investment, TOU pricing applied to EV demand could also potentially create network stability issues with a very rapid step change in demand occurring at the start of off-peak periods. This rapid step change in demand is not observed with flat rate charging, and will be made much worse if vehicle to grid technology becomes mainstream<sup>2</sup>.

Thus, while TOU pricing may be appropriate for sending efficient signals to consumers for some of their electricity decisions, it is potentially a worse solution than flat rate pricing over the long term when applied to EV demand given the special ‘storage’ characteristics of EV demand.<sup>3</sup>

- ‘Peak demand’ pricing<sup>4</sup> could overcome this problem by adjusting prices based on actual demand conditions. But this may be unsuitable for most residential consumers, due to the lack of pricing predictability<sup>5</sup>, and issues around bill shocks, higher winter costs, and the ability of consumers to make good decisions in response to such complex pricing approaches.

In addition, both of the above pricing approaches will likely need to apply to the whole of a household’s electricity consumption, not just the EV demand. Changing consumer pricing structures, will inevitably lead to ‘winners’ and ‘losers’, with some of the losers potentially facing significant bill shocks. This raises some challenging policy choices:

- On the one hand, having a phased transition to smarter cost-reflective pricing over many years may be desirable to avoid many of the poor outcomes from bill shocks for some consumers.
- On the other hand, delaying the transition to smarter cost-reflective pricing, will also delay the time when consumers will be fully incentivised to make good vehicle decisions. This will tend to slow the uptake of EVs which, given that vehicles tend to be 20-years old by the time they are

<sup>2</sup> Vehicle to grid, or V2G, technology provides the ability for EV battery charge to be injected *back into* the grid.

<sup>3</sup> We characterise storage energy technologies as those where the timing of energy consumption can be significantly altered within a day, without fundamentally affecting delivery of the energy *service* (e.g. an EV battery can be charged overnight rather than during periods of peak electricity demand, but this doesn’t affect the ability of the consumer to drive whenever they want during the day), ditto for hot water where households can have a shower anytime during the day (including peak demand periods) but the cylinder can be heated up outside of these periods of peak).

<sup>4</sup> We refer to this as coincident maximum demand (CMD) pricing in the main body of the report, as that term is more widely used in the industry.

<sup>5</sup> Not just in real time, but pricing predictability regarding knowledge of what the price will be in a few hours’ time. In other words, if consumers react to a real time high price and delay using electricity, will may create a further peak and higher pricing later. This future price predictability is difficult to overcome.

scrapped, will lock-in many more high-emissions vehicles over the next few decades than is necessary.<sup>6</sup>

***EV-specific managed-charging pricing will likely be necessary – but with challenges to implement***

A possible alternative pricing approach to enable the adoption of emerging technologies like EVs, whilst minimising customer bill shock and without compromising carbon goals, is ‘managed-charging’ pricing which only applies to a household’s EV demand.

This would involve consumers agreeing to another party (e.g. retailer, load aggregator, or network company) managing their EV charging, in return for discounted network and/or energy pricing for such managed EV load. This approach recognises the distinct nature of EV load, with its storage characteristics, and would deliver materially better outcomes of smoothed coordinated charging of New Zealand’s EV fleet and lowering the cost of EV charging to consumers, but in a way which has reduced risk of causing bill-shocks for consumers.

Managed-charging would be similar in some ways to the approaches taken to manage hot water cylinders, with consumers being rewarded with cheaper electricity for hot water load being managed at times of peak network demand.

Luckily, the technology coming within EVs and dedicated EV-chargers, and broader internet-based communications technology, not only provides the means to enable these smarter ways of charging our EV fleet, but to do so in a much more sophisticated way than the relatively crude ripple control that is currently used for hot water management.

Thus vehicle-specific management is feasible, with the ability to recognise a variety of factors – such as how empty different EV batteries are, where along a low-voltage network (of approximately 50-100 houses) EVs are located, or consumer requirements for when they need to next drive their EV – in order to coordinate which EVs should be charged, and when, in order to meet consumer requirements without imposing excessive supply costs.

However, to take advantage of such technology requires EV-owners to receive price signals or rewards which are of sufficient size to encourage them to take-up such managed-charging options.

It remains to be seen what form such managed-charging pricing options could or should take, or whether/how to develop NZ-wide standards and/or mandate open access to the technology to deliver EV charging management.

It also remains to be seen how many EV-owners will be willing to pass control of their charging to third parties such as retailers and networks. We believe these options should be voluntary for consumers to choose, and it is possible that many consumers may suffer anxiety that handing over control may mean that their vehicle may not be charged when they need it.<sup>7</sup>

However, what this study highlights is that, if we are to achieve mass-EV uptake without significant electricity supply cost impacts, we will need significant uptake of managed EV-charging pricing options.

A final additional consideration around the development, and extent of consumer uptake, of managed-charging options is that if consumers opt not to take up a managed-charging option, we

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<sup>6</sup> A long transition to cost-reflective pricing will also result in distorted consumer decisions in relation to other energy technologies in addition EVs. In many cases this will also result in poor economic, environmental and (in some cases) social outcomes such as the costs from a technology choice being made by one consumer being ‘shifted’ onto other consumers. Consideration of these other matters is out of scope for this study.

<sup>7</sup> While these consumer concerns are reasonable, we think well-designed managed charging options should enable good electricity supply outcomes, without impacting on consumers’ ability to have their vehicles charged for when they need them.

believe they should face any increased electricity supply costs they impose on the system – rather than cause such costs to be ‘shifted’ onto others.

This highlights a general issue with current, non-cost-reflective prices: Not only are they causing higher electricity supply costs, but with the advent of new technologies such as EVs, solar PV and static batteries, they are resulting in consumers who purchase such technologies being able to ‘shift’ the electricity supply costs they are responsible for onto other consumers who don’t have (sometimes because they can’t afford) such technologies.

### *Broadening and deepening the debate*

Addressing all of the above challenges and questions requires coordinated pan-industry effort in conjunction with government, regulator(s) and transport authorities.

Some of this is starting to happen, in particular through the electricity networks association (ENA) progressing its network pricing reform initiative, and the Electricity Authority through its various market development programmes. However, to-date, most of this focus has been on pricing options that will apply to the whole of a property, rather than the specific challenges of EVs (and other storage technologies) whose special characteristics may require specific pricing solutions.

Further, changes to consumer electricity prices will also require broader community and political engagement to help make the inevitable tough choices which carry the risk of bill shocks for some consumers in the short-term, but which will help deliver better economic, environmental, and social outcomes in the long-term.

The three network companies who have commissioned this study all strongly support a shift to EVs and they hope that this study will be a valuable contribution to this broader public debate.

All are aware that time is of the essence in terms of putting in place arrangements to facilitate the most positive EV outcomes before mass uptake starts to happen, and all believe that pricing and managed charging – be it by a retailer, aggregator, network company or other third party – is central to this debate.

EVs offer an enormous positive opportunity for New Zealand – the question is, how do we maximise that opportunity?

# 1 Introduction

## 1.1 Background

The New Zealand government has set a target of achieving net-zero greenhouse emissions by 2050.

In 2015 road transport accounted for 43% of New Zealand's energy-related greenhouse emissions, and road transport has been one of the fastest growing sources of New Zealand's emissions. Therefore, to achieve the government's target will require a transformation of New Zealand's transport fleet away from internal combustion engine vehicles (ICEs), to alternative, low-carbon fuels.

Currently, electric vehicles (EVs) are the most economic low-carbon transport alternative, and are projected to become increasingly cost-effective as battery costs and technology improve. It therefore looks likely that mass uptake of EVs will be the most cost-effective means of achieving this transport transformation – particularly for the light fleet.

This is a view that is increasingly becoming mainstream around the world, with governments and industry bodies projecting that EVs will rapidly replace ICEs, and with governments developing policies to facilitate this transformation. For example, some countries and cities are implementing policies which will completely ban the purchase of new ICEs from 2025.

However, large-scale replacement of ICEs by EVs has the potential to significantly increase electricity consumption. For example:

- If all light private vehicles were changed overnight to EVs, annual residential electricity consumption would increase by approximately 50%<sup>8</sup>
- If all vehicles (including trucks) were changed overnight to EVs, this would increase total New Zealand electricity consumption by approximately 16 TWh – a 41% increase<sup>9</sup>

## 1.2 Purpose of study

Concept Consulting and the three networks who have commissioned this study firmly believe that EVs are a great opportunity for New Zealand – both from an environmental and consumer perspective. We all strongly support EVs.

However, we also acknowledge that there are likely to be some challenges associated with the large-scale uptake of EVs, particularly associated with the manner in which EV batteries are charged.

Our aim with this study is to promote debate on how EVs can be charged in a manner that is acceptable to consumers, at lowest financial and environmental cost to the country, and ensures a continued reliable electricity system.

In particular, while EVs and EV-chargers are arriving with increasingly advanced technology to enable sophisticated charging, this study addresses concerns that the significant potential benefits will not be maximised unless consumers are sent appropriate price signals to incentivise them to charge their vehicles in a 'smart' fashion. The aim of the report is not to discourage or dampen enthusiasm for EVs, but rather ensure we as a country seek to optimise the benefits they bring. We don't want a situation where we look back in twenty years' time and regret big missed opportunities.

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<sup>8</sup> Assuming: average electricity demand per residential property  $\approx 7,050$  kWh/yr; the average annual quantity of electricity required to charge a light private EV travelling an average distance each year is  $\approx 2,000$  kWh/yr; and the average number of vehicles per household is  $\approx 1.75$ .

<sup>9</sup> In 2015, approximately 200 PJ of fuel was consumed in New Zealand's land transport fleet, and assuming that EVs are approximately 3.5 times more efficient on average at converting stored energy to motive power.



## 1.3 Issues addressed in study

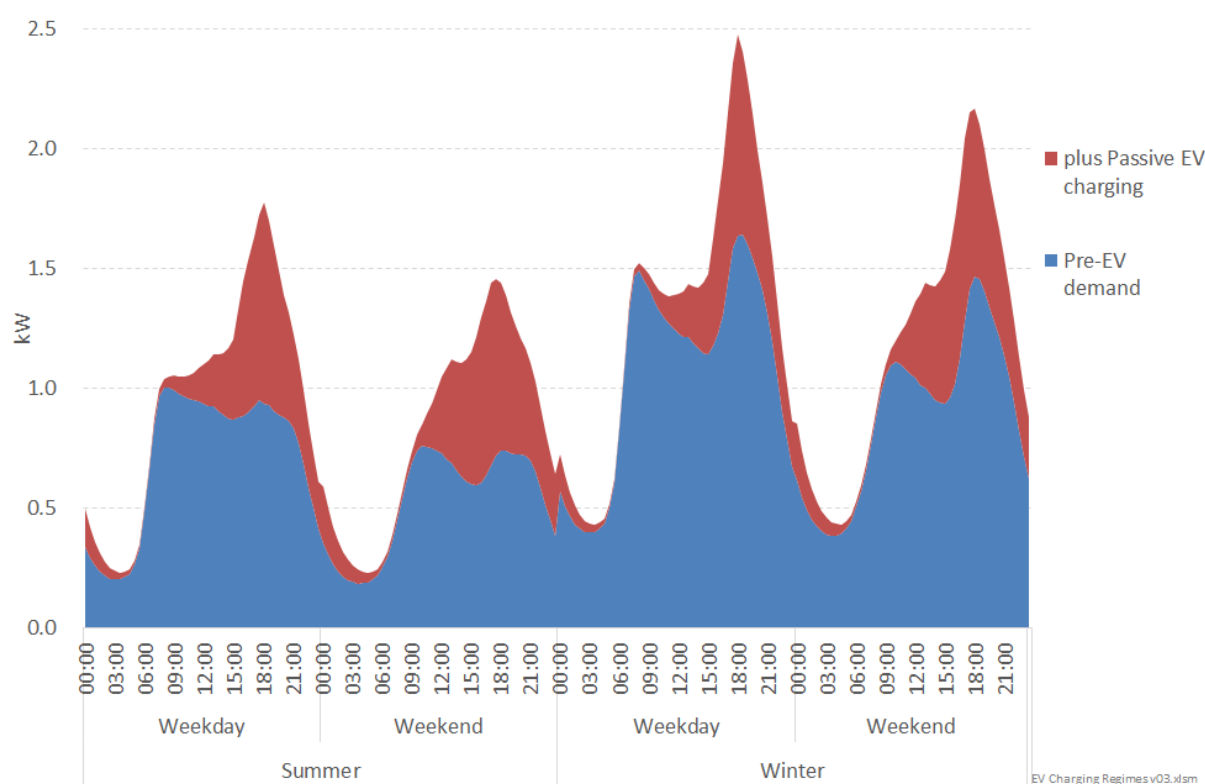
### 1.3.1 The nature of the problem

Put simply, the key issue is that current electricity supply arrangements provide no incentive for most consumers to avoid charging their EVs at times which will impose significant costs on the electricity system.

This study sets out analysis which shows that the current predominant ‘flat’ \$/kWh consumption price will result in consumers adopting a ‘passive’ EV charging approach. i.e. simply plugging-in and charging as soon as they get home. Unfortunately, the time at which most people get home – early evening – also coincides with the time of peak electricity system demand.

Figure 1 illustrates that if every household had one EV<sup>10</sup> which was charged passively, this would substantially increase winter evening peak demand.

**Figure 1: Impact on an average household demand profile of charging an EV passively<sup>11</sup>**



Given that a substantial amount of network and generation costs are driven by the need to meet peak demand, passive charging of EVs will substantially increase electricity supply costs as EV penetration rates grow.

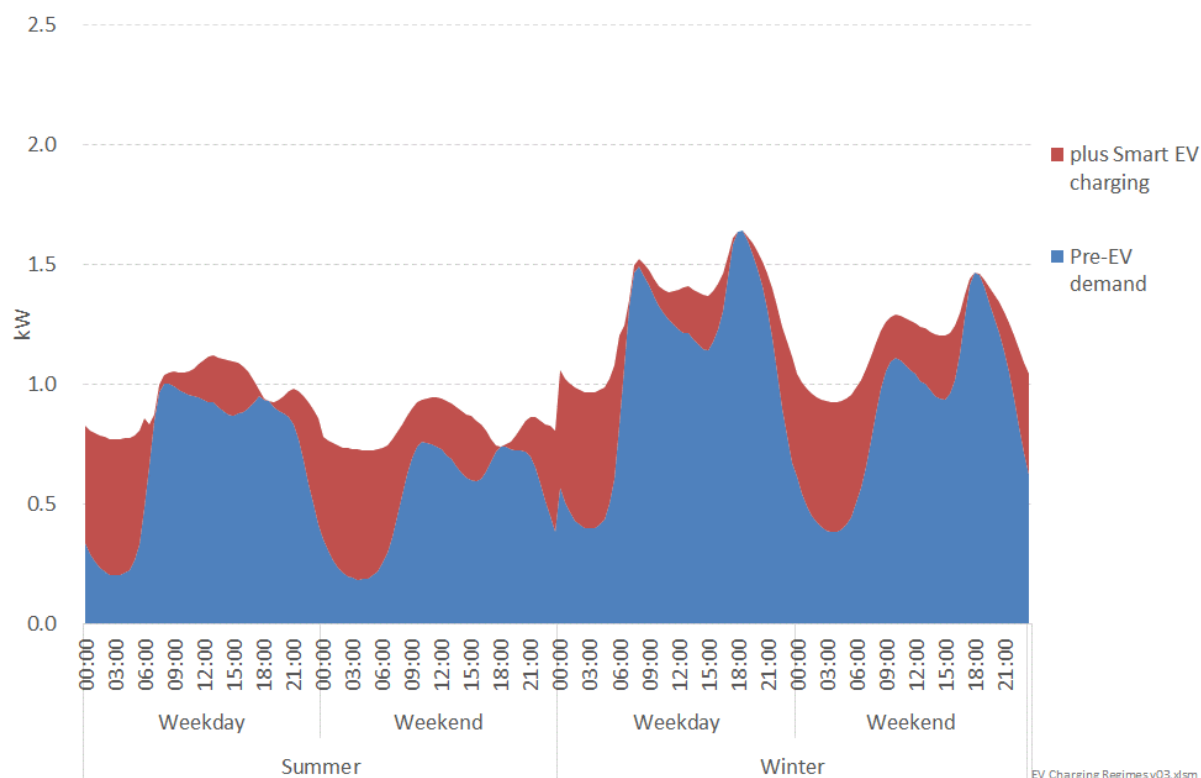
However, it doesn't need to be like this. Most vehicles are not driven between the hours of 9pm and 7am. This is ample time to re-charge EV batteries for the vast-majority of journeys undertaken in the previous day – even for vehicles being charged slowly using a standard domestic plug.

<sup>10</sup> One EV per household equates to approximately 57% of cars being EVs, given that the average household owns 1.75 vehicles.

<sup>11</sup> This profile is based on the average household demand profile, and assumes that each household owns one EV.

Figure 2 shows that if EVs were charged in a ‘smart’ fashion – i.e. predominantly overnight, with the charging across all EVs staggered across the night period to ‘smooth’ demand – there need not be any impact on peak demand.

**Figure 2: Impact on an average household demand profile of charging an EV ‘smartly’**



Section 2 of this report estimates the likely nature and scale of electricity system cost impacts from large-scale EV uptake under:

- current consumer electricity supply arrangements – with most EVs charged ‘passively’
- alternative consumer electricity supply arrangements which incentivise ‘smarter’ EV charging

This analysis is the principal purpose of this report, and is intended to demonstrate that this is a significant issue for New Zealand.

Section 2 also addresses the fact that the current ‘flat’ electricity price structure which is a key cause of ‘passive’ charging, will also result in EV-owners paying significantly more than they should for charging their vehicles. This will likely frustrate the rate of uptake of EVs, significantly increasing New Zealand’s emissions and reduce the overall economic benefits possible from EVs.

### 1.3.2 How do we encourage consumers to charge their EVs in a smart fashion?

Given that the current predominant ‘flat’ price structure is the problem driving poor EV outcomes, it is likely that changes to consumer prices to make them more cost-reflective will be a necessary part of the solution to drive better EV outcomes.

However, changing consumer prices is never easy, with inevitable ‘winners’ and ‘losers’, and the potential for unintended poor outcomes.

The secondary purpose of this study, detailed in Section 3, is to start to explore the options for achieving better EV charging, in a way which maximises the good outcomes and minimises the bad.

In particular, it explores whether the special characteristics of EVs may mean that more cost-reflective electricity pricing approaches which may be appropriate for the rest of a household's electricity consumption, may not be appropriate for EVs which might require EV-specific pricing approaches.

### **1.3.3 Public charging issues**

Although the principal focus of this study is on charging of EVs at consumers' premises, in undertaking this study Concept gained better understanding of issues in relation to public charging – i.e. charging of EVs away from home using commercial public chargers.

These issues could affect the rate of EV uptake, and thus the extent to which the benefits of EVs are realised. Section 0 briefly outlines these issues, but does not address them in any detail.

## 2 Estimation of the costs of large-scale EV uptake under ‘passive’ and ‘smart’ charging futures

This section of the report presents the results of Concept modelling on the outcomes relating to large-scale EV uptake under different EV pricing and charging approaches.

Sections 2.1 to 2.4 estimate the likely cost and emissions consequences from large-scale uptake of EVs, under two different EV charging approaches:

- ‘Passive’ charging whereby consumers simply plug-in and charge their vehicles as soon as they get home. This charging approach is likely to occur based on current consumer prices.
- ‘Smart’ charging, whereby EVs are charged predominantly in a smoothed fashion through the night

Section 2.5 addresses the fact that the current ‘flat’ electricity price structure which is a key cause of passive charging, will also result in EV-owners paying significantly more than they should for charging their vehicles. This will likely frustrate the rate of uptake of EVs, significantly increasing New Zealand’s emissions and increasing overall economic costs.

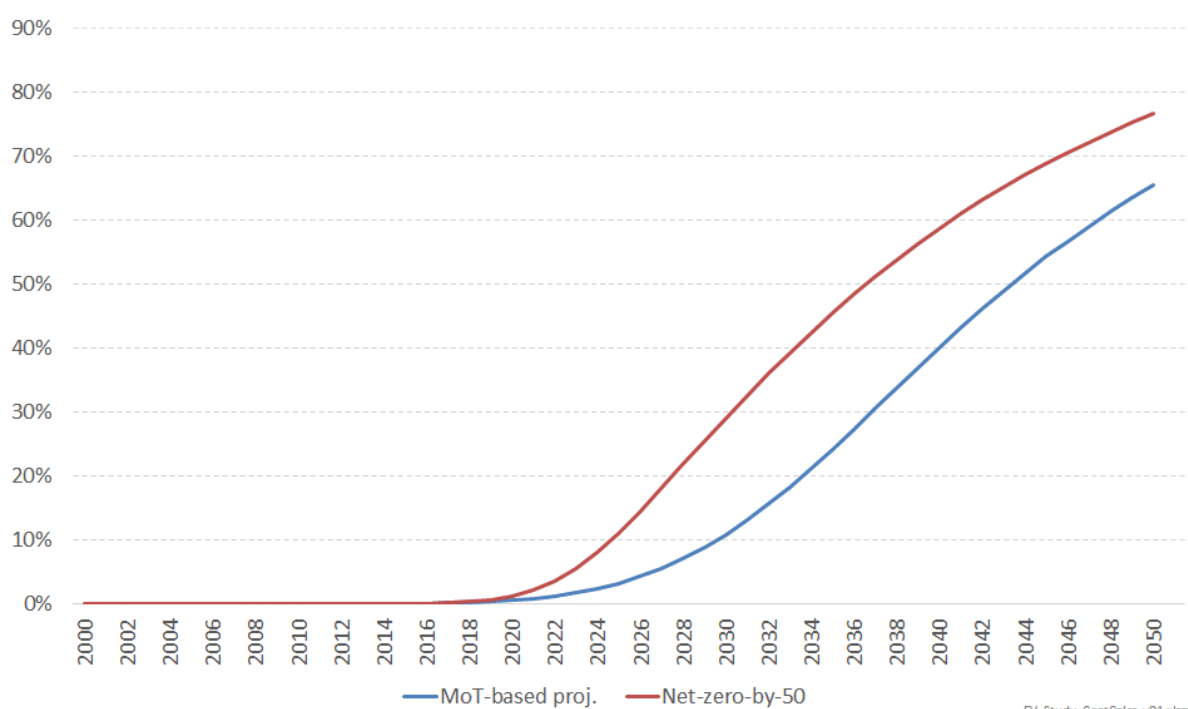
### 2.1 How soon might large-scale uptake of EVs occur?

Appendix A presents the results of the modelling Concept has undertaken to project the potential level of EV uptake. Two main projections are presented:

- Projections consistent with the central Ministry of Transport (MoT) projection in its recent report “New Zealand Transport Outlook: Future State”.
- Projections consistent with New Zealand seeking to achieve net-zero greenhouse gas emissions by 2050.

Figure 3 illustrates the differences between these two projections in terms of the proportion of the light private fleet (i.e. cars) which are EVs.

**Figure 3: Proportion of light private fleet which are EVs**



It is understood that the projection developed by MoT reflects current policy settings and expected levels of EV cost reduction that will anyway occur. i.e. the MoT projection recognises that EVs are likely to become increasingly cost-effective transport options for New Zealand, irrespective of specific climate-related policies.

Under this projection, the level of uptake is such that  $\approx 40\%$  of the overall vehicle fleet is electric by 2040 (with the proportion of the light fleet being much higher than for the heavy fleet). By 2040, almost all light vehicles entering New Zealand will be EVs.

The second projection reflects the fact that the New Zealand government has recently re-confirmed its ambition of achieving net-zero<sup>12</sup> emissions by 2050, and is in the process of developing and consulting on policies to achieve this goal.

We have used our models of the New Zealand transport sector, plus our models of whole-of-New Zealand greenhouse emissions, to estimate the level of EV uptake required to meet the target of net-zero greenhouse emissions by 2050.

This NZ-net-zero-by-2050 projection has a very rapid uptake of EVs, such that by 2030 almost all new light vehicles (private & commercial) entering New Zealand will need to be EVs.

The reason why there is a need for such a rapid transformation of vehicle purchasing patterns is because vehicles entering the NZ fleet remain in the fleet for many years: the average age of a vehicle scrapped in New Zealand is 20 years. Thus, an ICE vehicle purchased in 2030 could still be on the road and producing exhaust emissions in 2050.

While this rate of uptake may have seemed fanciful a few years ago, rapid reductions in battery costs mean that EVs are close to purchase cost parity with ICEs – making rapid uptake of the scale projected here plausible.

Further, this is consistent with projections and policies in other countries, with a growing number of countries implementing policies which will effectively ban new ICE vehicles from around this time. For example: 2025 for Norway, 2030 for the Netherlands, 2032 for Scotland, and 2040 for France and the UK. Other major countries and economies such as China, India and California are also in the process of developing similar policies, with many other European and Asian countries, and some US states, setting ever-more ambitious targets for EV uptake.

That said, it should be noted there is a significant degree of uncertainty around the projections set out in Appendix A given that the rate and scale of EV uptake will be significantly affected by a number of factors which are subject to significant inherent uncertainties, including:

- future battery cost reductions, which will in turn be significantly affected by future international policies by the world's major economies on climate change generally, and EVs specifically.<sup>13</sup>
- the development of autonomous vehicles, which may also materially affect outcomes in a hard-to-predict fashion.<sup>14</sup>

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<sup>12</sup> 'Net' emissions are calculated as New Zealand's gross emissions, less any sequestration achieved through re-forestation.

<sup>13</sup> Japan's policies on de-carbonising its transport fleet may have a particular effect on New Zealand, given that a very large proportion of New Zealand's vehicles come second-hand from Japan. Thus, if Japan heads down the hydrogen-fuelled vehicle route, whereas America and Europe head more down the battery EV route, this will be likely to materially affect New Zealand's transport de-carbonisation abilities.

<sup>14</sup> It is hard to know whether autonomous vehicles would materially decrease overall light passenger travel by car. However, it would almost certainly reduce rates of car ownership, and consequent impacts on household electricity demand.

- the rate of NZ population growth, which will also significantly affect the scale of EV uptake and associated impact on national electricity demand

All of these factors are very hard to predict.

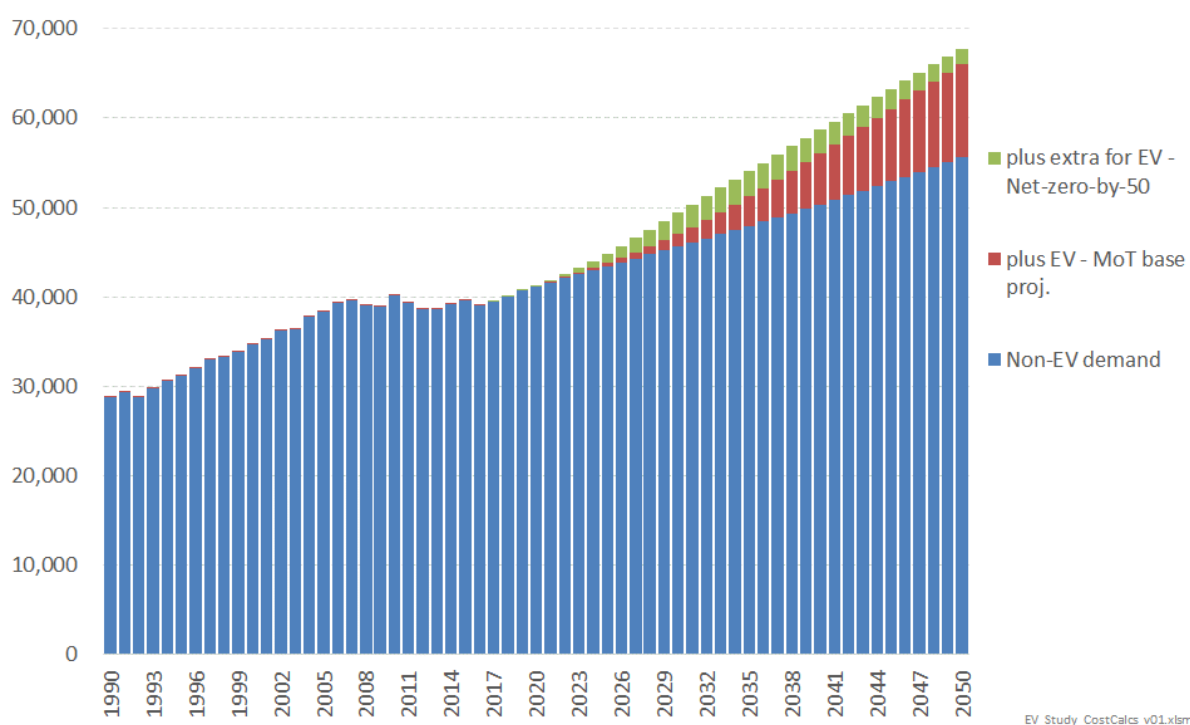
Nonetheless, these uncertainties around future EV uptake are considered differences in *degree*, rather than fundamental uncertainties over the nature and scale of outcomes. Thus, we have a high degree of confidence that, to de-carbonise our transport fleet to meet our emissions reductions targets, the rate and scale of EV uptake over the next few decades will be large and rapid – of a magnitude consistent with the projections set out in Appendix A.

Further, the purpose of this report is not to try and accurately forecast EV uptake, but to use order-of-magnitude forecasts to highlight the nature and broad scale of outcomes arising from electricity sector settings which will apply to EV charging, and also to highlight the nature and scale of issues which could emerge from rapid large-scale EV uptake.

## 2.2 What would be the impact on electricity demand of such large-scale EV uptake?

EV uptake of the scale set out in these two projections would materially increase electricity consumption. Figure 4 below shows that on an annual energy basis, large-scale EV uptake would give rise to significant electricity consumption growth.

**Figure 4: Projected New Zealand electricity consumption (GWh)<sup>15</sup>**



<sup>15</sup> The projections for non-EV demand are for illustrative purposes, and not based on any detailed modelling. For the years 2017 to 2026, non-EV demand is projected to grow at the rate projected by Transpower for its basecase in its 2017 Annual Security of Supply Assessment, and then continue at the same rate beyond then (1% per annum).

This increase in consumption will inevitably give rise to a need for increased electricity generation. Crucially, the type and cost of electricity generation to meet this consumption will be strongly driven by the pattern of EV charging:

- EV charging which occurs at times of peak demand will give rise to increased ‘peaking’ generation – i.e. generation which is required relatively infrequently to meet peak demand. In New Zealand (and indeed all countries around the world) this is predominantly from fossil-fuelled gas and coal-fired generation.
- EV charging which occurs during off-peak periods will predominantly be met by increased ‘baseload’ generation – i.e. generation which operates almost continuously. In New Zealand, the most economic form of new baseload generation is renewable power in the form of wind or geothermal power stations.

The pattern of EV charging will also determine the impact on network costs (i.e. the costs of building and operating the transmission and distribution wires):

- An increase in peak demand will, over the long-term, give rise to a need to invest in additional network capacity.
- An increase in demand in off-peak periods, if ‘smoothed’ across the off-peak periods, will not have any material impact on network costs.

Sub-section 2.2.1 below estimates the likely pattern of charging which will occur based on current electricity supply arrangements, with sub-section 2.2.2 estimating the potential impact on demand if EV charging were to occur in a ‘smarter’ fashion.

## 2.2.1 What pattern of EV charging is likely to emerge?

Appendix B presents the results of modelling undertaken by Concept to estimate the likely pattern of residential EV charging undertaken by consumers if they face no price signal as to when they should charge their EV. This is currently the case for the vast majority of consumers (we estimate over 95%) in that they face a ‘flat’ variable \$/kWh consumption price for charging their EV which doesn’t change by time of day.

Experience in NZ and overseas indicates that a significant proportion of individuals will simply plug-in their vehicles to start charging as soon as they get home – a charging approach we refer to as ‘passive’ charging. Unfortunately, most people tend to arrive home in the early evening – which in winter is the time of system peak demand.

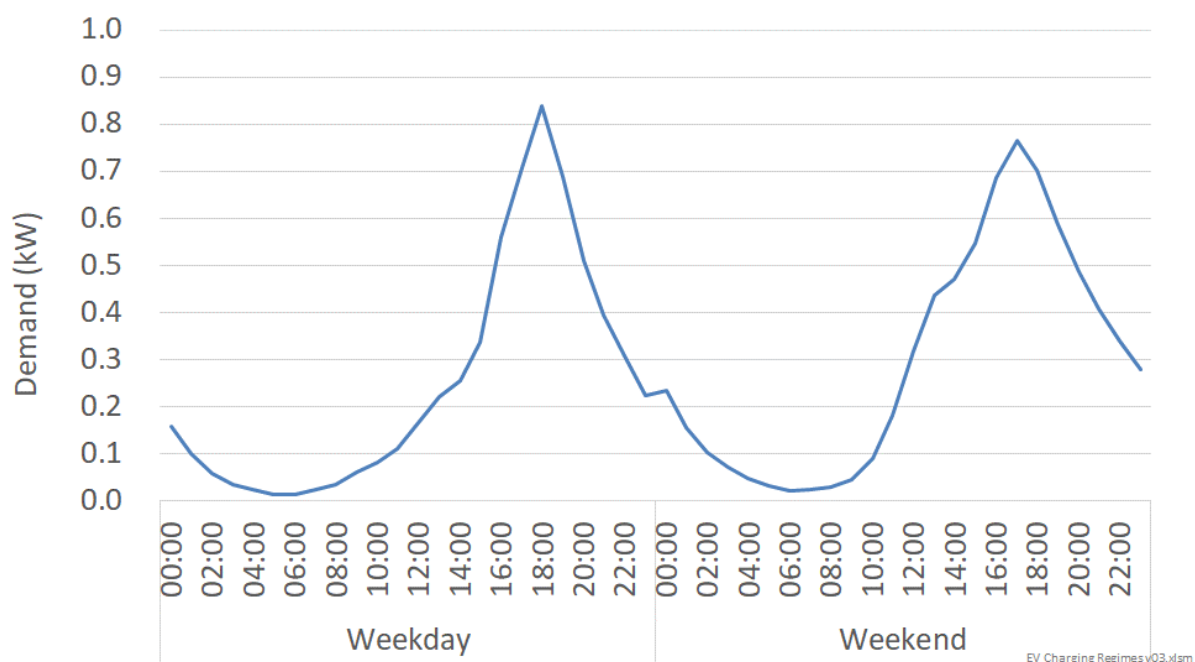
With the capacity drawn from residential EV charging ranging from 1.8 kW (for charging through a standard domestic socket) through to 7 kW (from installing a dedicated EV residential charger), this has the potential to significantly increase average residential peak demand above its current levels.

However, the modelling in Appendix B indicates that there is a significant amount of diversity associated with EV charging. In particular:

- Diversity of when people arrive home. i.e. the majority of people arrive home over a 3.5 hour window.
- Diversity of how empty their batteries are when they arrive home. Based on typical travel patterns, most EV batteries won’t be that empty, and will only require a relatively short time charging – particularly if they are using a 7kW charger.

This combination of diversity factors means that there is reduced overlap of people charging at the same time. Our modelling projection of a likely after-diversity<sup>16</sup> 'passive' residential EV charging profile is shown in Figure 5.

**Figure 5: Modelled 'passive' after-diversity average per-EV residential charging profile**



Despite the diversity effects, an increase in after-diversity peak demand of approximately 0.8 kW per EV is a substantial amount when compared with average residential peak demands. This is illustrated in the following diagram. (Note, this is in a situation of one EV per household which, given average car ownership in New Zealand of 1.75 vehicles per household, equates to an EV penetration rate of approximately 57%. This is the penetration rate forecast to be reached by around 2040 if New Zealand is to achieve net-zero greenhouse gas emissions by 2050. If all vehicles in New Zealand were converted overnight to an EV, this EV charging impact per household could be up to 1.75 times greater.)

<sup>16</sup> 'After-diversity' means the average across a large number of consumers.



**Figure 6: Impact on an average household demand profile of charging an EV passively**

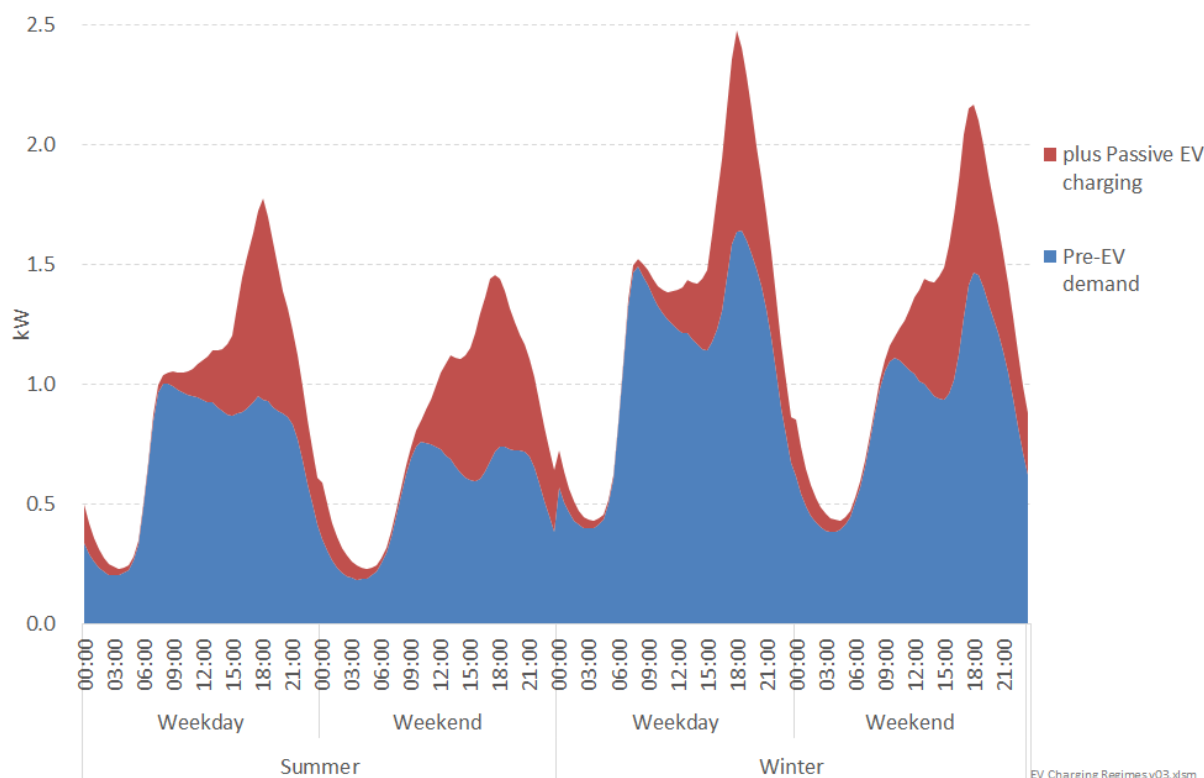
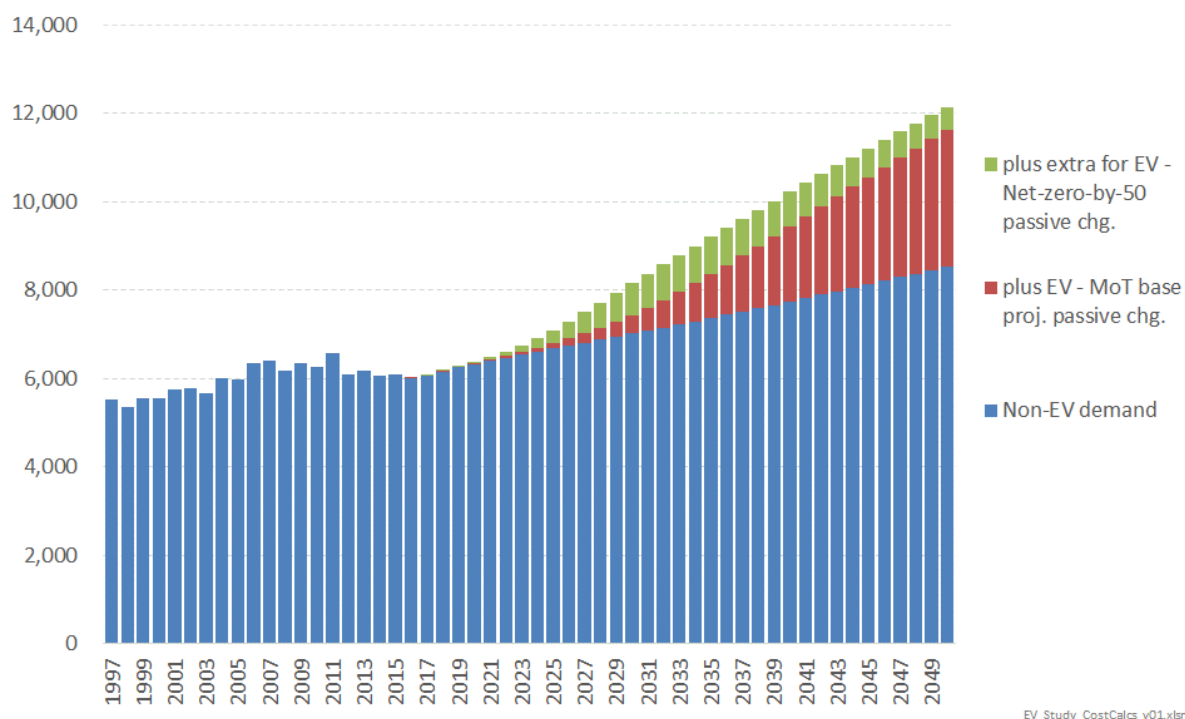


Figure 7 shows our projected modelling of the impact on national peak demand.

**Figure 7: Projected New Zealand peak MW demand impact of EVs with passive charging<sup>17</sup>**



<sup>17</sup> The non-EV demand projection is not based on any detailed modelling, but is for illustrative purposes. It uses the simple assumption that peak MW demand will grow at the same rate as annual GWh energy – i.e. using the Transpower figures for GWh growth.

Thus, if EV uptake occurs at the levels projected, and the majority of consumers continue to face non-cost-reflective 'flat' electricity prices for charging their EVs, New Zealand peak demand could grow by approximately 3,000 MW by around 2050 – an additional 50% on top of today's peak MW levels.

This matters because, as set out in more detail in section 2.3, an increase in peak demand will give rise to a need to build generation and network capacity to meet this peak, which can be very expensive.

Further, as first mentioned on page 14, peaky demand growth will likely increase the proportion of generation from fossil stations. These emissions impacts of EV charging are explored in more detail in section 2.4 later.

### **2.2.2 Can EV's be charged in a 'smarter' fashion?**

However, increased peak demand isn't an inevitable consequence of EV uptake.

As Figure 6 above shows, the periods of lowest non-EV demand on the system are overnight when most people are asleep. This also coincides with when most people are not using their vehicles.

If people charged their vehicles overnight, with such charging undertaken in a 'smoothed' fashion across the night, there need not be a material net increase in peak demand. Our modelling indicates that, even with using a standard domestic plug, there is plenty of time to re-charge vehicles during the hours between 9pm and 7am for the vast majority of daily journeys undertaken by private vehicles.

Figure 8 shows a simulation of the impact on average residential demand if EVs were charged 'smartly' – i.e. predominantly overnight and smoothly through the night. This shows that such smart charging would not result in any material increase in peak demand.

**Figure 8: Impact on an average household demand profile of charging an EV 'smartly'<sup>18</sup>**

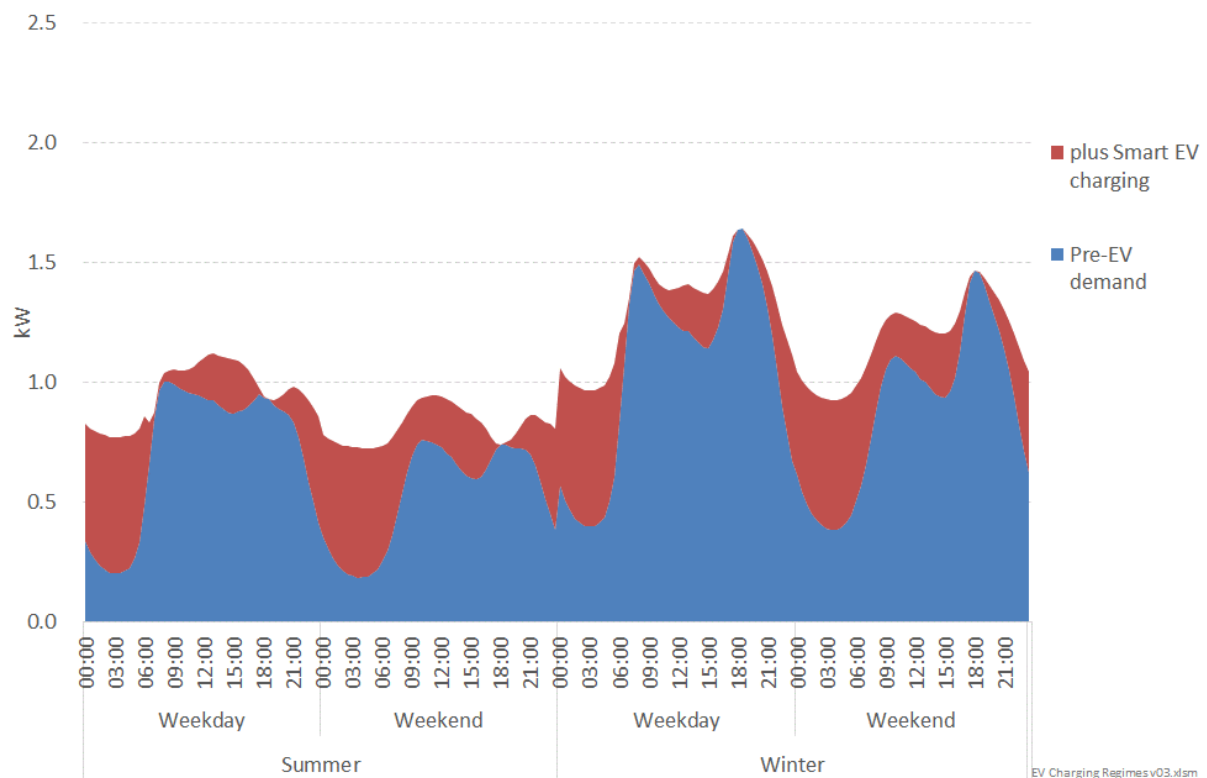
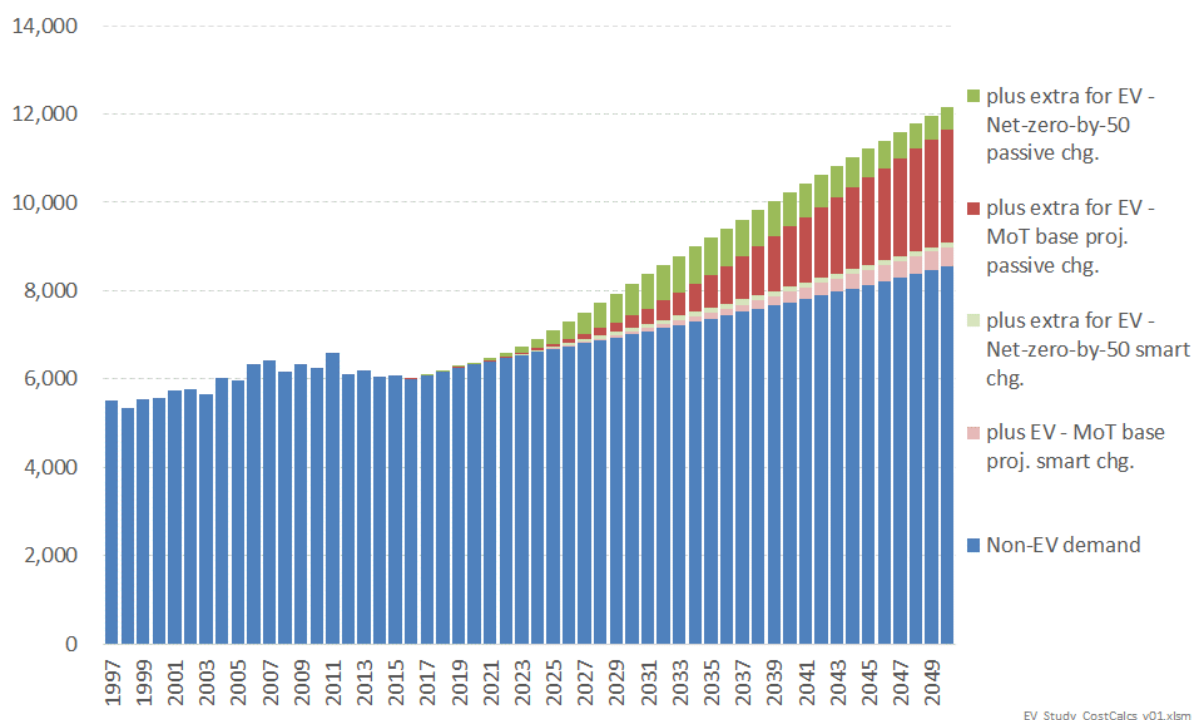


Figure 9 shows the revised impact on peak demand for the two projections if all vehicles were charged in such a 'smart' fashion. This shows that instead of peak demand due to EV charging growing by approximately 3,000 MW by 2050 with 'passive' charging, peak demand would only increase by approximately 500 MW with 'smart' charging.<sup>19</sup>

<sup>18</sup> This analysis is based on an average of one EV per household.

<sup>19</sup> Figure 8 shows no impact on peak demand. However, this assumes that all vehicles have complete flexibility around charging times. In reality, there will be some (relatively small) proportion of vehicles who absolutely must re-charge during early-evening peaks in order to meet driving requirements later in the evening. The analysis in Figure 9 attempts to reflect this scale of need.

**Figure 9: Comparison of projected New Zealand peak MW demand for high EV-uptake between passive and smart EV-charging approaches**



## 2.3 Estimating the cost of meeting EV demand from these different approaches

Appendix C sets out our analysis on the network and generation costs of meeting demand growth. It highlights that:

- Network costs are largely driven by growth in peak demand, with the combined transmission and distribution network cost estimated to be approximately \$160-220/kW/yr
- Generation costs are driven by a combination of kWh energy and peak kW requirements. A relatively 'peaky' profile such as a passive EV charging profile is estimated to cost approximately \$90/MWh on average, whereas a smart EV charging profile would cost approximately \$70/MWh on average.

Table 1 below shows the results of bringing all these various modelling components together. i.e.

- Projections of EV uptake, and associated GWh electricity demand.
- Projections of the profile of 'passive' and 'smart' EV charging approaches.
- Estimates of the electricity system costs of meeting the associated peak demand increase (for network costs) and GWh profiles (for generation costs) for the different projections and charging profiles.

**Table 1: Projected electricity system costs of meeting EV-related demand growth under different EV-uptake scenarios, and Passive vs Smart charging approaches (\$bn)<sup>20</sup>**

Uptake scenario	Cost Component	EV demand-driven cost projections for 2018 to 2050 (\$bn)					
		Non-discounted			Discounted PV		
		Passive	Smart	Diff.	Passive	Smart	Diff.
EV - MoT base proj.	Generation	11.4	9.0	2.4	2.9	2.3	0.6
	Network	7.1	1.0	6.1	1.8	0.2	1.5
	Total	18.5	10.0	8.5	4.7	2.5	2.1
EV - Net-zero-by-50	Generation	17.0	13.4	3.5	4.8	3.8	1.0
	Network	10.6	1.5	9.1	3.0	0.4	2.6
	Total	27.6	14.9	12.6	7.8	4.2	3.6

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This highlights that large-scale EV uptake with passive charging approaches is likely to cost New Zealand of the order of 8-12 billion dollars in additional electricity system costs (2 to 3.5 billion in present value terms) – largely through causing significant extra network investment.

As noted previously, there is a reasonable degree of uncertainty as to these estimates, due to uncertainties over the timing and scale of network investments (including the extent of cost impact on the low-voltage parts of the distribution networks), and uncertainties over the rate of uptake of EVs for different parts of the transport fleet. Thus, it is possible that the ‘true’ value could be higher or lower than the estimates presented here.

Nonetheless, these uncertainties are considered differences in degree, rather than fundamental uncertainties over the nature and scale of outcomes. Thus, we have a high degree of confidence that, if non-cost-reflective electricity pricing for charging EVs was to continue over the next few decades, the consequent passive charging of EVs would result in many billions of dollars of unnecessary electricity system cost impacts.

## 2.4 Emissions impacts of different EV charging approaches

As first mentioned on page 14, the pattern of EV charging will also affect what type of electricity generation meets the increase in consumption:

- EV charging which occurs at times of peak demand will give rise to increased ‘peaking’ generation – i.e. generation which is required relatively infrequently to meet peak demand. In New Zealand (and indeed all countries around the world) this is predominantly from fossil-fuelled gas and coal-fired generation.
- EV charging which occurs during off-peak periods will predominantly be met by increased ‘baseload’ generation – i.e. generation which operates almost continuously. In New Zealand, the most economic form of new baseload generation is renewable power in the form of wind or geothermal power stations.

This issue was explored in some detail in a 2016 Concept report: *“Electric cars, solar panels and batteries – how will they affect New Zealand’s greenhouse gas emissions?”*.<sup>21</sup>

The key results from this analysis were that, in the medium-to-long-term, an increase in EV demand would largely be met by increased renewable generation (largely wind, but some geothermal), but

<sup>20</sup> The discounted present value numbers, use a discount rate of 6% to bring back costs which occur in the future to a present value.

<sup>21</sup> This report is available for download at <http://www.concept.co.nz/publications.html>

with the extent of renewable versus fossil generation varying between passive and smart charging approaches:

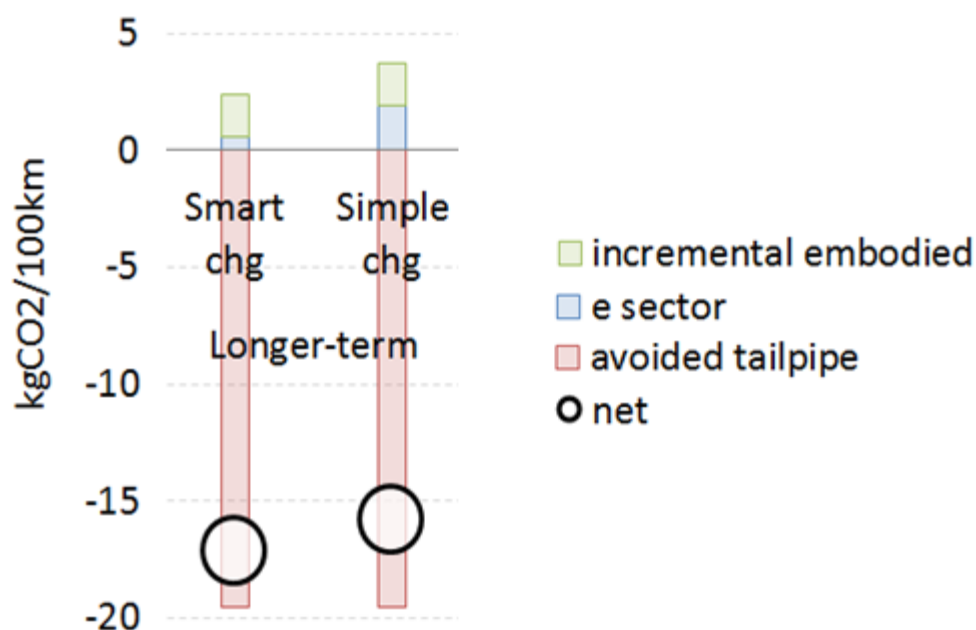
- Under a passive EV charging approach, approximately 20% of the generation to meet the demand would be from increased fossil generation, with the remainder from renewable generation.<sup>22</sup>
- Under a smart EV charging approach, just over 5% of the generation to meet the demand would be from increased fossil generation.

Figure 23 of that 2016 report indicates that the long-term emissions intensity of generation to meet a passive charging profile would be 0.1 kgCO<sub>2</sub>/kWh, whereas that of a smart charging profile would only be 0.035 kgCO<sub>2</sub>/kWh.

Therefore, not only would passive EV charging have significant (and unnecessary) economic costs, it would give rise to unnecessary environmental costs.

That said, it should be noted that, even for the passive charging regime, the overall environmental effect of EV uptake is strongly positive due to the electricity-generation-related emissions being more than offset by the avoided exhaust emissions from ICE vehicles. This is illustrated in Figure 10 below (which is taken from Figure 24 in the 2016 report). (Noting that ‘passive’ charging was referred to as ‘simple’ charging in the 2016 report.)

**Figure 10: Estimated longer-term emissions impacts of EV uptake<sup>23</sup>**



<sup>22</sup> The reason that passively-charged EV demand doesn't give rise to a greater amount of fossil generation is because on a within-year basis, EV demand is effectively baseload. This substantially affects the type of generation required to meet an increase in demand. Further, the modelling assumed that over the medium-to-long-term CO<sub>2</sub> prices would rise above current levels. This lowers the threshold capacity factor below which it is more cost-effective to use fossil stations rather than renewables.

<sup>23</sup> The 'incremental embodied' emissions indicate the higher greenhouse emissions associated with manufacturing an EV compared with manufacturing an ICE vehicle (noting that battery production is very energy intensive), but spread over the typical number of km travelled by a vehicle over its lifetime. The 'e sector' emissions represent the emissions from any fossil-fuelled generation used to re-charge EV batteries. The 'avoided tailpipe' emissions represent the avoided ICE exhaust emissions that would otherwise have occurred from driving an ICE vehicle.

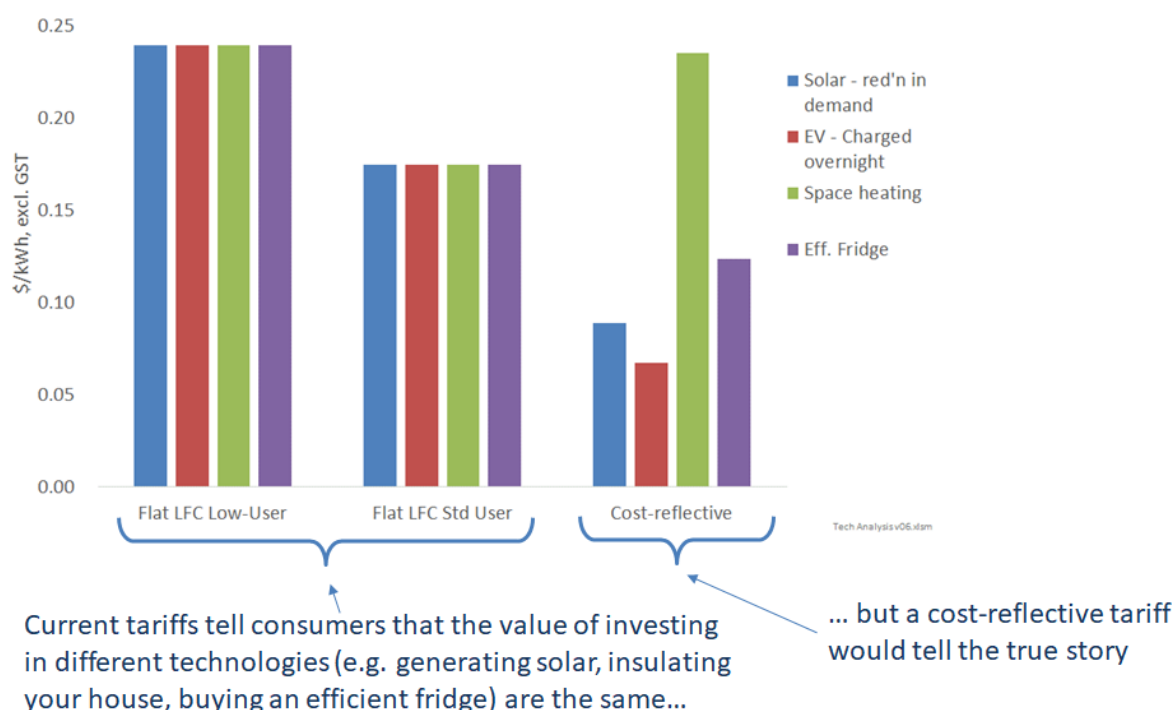
## 2.5 The cost and emissions impacts of passive versus smart charging are likely to be even greater than set-out above

The above analysis compares the cost and emissions impacts of passive versus smart charging, for a given level of EV uptake.

However, the price signals from the current predominant ‘flat’ prices that give rise to ‘passive’ charging approaches will also result in EV-owners paying more to charge their EVs than they would if they charged overnight and paid a (low) cost-reflective price for such overnight charging. The current low-fixed charge regime exacerbates this effect.

This is illustrated in Figure 11 which shows the price paid/received by consumers for using/generating electricity for four different consumer appliances including EVs (and also solar PV which is a generation technology).

**Figure 11: Demand (or generation)-weighted average price seen by different consumer technologies<sup>24</sup>**



These distorted price signals will harm the economics of EVs relative to ICEs for vehicle owners, and likely result in EV uptake being suppressed relative to what could be achieved.

Appendix A details how a projection was developed which estimates the extent to which EV uptake would be frustrated if all other factors which gave rise to the net-zero-by-2050 projection were in place (e.g. battery cost reductions, CO<sub>2</sub> price increases), but consumer electricity prices continued with a non-cost-reflective structure. This is illustrated in Figure 12 below.

<sup>24</sup> LFC = ‘low-fixed charge’

**Figure 12: Projected impact on the proportion of the light private fleet which are EVs due to delayed uptake due to a continuation of non-cost-reflective consumer electricity prices**

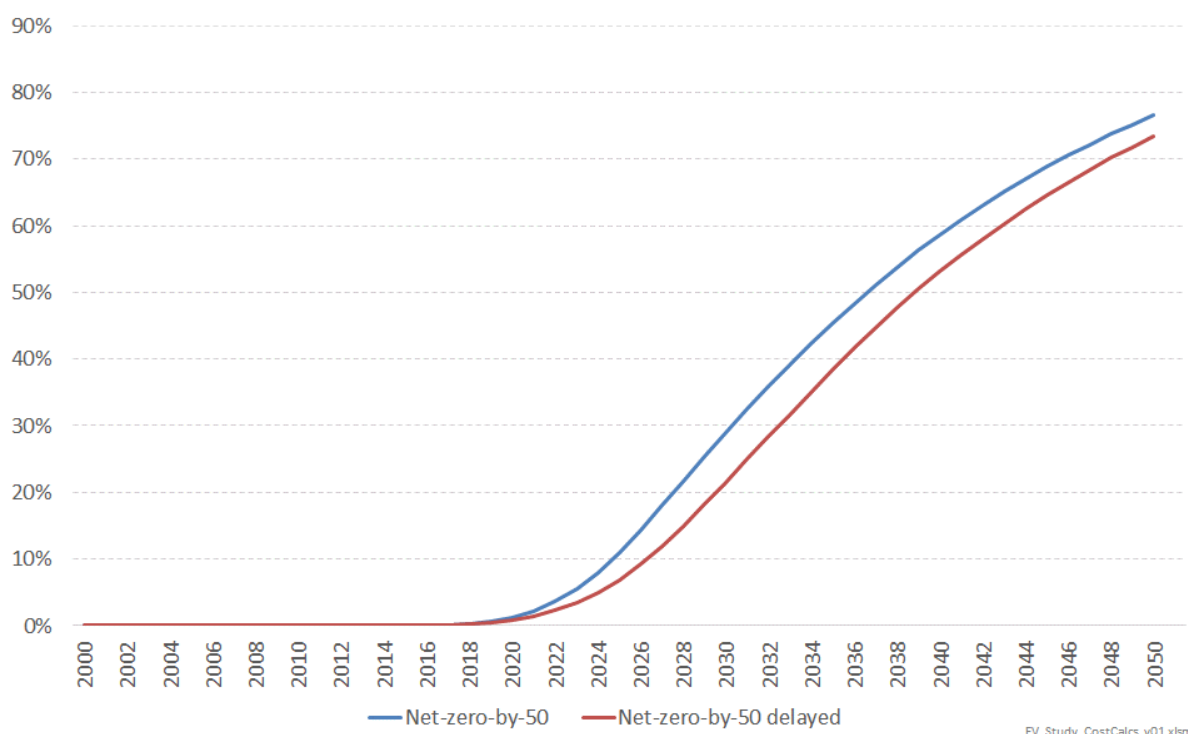


Table 2 below illustrates how this altered rate of uptake translates into a significant increase in emissions for New Zealand's light private fleet. Thus, by 2050, emission from the light private fleet will be 37% higher if uptake is delayed due to a continuation of non-cost-reflective prices. This is due to:

- Higher exhaust emissions from the increased number of ICE vehicles
- Electricity generation emissions being higher due to a higher proportion of fossil generation to meet the peakier demand profile of EVs.

**Table 2: Projected difference in emissions outcomes due to a continuation of non-cost-reflective consumer electricity prices (MtCO<sub>2</sub>-e)**

Projection scenario	2018-2050 cumulative			2050		
	ICE exhaust emissions	EV elec-gen emissions	Total	ICE exhaust emissions	EV elec-gen emissions	Total
EV - Net-zero-by-50	144	3.7	148	1.3	0.2	1.5
EV - Net-zero-by-50 delayed	156	9.3	165	1.5	0.6	2.0
Difference	12	6	18	0.2	0.4	0.6
MtCO <sub>2</sub> -e						
%	8%	154%	12%	15%	177%	37%

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This delayed uptake due to non-cost-reflective electricity prices will also deliver poor economic outcomes:

- Higher electricity system costs due to EV demand being significantly peakier from a passive charging profile. (This significantly outweighs the impact from reduced GWh from delayed EV uptake)



- Higher vehicle costs, principally from increased oil purchases to fuel the greater number of ICE vehicles.

Table 3 sets out the estimates of this economic impact.

**Table 3: Projected economic impact of delayed EV uptake due to a continuation of non-cost-reflective consumer electricity prices (\$bn)**

Projection scenario	Non-discounted						Discounted present value					
	Elec. system		Vehicle			Total	Elec. system		Vehicle			Total
	Gen.	Nwk.	Capital	Maint.	Oil		Gen.	Nwk.	Capital	Maint.	Oil	
EV - Net-zero-by-50	13.4	1.5	99.2	35.6	46.1	195.9	3.8	0.4	49.8	16.6	26.0	96.5
EV - Net-zero-by-50 delayed	15.0	9.3	99.6	36.0	50.1	210.0	4.1	2.5	49.5	16.8	27.6	100.4
Difference	1.6	7.8	0.4	0.4	4.0	14.2	0.3	2.1	-0.2	0.1	1.6	3.9

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## 3 Options for incentivising better outcomes

### 3.1 Introduction

The preceding section has identified that the current pricing approach for electricity – i.e. predominantly ‘flat’ \$/kWh prices which don’t vary throughout the day – will result in poor EV outcomes:

- EV-owners will pay significantly more than they should for charging their vehicles. This will slow the rate of uptake of EVs, significantly increasing New Zealand’s emissions and overall economic costs.
- Those households who do purchase EVs will mostly adopt a ‘passive’ approach for re-charging their batteries – i.e. simply plugging-in and charging as soon as they get home – resulting in a significant increase in peak demand and associated costs.

These outcomes have been identified by the Electricity Authority (and others, including the Electricity Networks Association) as being symptomatic of the current predominant electricity pricing approach not being cost-reflective.

This section starts to explore what opportunities may exist to move to more cost-reflective pricing approaches which may achieve the ‘win-win’ of increased EV uptake, but with EV charging undertaken in a way which doesn’t materially increase peak demand and associated costs.

The purpose of this section is not to identify specific solutions, but to start to highlight:

- the range of possible options
- the types of challenges associated with each option
- possible areas for the industry to progress to resolve such challenges.

### 3.2 Time-of-use pricing

One potential option to encourage EV owners to charge their vehicles away from peak periods is the use of time-of-use pricing: i.e. having time-differentiated variable c/kWh consumption prices with a ‘peak’ period and an ‘off-peak’ period. This is a form of cost-reflective price that seeks to signal to consumers the periods where increased demand will result in increased cost of supply – and is one of the three main families of options that the ENA has identified as potentially being appropriate to deliver more cost-reflective prices.<sup>25</sup>

Experience overseas, and with trials in New Zealand<sup>26</sup>, indicates that this does result in a substantial shift in EV charging behaviour, with people using the built-in functionality within their EVs or wall chargers to program charging to begin within the off-peak period.

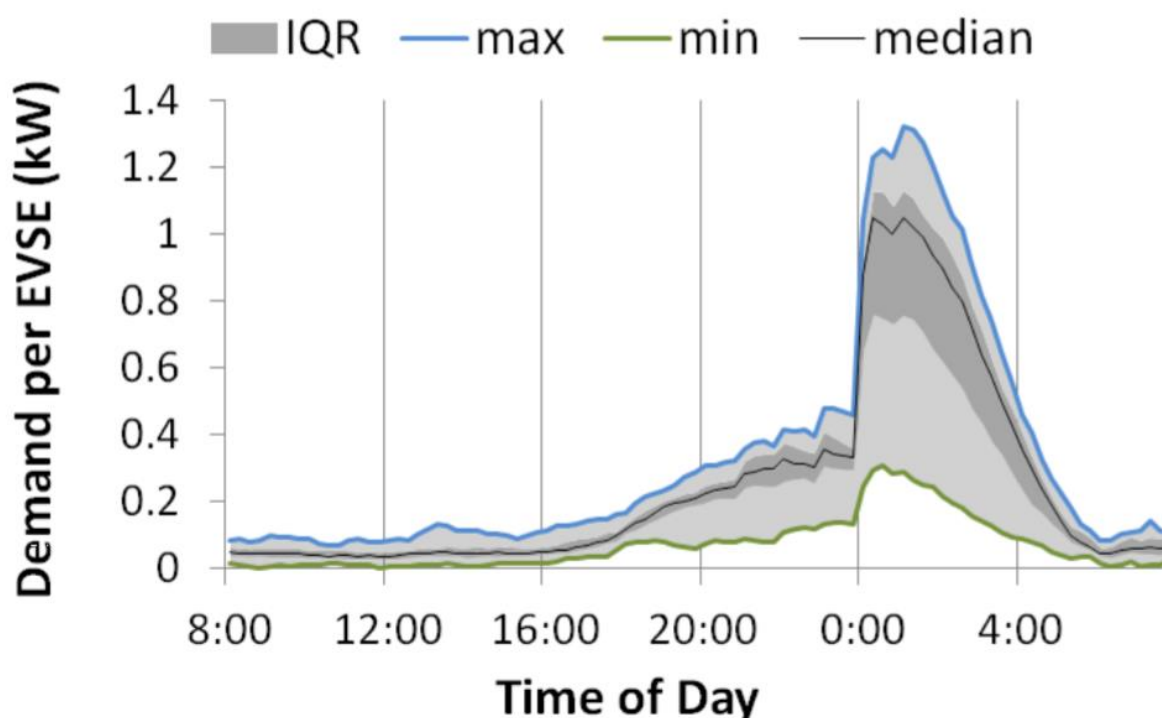
<sup>25</sup> The other two main options are peak demand-based, and capacity-based prices. The ENA’s main report on these issues is available here: <http://ena.org.nz/news-and-events/news/final-pricing-guidance-report-published/>

<sup>26</sup> For example, see: <http://www.energynews.co.nz/news-story/electric-vehicles/35753/overnight-tariffs-drive-ev-charging-shift-mercury>

For example, a United States study on EV charging patterns<sup>27</sup> highlighted the significant differences in charging behaviour between:

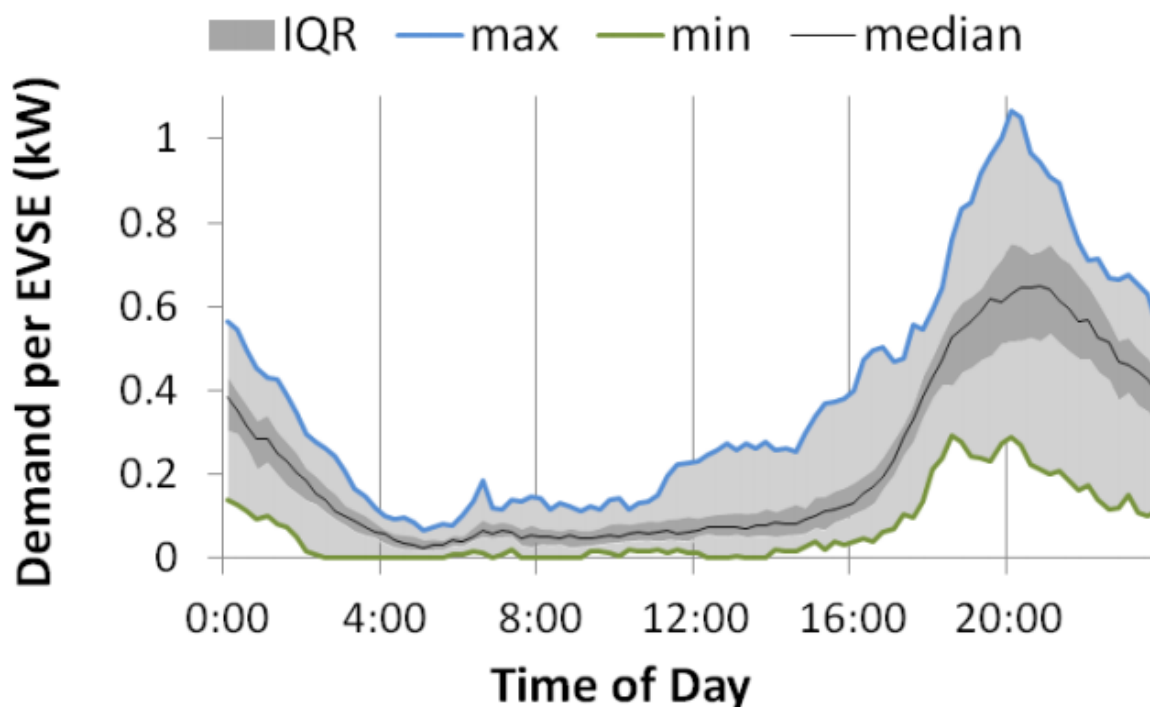
- customers who faced a time-of-use electricity price (as shown in Figure 13 below for San Francisco, where Pacific Gas & Electric offered EV-owning customers a time-of-use price with an off-peak period starting at midnight.)
- customers who faced a flat electricity price. (as shown in Figure 14 below, for Nashville)

**Figure 13: Weekday EV charging demand for San Francisco (Note: x-axis starts at 8am)**



<sup>27</sup> "A First Look at the Impact of Electric Vehicle Charging on the Electric Grid in The EV Project", EVS26, May 2012 [https://energy.gov/sites/prod/files/2014/02/f8/evs26\\_charging\\_demand\\_manuscript.pdf](https://energy.gov/sites/prod/files/2014/02/f8/evs26_charging_demand_manuscript.pdf)

Figure 14: Weekday time-of-day EV charging demand for Nashville (Note: x-axis starts at midnight)

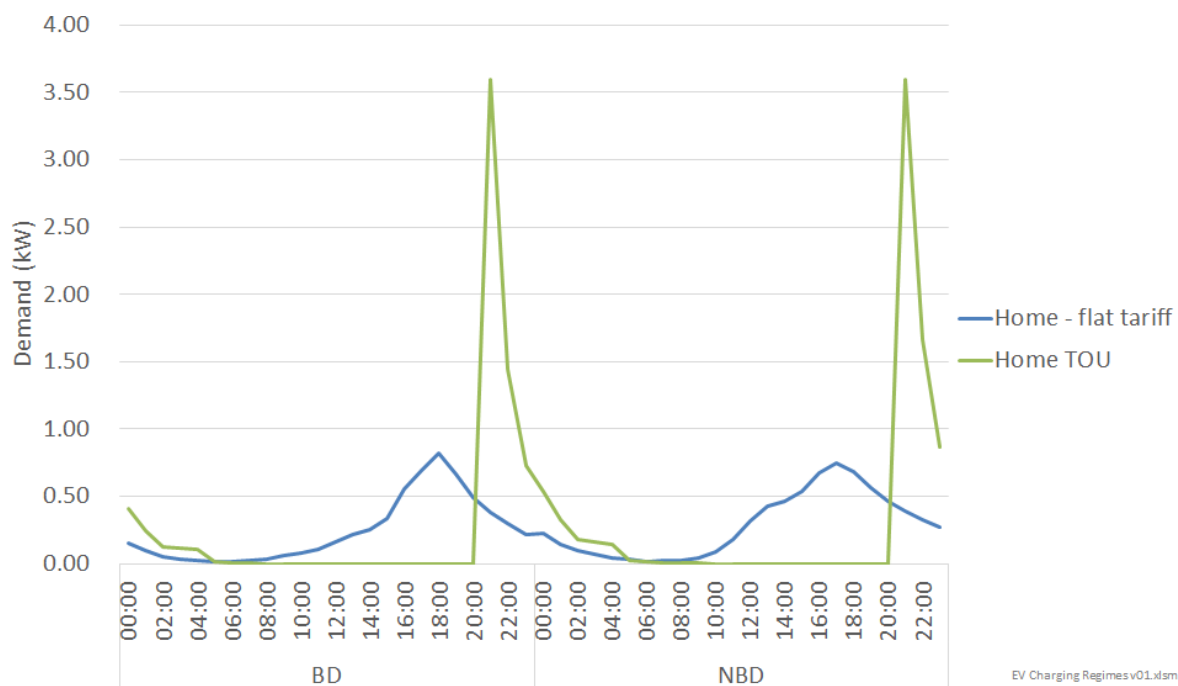


While TOU pricing has shown to be successful in shifting EV demand out of the current peak, such success is a double-edged sword in that it creates a likelihood of a new, greater peak:

- As almost all EVs have the functionality to set the vehicle to start charging at a certain time, there is a risk that large numbers of EV-owners will set their vehicles to start charging at the start of the off-peak period. (As has been observed in the San Francisco case shown in Figure 13 above.) This is because, even if vehicle technology allows a later start time for charging, there is no economic advantage for a driver to set the start time of their vehicle charging at any time later than the start of the TOU period. Indeed given the (albeit small) risk of electrical outage there is disadvantage to doing so.
- Such a charging approach would lose all the diversity benefits associated with people starting their EV charging at different times.

Figure 15 illustrates the potential charging outcome in New Zealand if every EV owner who arrives home prior to 9pm were to start charging their vehicle at 9pm ('Home TOU') compared with the previously estimated passive charging outcome for consumers who plug-in whenever they get home because they face a 'flat' price.

**Figure 15: Modelled after-diversity EV charging pattern for 'passive' (flat price) and 'simple TOU' charging approaches (average impact per EV)**



If such an outcome were to occur from TOU pricing (noting that a proportion of consumers may not respond to this signal and continue to charge passively), then our analysis suggests it would only require 9% of households to have an EV for the peak system demand to shift to 9pm, from the current 6pm system peak.

Further, because each additional EV operating under this TOU pricing paradigm adds 3.6 kW to 9pm demand, whereas under a flat price paradigm each EV only adds 0.8 kW to system peak (due to diversity effects), the rate of increase in peak with EV uptake is much greater.

Therefore, for EV penetrations of 15-20% and above, the peak demand arising from everyone following this 'simple TOU' pricing approach would be *greater* than if everyone had continued to follow a 'passive' charging approach.

Clearly, not everyone will follow a 'simple TOU' pricing approach (i.e. start charging at 9pm as in the example) as some will disregard price and simply charge their vehicles when they want. However, the experience of trials, such as that illustrated in Figure 13, and a significant portion of customers wishing to save money suggests that a large proportion will. It is thus considered likely that large-scale EV uptake with TOU prices is likely to result in the type of adverse outcomes described above.

Further, large step-change increases in demand at the same time create additional voltage and frequency impacts on networks. This means a 'simple TOU' approach may lead to network stability issues (at local, or regionally/nationally if neighbouring network companies TOU periods start at the same time) that aren't experienced if passive charging or a truly smart charging approach is adopted. Such network stability issues may reduce the confidence of homeowners to convert to EVs and slow the rate of adoption – with consequent impact on carbon reductions.

One possible option to address the phenomenon of a new larger instantaneous peak is to introduce stepped TOU pricing – such as an intermediate 'shoulder' period. For example, having a mid-rate period between 9pm and 11pm.

However, this is not considered likely to fundamentally resolve the problem. This is because there is no incremental effort or loss of utility for an EV owner programming their car to start charging at

11pm compared to 9pm. As such, it is considered likely that we will get the extreme demand step-change at 11pm rather than 9pm and with similar consequences.

As evidence that stepped TOU pricing is unlikely to resolve this issue, Orion in the late 20<sup>th</sup> century had this approach for the management of hot water cylinders. Over time, as the number of hot water cylinders increased, they found stepped TOU pricing to cause the negative effects discussed here. Consequently, in the late 1990's Orion moved to solve this issue by shifting to a reward-based approach where the start time of charging of hot water cylinders was de-linked from a specific period.

Another option that has been suggested is to have the TOU time periods being different for different consumers. For example, one household having off-peak starting at 9pm, another at 9.15 pm, another at 9.30 pm, etc.

While this would certainly reduce the demand step-change phenomenon, it is considered this approach would introduce high transaction costs to implement, as this dispersion of times would need to be for all customers *within* each LV network (i.e. the group of approximately 50-100 properties served by the same LV transformer). This would impose high cost-to-serve for networks and electricity retailers (which would be passed-on to consumers) and would also tend to act as a constraint on electricity retail competition. In this respect, it is worth noting that electricity retailers, based on feedback from their customers, have repeatedly suggested that network pricing needs to get simpler – not more complicated.

The last potential issue associated with using TOU pricing to incentivise off-peak EV charging is that it may raise additional issues once so-called 'vehicle-to-grid' (V2G) technology (i.e. EVs injecting power back into the grid at times) becomes more prevalent. With potential cost-reflective time-of-use price differentials between peak and off-peak periods of approximately 15 c/kWh, there would be strong financial incentives for vehicle owners to use their vehicles as storage batteries: i.e. vehicles injecting power back into the grid at times of high price, and re-filling the battery at times of low price. Such behaviour would tend to significantly exacerbate the step-changes in demand between peak and off-peak periods illustrated in Figure 15 above, until such a point when night time becomes the new peak, and customer pricing needs a dramatic overhaul.

In summary, while TOU pricing is an excellent means of shifting EV charging to periods classed as 'off peak', it does not overcome the fundamental other requirement required for 'smart' charging, namely smoothing EV charging across users over the off-peak period.

Indeed, for the reasons set out above, TOU is so good at shifting EV charging patterns that it will give rise to a new (and faster growing) peak at relatively low levels of EV penetration than would occur with passive charging under the current flat price structure. As set out previously in section 2 such a higher peak will deliver adverse economic and environmental outcomes.

Further, the sharp step-change in demand at the start of the time period classed as 'off-peak' could potentially create network stability issues.

Clearly, as such outcomes start to emerge, it would be likely that the industry would move away from TOU pricing. However, it is not considered desirable to introduce TOU pricing, only for consumers to go through the upheaval of moving to another pricing approach as undesirable outcomes from TOU pricing for EV charging start to emerge.

It is considered that these poor outcomes in relation to TOU pricing applying to EV load is because EVs are *storage* technologies. Hot water cylinders are also storage technologies.

By their very nature, storage technologies offer significant flexibility to alter the timing of energy consumption without materially impacting on delivery of the underlying energy service – i.e. transport in the case of EVs, hot water in the case of hot water cylinders. For example, whether an

EV is charged at 6pm or 3am doesn't affect the utility received by a vehicle owner from driving it to work at 9am.

It is potentially the case that TOU pricing may be appropriate to deliver improved consumer decisions in relation to other, non-storage energy technologies (e.g. incentivising least-cost investment in efficient lighting, or home insulation) without resulting in the significant step-changes in demand associated with storage technologies. It is beyond the scope of this report to consider the suitability of TOU pricing for these other consumer demands.

### 3.3 Coincident maximum demand charging

An alternative more cost-reflective pricing option could be to introduce coincident maximum demand (CMD) or 'peak' pricing – i.e. a 'stick' of penalty prices for charging during periods of peak demand, to incentivise people to charge their EV outside of periods which are likely to be peak periods.

The key differences between CMD and TOU pricing are:

- TOU pricing is 'static' (the peak and off-peak periods are determined in advance), and with relatively low peak prices;
- CMD pricing is 'dynamic' (which periods are classed as peaks is not known in advance), with relatively high peak prices:

For example, a simple peak & off-peak TOU structure may have the peak period being four hours in the morning and four in the evening (2,920 hours in total across the year), with the peak network price being 15 c/kWh and the off-peak network price being 0 c/kWh.

Conversely, a CMD pricing approach may only have 125 hours in the year classed as peak with

- periods only classed as peak either shortly in advance (e.g. a couple of hours prior) or after the event (sometimes several months after)
- the peak network price applying during such periods being as high as \$2.50/kWh (i.e. fifteen times greater than the TOU peak price.)

While CMD pricing is likely to deliver better demand outcomes than TOU pricing – i.e. it is much less likely to deliver the sharp step-changes in demand associated with the start of a TOU off-peak period – there are other aspects of CMD pricing which may prove challenging arising from the fact that the CMD pricing would need to apply to all electricity consumed at the property (not just the EV charging):

- As the experience with The Lines Company's implementation of such pricing indicates, it is not clear that mass-market consumers have the 'sophistication' to make good decisions in the face of such extreme, and dynamic prices.
- CMD pricing inherently imposes relatively high transaction costs on networks, retailers and consumers in terms of signalling, monitoring, and responding to the real-time peak price signals. For customers, it is generally hard to predict when peaks will occur. And with the emergence of large controllable loads (such as EVs and hot water cylinders), phenomena such as 'peak hunting' can occur whereby large numbers of customers shift load out of one period, only to cause the peak to shift to another period if this load movement is uncoordinated between customers. This causes costs (and stress) for customers seeking to minimise their bills.
- Applying CMD pricing can raise some social welfare issues for consumers suffering income deprivation, particularly:
  - managing much higher winter / summer bill differentials; and

- undesirable incentives on people to under-heat their home, particularly at times of greatest need (i.e. during periods of extreme cold weather – which tends to drive peak demand).

For the above reasons, it is not clear that CMD pricing would be a desirable approach to incentivising households to undertake good EV charging approaches.

### 3.4 General issues with TOU and CMD prices

#### 3.4.1 The potential for bill shock

The above analysis highlights the significant general challenge with using more cost-reflective prices to incentivise good EV charging approaches: Cost-reflective prices which reward night-time charging will also penalise peak-time charging. This altered pricing approach will also apply to the rest of household demand.

Previous analysis undertaken by Concept has identified that some consumers will face significant ‘bill shocks’ with such a move – albeit with other consumers enjoying counter-balancing bill reductions.<sup>28</sup>

Given the uncertainty that most consumers face as to whether they would be ‘winners’ or ‘losers’ from moving to such cost-reflective pricing, it is possible that most consumers will elect to continue with their current pricing approaches if given the choice. Indeed, that is the overwhelming experience to-date for those networks who have offered time-of-use prices for several years.<sup>29</sup>

However, if a significant number of consumers elect to continue on ‘flat’, non-cost-reflective prices, one of two undesirable outcomes will likely occur:

- If they do purchase an EV, they will likely charge in a ‘passive’ fashion giving rise to the increase in system costs identified above.
- They will be less likely to purchase an EV in the first place, given that the costs of charging their vehicle will be significantly higher. As set out in section 2.5, this will increase the costs of oil purchases, plus cause significantly higher greenhouse emissions.

The alternative approach is to make cost-reflective prices compulsory. This would in principle deliver improved EV outcomes in terms of higher uptake for lower costs. However, many consumers would be ‘losers’ and suffer bill shocks from such a move – albeit offset with other consumers being ‘winners’. Given the experience of The Lines Company introducing CMD pricing, it is not clear that a rapid introduction of compulsory cost-reflective prices would be desirable.

Rather, a more considered, phased approach is regarded as preferable, particularly as there are some complex design issues to resolve with moving to cost-reflective pricing, with difficult trade-offs to resolve. For example,

- At the moment, a lot of network and retail costs which are not driven by kWh consumption are currently recovered via variable c/kWh consumption charges. Moving to recovering a higher proportion of costs from fixed charges is likely to deliver better economic, environmental and, in many cases, social outcomes over the long-term. For example, it would improve the economics of owning an EV, thereby facilitating EV uptake and improved environmental outcomes. However, high fixed charges are prohibited for most residential consumers under the low-fixed charge regulations, and run counter to many people’s perception of ‘fairness’.

<sup>28</sup> See: “Electric cars, solar panels, and batteries in New Zealand – the social impacts”, March 2017. Available for download at [www.concept.co.nz/publications.html](http://www.concept.co.nz/publications.html) - along with a summary presentation “New technologies + Old tariffs = Problem!”

<sup>29</sup> While some EV owners in New Zealand have shown a greater propensity for moving to TOU prices, it is considered that these early adopters (who tend to be engaged in the electricity market to an unusual extent) are not representative of the general public.



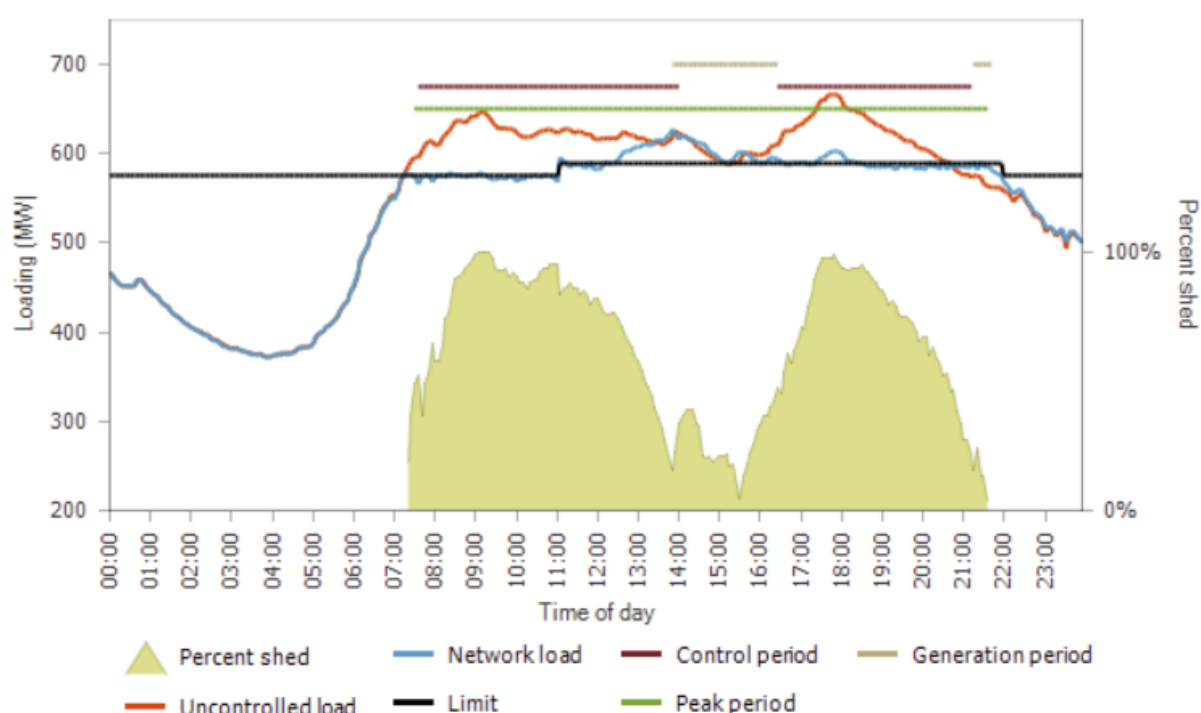
- There are some design choices for the approach to recovering those network costs not driven by demand (so-called 'residual' network costs), particularly with regards to cost-allocation between consumer groups, and issues such as rural / urban pricing.

### 3.4.2 Limited ability to deliver very-smart charging approaches

The other general issue with TOU and CMD pricing is that neither option is considered very good at achieving the 'smoothing' in demand that will be necessary at even modest levels of EV penetration to prevent an increase in peak demand.

An example of smoothing in demand is shown in Figure 16 for hot water demand in Christchurch. This shows how the proportion of hot water load shed was varied in a highly coordinated fashion throughout the course of the day so as to give a flat overall demand curve.

*Figure 16: Orion's network load and management for 12 Jul 2017*



Source: Orion

While both TOU and CMD are good at avoiding current system peaks, neither TOU or CMD is considered capable of delivering this highly coordinated charging approach to fill up night-time troughs in a way which prevents new peaks emerging with large-scale EV uptake.

## 3.5 Managed charging

A third option which may avoid many of the above undesirable outcomes from TOU and CMD pricing is for EV charging to be managed by an electricity retailer, aggregator, or network company.

Such management would involve interrupting EV charging during periods of peak demand, and managing EV charging over the rest of the period to prevent new peaks occurring, whilst ensuring that the EV battery is fully charged by the time a customer needs it for the start of their daily commuting. This would facilitate the highly coordinated 'smoothed' EV demand charging that is currently achieved by some networks for hot-water demand, whilst still providing customers with a service level they are happy with.

The key questions with managed charging are:

- How to incentivise the majority of consumers to grant another party the right to manage their EV charging?
- Can such incentives be arranged in a way which doesn't cause bill shocks?

#### *Mandated approach?*

In the past, some networks used a form of mandated approach (to varying degrees) to secure the ability to manage the hot water cylinders on their network. i.e. the terms in a customer's contract granted the network the ability to manage a hot water cylinder that is connected to the network. Generally, this was explicitly rewarded in the form of lower pricing for hot water cylinders, recognising the costs savings to the network through not having to build as much network capacity to meet peak demand.<sup>30</sup>

However, it is considered that these mandated approaches for hot water were historical legacies which reflected the circumstances of the time. It is not considered that mandating that a third party must be able to manage in-home devices is a desirable approach to take for new consumer energy technologies, including EVs. This is particularly because mandate risks:

- The relative value that different consumers place on a service not being properly recognised
- Management through mandate being used only for the part of the supply chain associated with the mandate (e.g. provision of network services), and not being effectively used for delivering value for other parts of the supply chain (e.g. generation).

Further, mandates are only likely to be practicable if the mandate can be associated with the installation of a device in a consumer's premises which are subject to regulation. While this is the case for hot water cylinders – i.e. they require a qualified electrician, and the installation of a cylinder which meets New Zealand standards – it is not the case for EVs given that EVs can be charged from a standard domestic socket.

It is possible that a mandate could be associated with installation of dedicated chargers. This approach appears to be being pursued by the UK government, where the "Autonomous and Electric Vehicles Bill" has reached its second reading. Amongst other things, this Bill will allow regulations to be easily introduced, if they are determined necessary in the future, around the technical requirements for EV charging points.

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<sup>30</sup> In some cases there was no explicit recognition through a discounted hot water price, but rather the benefit to consumers was implicitly achieved through the networks not having to build as much network, and thus bills generally being lower than they would otherwise have been.

## 12 Smart charge points

- (1) Regulations may provide that a person must not sell or install a charge point unless it complies with prescribed requirements.
- (2) The requirements that may be imposed under subsection (1) include requirements relating to the technical specifications for a charge point, including for example the ability of a charge point –
  - (a) to receive and process information provided by a prescribed person,
  - (b) to react to information of a kind mentioned in paragraph (a) (for example, by adjusting the rate of charging or discharging),
  - (c) to transmit information (including geographical information) to a prescribed person,
  - (d) to monitor and record energy consumption,
  - (e) to comply with requirements relating to security,
  - (f) to achieve energy efficiency, and
  - (g) to be accessed remotely.
- (3) Regulations under subsection (1) may also prescribe requirements to be met in relation to the sale or installation of a charge point.
- (4) In this section –
  - (a) “sell” includes let on hire, lend or give;
  - (b) references to a prescribed person include references to –
    - (i) a person of a prescribed description, and
    - (ii) a device operated by one or more prescribed persons.

It is not clear how appropriate or successful such an approach would be in terms of incentivising management of EVs in New Zealand – particularly as it is possible that most consumers may elect to charge their EVs from a standard domestic socket, rather than install a dedicated charger. This is because there is an up-front cost to consumers from installing a dedicated charger<sup>31</sup>, and many consumers may perceive no real need for such charging, as slow charging overnight using a standard socket will be more than adequate for the vast majority of journeys undertaken by drivers.

Where it might be more achievable to use mandate to incentivise managed EV charging is in relation to managing vehicle-to-grid (V2G) dynamics – i.e. managing the potential for EVs to inject power back into the grid. Because there are significant safety aspects with injecting power into the grid, it is more likely that regulations could be introduced which mandate particular approaches by consumers wishing to inject power from their vehicle into the grid. Such regulations could include mandate that injection can only be via approved charging points which are subject to management.

However, it is not considered desirable that such a mandate should move beyond the safety aspects of V2G, to also using such control to address the economic aspects of V2G.

In this respect, V2G has the potential to deliver significant additional economic benefits through reducing peak demand. However, as set out previously on page 29, there is the potential for inefficient outcomes if consumers use their batteries to respond to a static TOU price signal. If a network, retailer or aggregator were to manage the charging and injection of the battery, much more cost-effective outcomes would be achievable.

However, mandating such control may risk inadvertent outcomes, rather than an approach which enables EV owners to opt-in in return for sharing the economic benefit.

In summary, it is not considered that using a mandate is a desirable approach to achieving better EV charging outcomes.

<sup>31</sup> The up front cost for many households may include an upgrade in the electricity wiring both to and within their home.

### *Reward?*

The other approach to incentivise consumers to grant networks or other parties (e.g. electricity retailers) the rights to manage their EV charging is a financial reward. I.e. consumers are offered some form of discount/reward in return for granting a third party the rights to manage the charging of their EV.

This is the approach currently taken by many networks in terms of incentivising consumers to grant networks the rights to manage their hot water cylinder. Typically, consumers with managed hot water cylinders pay a discounted network price on their variable consumption, or sometimes pay a lower fixed daily charge. This recognises the costs savings to the network through not having to build as much network capacity to meet peak demand

A similar value proposition is likely to be appropriate for incentivising consumers to grant parties the rights to manage the charging of their EV. This also has the potential benefit of incentivising smart EV charging but in a way which minimises the bill shocks for consumers from introducing cost-reflective pricing to their other, non-EV consumption.

In addition, there may be other value propositions to incentivise consumers including:

- Improved battery management. A party (electricity retailer, network or other party) could charge the battery in a way which extends the life of the EV battery
- Payment for injection back into the network during periods of peak demand – i.e. vehicle-to-grid – or to provide other ancillary services such as frequency keeping, voltage support etc.

### *General challenges with developing EV management*

In practice there are likely to be a number of implementation challenges associated with managed EV charging:

- Designing an EV price that supports managed EV charging which has a sufficiently large ‘carrot’ to incentivise uptake, but which is consistent with other cost-reflective prices (such as TOU) which may apply to unmanaged load. This may require the electricity supply for managed EVs to be separately metered – increasing the costs for such an approach. This contrasts with hot-water management at the moment, whereby many properties have a single meter, with the discount for managing hot water load given to all consumption at the property.
- How to incentivise managed outcomes that recognise the value of management across the whole of the electricity supply chain. In other words, there may be certain times when management may be economic to avoid generation costs, but not local distribution costs, and which takes priority if say managing network load is not what retailers want at that point in time.

Currently, this whole-of-supply chain management is not well achieved by hot-water management due to limitations in the signalling infrastructure such that individual consumers can’t be switched off to different levels according to their preference. (E.g. one consumer cannot elect to have their load managed when generation costs rise above \$200/MWh, while another chooses a threshold of \$400/MWh).

To achieve whole-of-supply-chain management will likely require the ability to manage loads at an individual property level. Under such an arrangement, a household could elect whether to sign-up for management for network purposes (potentially to varying levels (e.g. no more than 50 hours a year, or 150 hours a year), and also for generation purposes (again, potentially to varying levels). The level of management they opt for would determine the level of discount/reward they receive. This would recognise variations in individual consumer preference, and also facilitate targeted management varying by system need – e.g. a network company may only need to manage load in one part of its network.

Further, to make the challenge even more challenging, it is likely that truly smart management will need *EV-specific* management. This means not just property-specific management, but also the ability for such management to recognise a variety of factors – such as how empty different EV batteries are, where along a low-voltage network (of approximately 50-100 houses) EVs are located, or consumer requirements for when they need to next drive their EV – in order to coordinate which EVs should be charged, and when, in order to meet consumer requirements without imposing excessive supply costs.

The internet and ubiquitous home wi-fi raises the potential for management exercised at an individual property level or EV level. Further, many of the latest EVs are being produced with the ability to interface with external management systems in order to provide information about the state of the EV battery to enable EV-specific management.

However, to achieve whole-of-supply-chain management requires the ability for different parties e.g. networks, retailers, specialist load-aggregators to be able to contract with consumers to deliver management and then access the technical infrastructure (and associated metering data) to execute such management. This may require some degree of coordination to facilitate the best long-term outcomes, including to manage the trade-offs between:

- Ensuring there is sufficient open-access to systems and data to facilitate competition, while not creating dis-incentives for companies to invest in technology. In this respect, vehicle manufacturers are starting to emerge as new players in this space, with tensions emerging internationally regarding allowing third parties access to the data collected by, and control interfaces with, vehicles.
- Ensuring that technical arrangements for accessing and interfacing with management infrastructure (and metering) data are standardised where appropriate, while not stifling innovation or closing-off possible better approaches
- Ensuring that any management is available when truly needed. For example, if there is a risk that internet may not be available due to an outage (e.g. due to something affecting a region, or all customers of an ISP) how large does this risk of outage need to be before the internet is deemed too unreliable to deliver electricity demand management?<sup>32</sup>

Or should standards be developed around required ‘fall-back’ modes for appliances in the event of an internet outage? E.g. a fall-back arrangement for EVs could be that managed EV chargers do not charge vehicles between the hours of 5pm to 10pm. This may require tricky evaluations given that the outcomes to a consumer from a flat EV battery could be more costly than temporary loss of service for hot water.

These challenges are not specific to EVs, but rather apply to all appliances which have the potential to be remotely controlled – which is rapidly growing to include most energy-consuming appliances as they become part of the ‘internet of things’.

There is no inherent reason why such arrangements can’t be developed within the competitive market construct which is at the heart of the New Zealand electricity system. However, it is likely to require a significant degree of industry coordination and regulatory oversight.

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<sup>32</sup> In this, early result from technology trials suggest that home Wi-Fi has a material degree of unreliability compared with ‘utility-grade’ control infrastructure. For example, sometimes the home Wi-Fi drops out in properties, or people change passwords / modems / suppliers, etc. which affect the ability of utilities to be able to communicate to managed devices. What this suggests is that utilities will need to apply some form of ‘unreliability factor’ to the aggregate amount of response across large numbers of households from appliances managed through home Wi-Fi.

Thus, the opportunities are likely to be much greater than the relatively crude (but reliable) form of control that is applied to hot water, but the challenges to achieve good outcomes are likely to be much greater.

It also remains to be seen how many EV-owners will be willing to hand over control of their charging to third parties such as retailers and networks. We believe these options should be voluntary for consumers to choose, and it is possible that many consumers may suffer anxiety that handing over control may mean that their vehicle may not be charged when they need it.<sup>33</sup>

However, if we are to achieve mass-EV uptake without significant electricity supply cost impacts, our analysis indicates we will need significant uptake of managed EV-charging pricing options.

A final additional consideration around the development, and extent of consumer uptake, of managed-charging options is that if consumers opt not to take up a managed-charging option, they should face any increased electricity supply costs they impose on the system – rather than cause such costs to be ‘shifted’ onto others.

This highlights a general issue with current, non-cost-reflective prices: Not only are they causing higher electricity supply costs, but with the advent of new technologies such as EVs, solar PV and static batteries, they are resulting in consumers who purchase such technologies being able to ‘shift’ the electricity supply costs they are responsible for onto other consumers who don’t have (sometimes because they can’t afford) such technologies.

### 3.6 Other emerging energy technologies face similar issues

As highlighted throughout this text, the root cause of the problems identified in this work is the fact that consumer electricity prices are not cost-reflective. In particular, ‘flat’ variable \$/kWh consumption prices.

Similar un-desirable outcomes from non-cost-reflective prices are starting to occur with other emerging technologies such as solar PV and in-home batteries.

A previous Concept study has identified that the lack of cost-reflective pricing is resulting in

- higher economic costs through consumers facing price signals which
  - encourage the uptake of some technologies which are not least-cost from a whole of NZ perspective (e.g. solar PV and/or in-home batteries, rather utility scale wind & geothermal delivered over the grid)
  - frustrate the uptake of other technologies which are least-cost (e.g. high efficiency lighting, home insulation, and smart appliances).
- poor social outcomes, through some consumers shifting the costs of supplying them with electricity onto other consumers. E.g. consumers who install solar PV shifting the costs of providing them with network and retailer services onto non-solar-owning consumers. Given that the poorest consumers are least likely to live in a property with solar panels, this has a social as well as equity dimension.

A continuation with non-cost-reflective prices will not only affect EV uptake and outcomes, but also these other technologies. It is not considered that these will in some way ‘cancel out’ the poor outcomes arising with EVs. Rather, it is considered that the undesirable economic, environmental and social outcomes will largely be additive across these different technologies.

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<sup>33</sup> While these consumer concerns are reasonable, we think well-designed managed charging options should enable good electricity supply outcomes, without impacting on consumers’ ability to have their vehicles charged for when they need them.



However, it should be appreciated that the ‘right’ cost-reflective price for these different technologies may differ. In particular, technologies which have significant storage characteristics (e.g. EVs, hot water cylinders, in-home batteries) may require managed pricing as set out in this study, whereas other energy technologies may be more appropriately addressed via simpler forms of pricing (e.g. simple TOU structures).

### 3.7 Conclusion on incentivising better EV charging outcomes

A move to more cost-reflective approaches for charging for electricity is going to be necessary to avoid the poor economic and environmental outcomes identified in section 2 (i.e. frustrated levels of EV uptake, and ‘passive’ charging of those EVs which are purchased leading to significant increases in peak demand). Technology alone will not solve this issue.

#### *Electricity pricing options which apply to the whole of a household will likely be inadequate to meet the special challenges of EVs*

However, identifying and transitioning to smarter electricity prices will itself have some challenges:

- ‘Time-of-use’ (TOU) pricing (e.g. having a simple peak / off-peak pricing structure based on pre-set times) might be appropriate for most household electricity demand, but will not deliver good long-term outcomes in relation to EV demand. TOU pricing will likely create new demand spikes with a majority of EVs simultaneously charging from the start of the off-peak period.

While such issues won’t matter for very low-levels of EV uptake, our analysis suggests for EV penetrations of 15-20% and above (i.e. approximately 1-in-6 households owning an EV), the peak demand arising from everyone following a TOU pricing approach would be *greater* than if everyone had continued to follow a ‘passive’ charging approach and the peak period will shift to 9pm, from nearer 6pm now. Aside from not avoiding the need for expensive network investment, TOU pricing applied to EV demand could also potentially create network stability issues with a very rapid step change in demand occurring at the start of off-peak periods. This rapid step change in demand is not observed with flat rate charging, and will be made much worse if vehicle to grid technology becomes mainstream.

Thus, while TOU pricing may be appropriate for sending efficient signals to consumers for some of their electricity decisions, it is potentially a worse solution than flat rate pricing over the long term when applied to EV demand given the special ‘storage’ characteristics of EV demand.

- ‘Peak demand’ pricing could overcome this problem by adjusting prices based on actual demand conditions. But this may be unsuitable for most residential consumers, due to the lack of pricing predictability, and issues around bill shocks, higher winter costs, and the ability of consumers to make good decisions in response to such complex pricing approaches.

In addition, both of the above pricing approaches will likely need to apply to the whole of a household’s electricity consumption, not just the EV demand. Changing consumer pricing structures, will inevitably lead to ‘winners’ and ‘losers’, with some of the losers potentially facing significant bill shocks. This raises some challenging policy choices:

- On the one hand, having a phased transition to smarter cost-reflective pricing over many years may be desirable to avoid many of the poor outcomes from bill shocks for some consumers.
- On the other hand, delaying the transition to smarter cost-reflective pricing, will also delay the time when consumers will be fully incentivised to make good vehicle decisions. This will tend to slow the uptake of EVs which, given that vehicles tend to be 20-years old by the time they are

scrapped, will lock-in many more high-emissions vehicles over the next few decades than is necessary.<sup>34</sup>

### *EV-specific managed-charging pricing will likely be necessary – but with challenges to implement*

A possible alternative pricing approach to enable the adoption of emerging technologies like EVs, whilst minimising customer bill shock and without compromising carbon goals, is ‘managed-charging’ pricing which only applies to a household’s EV demand.

This would involve consumers agreeing to another party (e.g. retailer, load aggregator, or network company) managing their EV charging, in return for discounted network and/or energy pricing for such managed EV load. This approach recognises the distinct nature of EV load, with its storage characteristics, and would deliver materially better outcomes of smoothed coordinated charging of New Zealand’s EV fleet and lowering the cost of EV charging to consumers, but in a way which has reduced risk of causing bill-shocks for consumers.

Managed-charging would be similar in some ways to the approaches taken to manage hot water cylinders, with consumers being rewarded with cheaper electricity for hot water load being managed at times of peak network demand.

Luckily, the technology coming within EVs and dedicated EV-chargers, and broader internet-based communications technology, not only provides the means to enable these smarter ways of charging our EV fleet, but to do so in a much more sophisticated way than the relatively crude ripple control that is currently used for hot water management.

Thus vehicle-specific management is feasible, with the ability to recognise a variety of factors – such as how empty different EV batteries are, where along a low-voltage network (of approximately 50-100 houses) EVs are located, or consumer requirements for when they need to next drive their EV – in order to coordinate which EVs should be charged, and when, in order to meet consumer requirements without imposing excessive supply costs.

However, to take advantage of such technology requires EV-owners to receive price signals or rewards which are of sufficient size to encourage them to take-up such managed-charging options.

It remains to be seen what form such managed-charging pricing options could or should take, or whether/how to develop NZ-wide standards and/or mandate open access to the technology to deliver EV charging management.

It also remains to be seen how many EV-owners will be willing to pass control of their charging to third parties such as retailers and networks. We believe these options should be voluntary for consumers to choose, and it is possible that many consumers may suffer anxiety that handing over control may mean that their vehicle may not be charged when they need it.<sup>35</sup>

However, what this study highlights is that, if we are to achieve mass-EV uptake without significant electricity supply cost impacts, we will need significant uptake of managed EV-charging pricing options.

A final additional consideration around the development, and extent of consumer uptake, of managed-charging options is that if consumers opt not to take up a managed-charging option, we

<sup>34</sup> A long transition to cost-reflective pricing will also result in distorted consumer decisions in relation to other energy technologies in addition EVs. In many cases this will also result in poor economic, environmental and (in some cases) social outcomes such as the costs from a technology choice being made by one consumer being ‘shifted’ onto other consumers. Consideration of these other matters is out of scope for this study.

<sup>35</sup> While these consumer concerns are reasonable, we think well-designed managed charging options should enable good electricity supply outcomes, without impacting on consumers’ ability to have their vehicles charged for when they need them.



believe they should face any increased electricity supply costs they impose on the system – rather than cause such costs to be ‘shifted’ onto others.

This highlights a general issue with current, non-cost-reflective prices: Not only are they causing higher electricity supply costs, but with the advent of new technologies such as EVs, solar PV and static batteries, they are resulting in consumers who purchase such technologies being able to ‘shift’ the electricity supply costs they are responsible for onto other consumers who don’t have (sometimes because they can’t afford) such technologies.

### *Broadening and deepening the debate*

Addressing all of the above challenges and questions requires coordinated pan-industry effort in conjunction with government, regulator(s) and transport authorities.

Some of this is starting to happen, in particular through the electricity networks association (ENA) progressing its network pricing reform initiative, and the Electricity Authority through its various market development programmes. However, to-date, most of this focus has been on pricing options that will apply to the whole of a property, rather than the specific challenges of EVs (and other storage technologies) whose special characteristics may require specific pricing solutions.

Further, changes to consumer electricity prices will also require broader community and political engagement to help make the inevitable tough choices which carry the risk of bill shocks for some consumers in the short-term, but which will help deliver better economic, environmental, and social outcomes in the long-term.

The three network companies who have commissioned this study all strongly support a shift to EVs and they hope that this study will be a valuable contribution to this broader public debate.

All are aware that time is of the essence in terms of putting in place arrangements to facilitate the most positive EV outcomes before mass uptake starts to happen, and all believe that pricing and managed charging – be it by a retailer, aggregator, network company or other third party – is central to this debate.

EVs offer an enormous positive opportunity for New Zealand – the question is, how do we maximise that opportunity?

## 4 Policy issues around public charging infrastructure

The earlier sections have identified that continuing with current pricing approaches won't just lead to high system costs from poor EV charging approaches, but will also likely slow the uptake of EVs.

The other area where electricity system arrangements may significantly affect EV uptake relates to public charging infrastructure.

Experience from overseas has shown that 'range anxiety' (i.e. the concern that an EV will run out of battery somewhere where there is no public charging facility nearby) is a considerable factor affecting consumers propensity to buy an EV. Having a wide-spread network of public charging stations has been shown to be a significant factor in overcoming such anxiety. Our analysis in Appendix D also suggests this is likely to be a significant factor in incentivising commercial and freight uptake of EV technology.

However, there are some tricky issues to address in relation to the development of such charging stations.

Our provisional analysis indicates that a significant proportion of charging stations will have a very low utilisation factor. i.e. most of the time they will not be used, but when they are used they could place significant demands on the system.

Some of these infrequently-used charging stations may simply be in remote parts of the roading network. Others may be on parts of the roading network which face infrequent, but severe 'spikes' in travel – e.g. along routes to, or at, major holiday locations. These can experience major increases in demand at the start and finish of public holidays.

Some of these infrequently-used charging stations may also be in places where there is a relatively weak electrical network. To install public chargers may require significant network investments – either the development of additional wires, or the installation of local batteries or diesel gensets to manage the spikes in demand. In this respect it should be noted that charging stations are being developed with capacities of 120kW in New Zealand, and overseas they are trialling 350kW, chargers. On an individual basis, some of these public charging investments for low-utilisation public charges may not appear cost-effective. However, when considered as part of a broader *network* of public charging, their value is likely to be a lot greater in terms of overcoming consumers' EV range anxiety. This is analogous to the positive externality known as 'network effects' in economics, whereby the value of a product or service increases according to the number of others using it.

This raises a number of interesting issues:

- Who should plan, and pay for, this public charging infrastructure?<sup>36</sup>
- How should users of such charging infrastructure be charged – noting that, while similar considerations apply with regards to incentivising users to avoid peak periods as apply to home charging, there are other factors to consider, including not driving additional forms of anxiety for EV drivers in terms of potentially having to pay penal prices to re-charge their vehicle while on the road.

It is beyond the scope of this report to address such issues. However, they are raised as an example of another issue that will likely require a coordinated approach – including between network companies, electricity-specific regulators, and transport agencies (including the Ministry of Transport, and the New Zealand Transport Agency).

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<sup>36</sup> In New Zealand, there may be a particular dimension in terms of thinking about possible disaster management in the immediate (and ongoing) aftermath of a major earthquake, and the need for people who wish to leave an area to be able to charge their vehicles.

## Appendix A. Projections of EV uptake

This Appendix presents modelling which estimates the potential nature and scale of EV uptake – with such projections forming the basis of the cost-benefit estimates of such uptake.

Three projections of EV uptake have been developed:

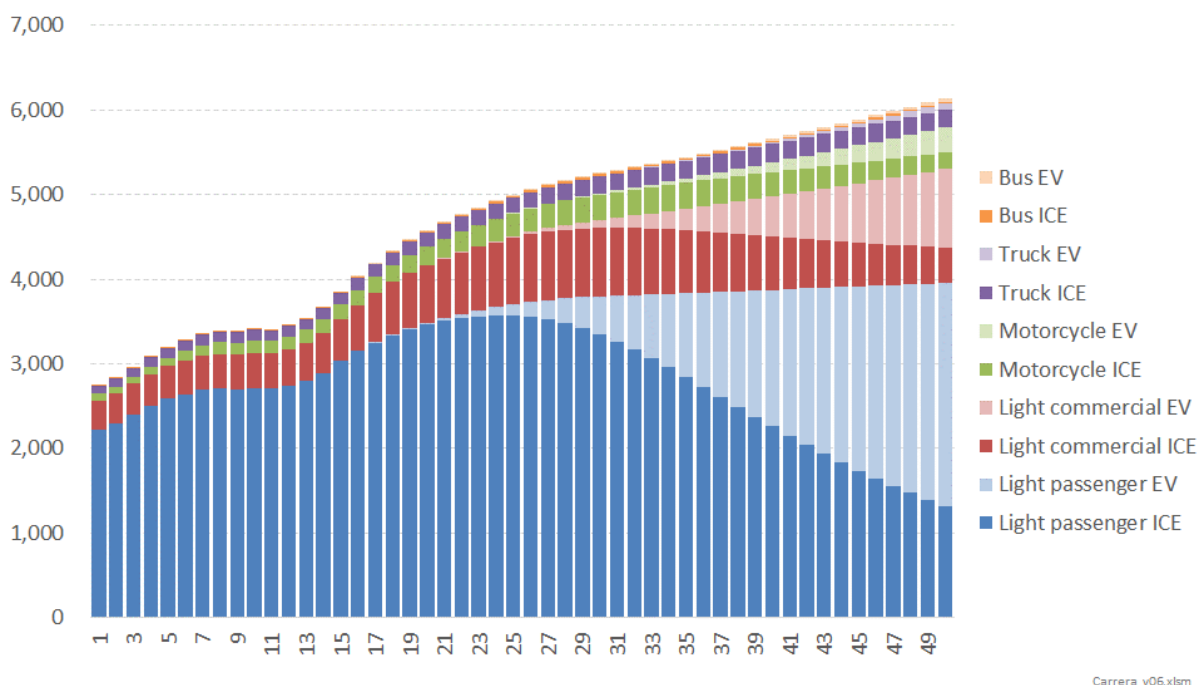
- Projections consistent with the central Ministry of Transport (MoT) projection in its recent report “New Zealand Transport Outlook: Future State”.
- Projections consistent with New Zealand seeking to achieve net-zero greenhouse gas emissions by 2050.
- A projection based on the second projection, but which simulates the effect of consumers continuing to face the current predominant, non-cost-reflective electricity pricing structure.

### *Projection consistent with base Ministry of Transport projection*

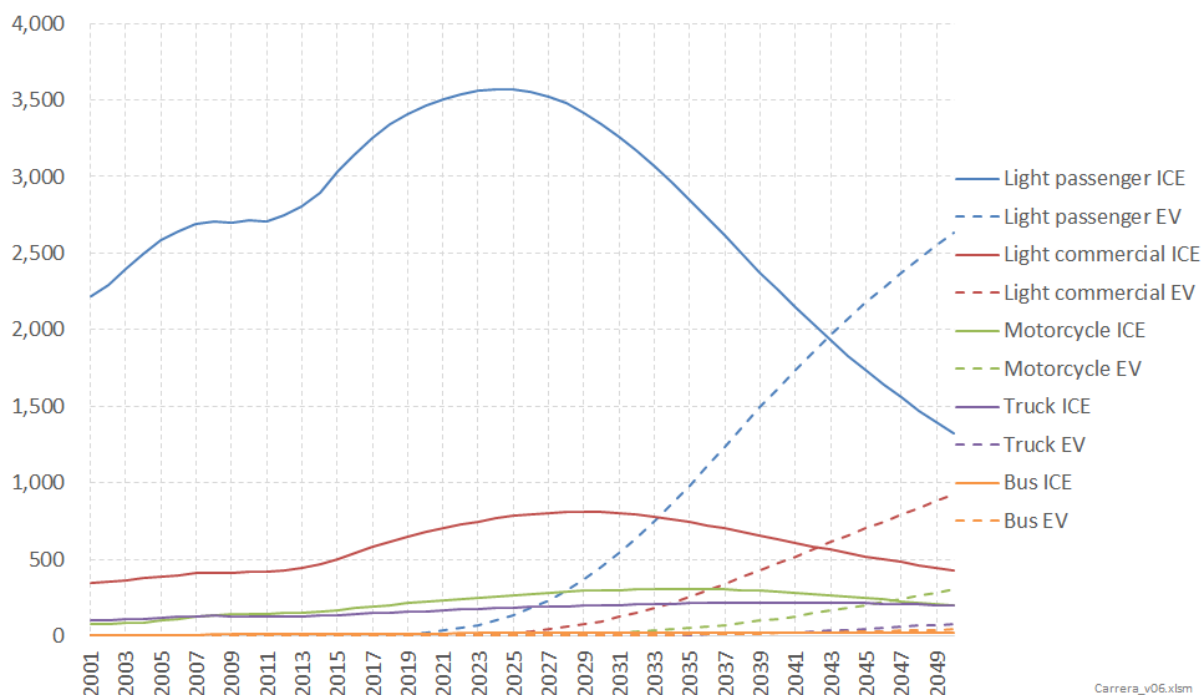
The projection developed by Concept for this scenario aims to achieve broadly the same level of uptake as projected by the Ministry of Transport in its recent report “*New Zealand Transport Outlook: Future State*”. It is understood that this MoT projection reflects current policy settings and expected levels of EV cost reduction that will anyway occur. i.e. the MoT projection recognises that EVs are likely to become increasingly cost-effective transport options for New Zealand, irrespective of specific climate-related policies.

Under this projection, which is illustrated in Figure 17 to Figure 20 below, the level of uptake is such that  $\approx 40\%$  of the overall vehicle fleet is electric by 2040 (with the proportion of the light fleet being much higher than for the heavy fleet). By 2040, almost all light vehicles entering New Zealand will be EVs.

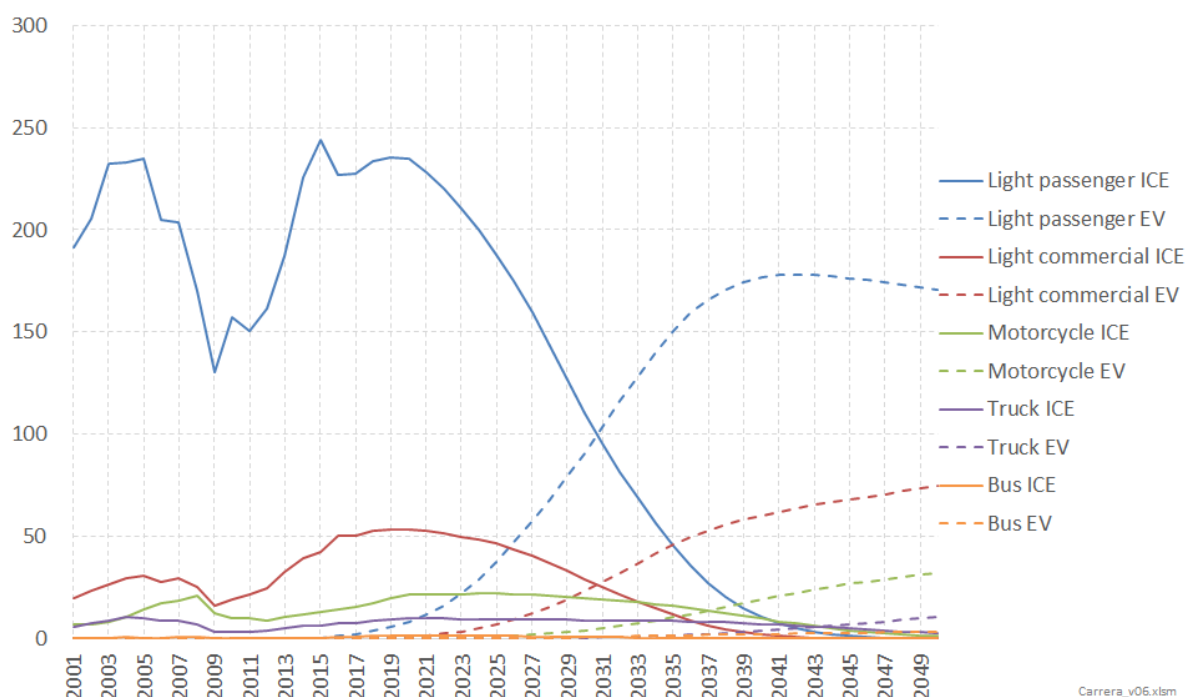
**Figure 17: Vehicle numbers by class and engine, based on base MoT projection – bar chart (,000)**



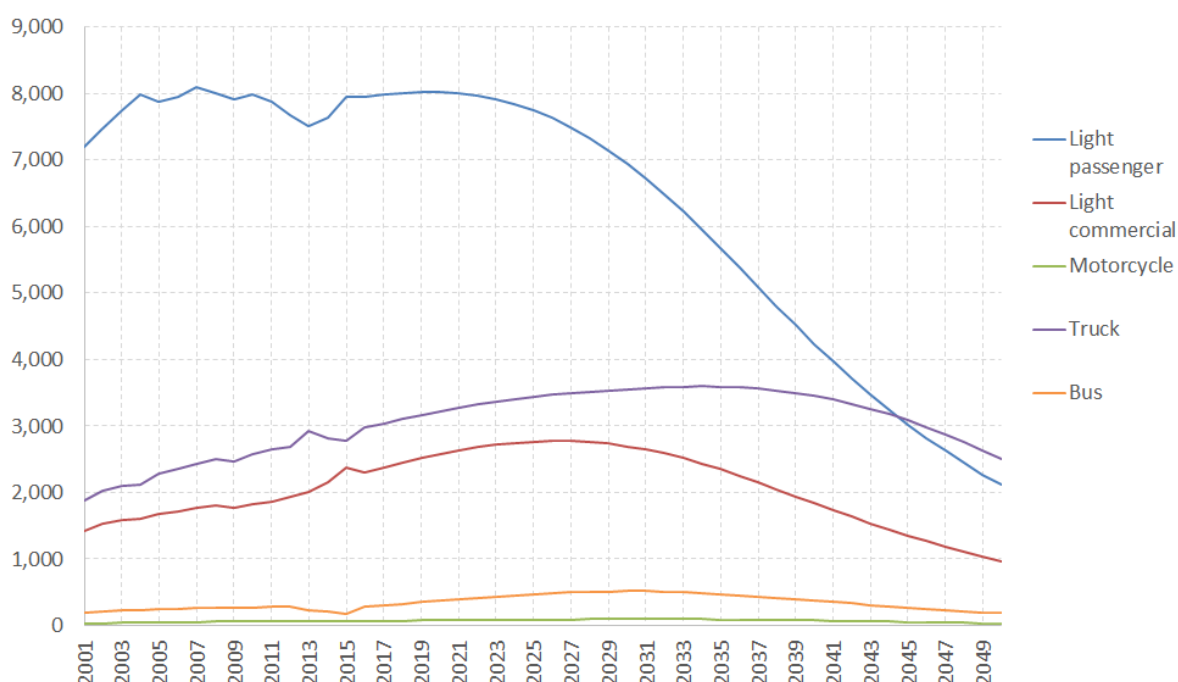
**Figure 18: Vehicle numbers by class and engine, based on base MoT projection – line chart (,000)**



**Figure 19: Vehicle entering NZ by class and engine, based on base MoT projection – (,000)**



**Figure 20: Projected CO<sub>2</sub> emissions by class, based on base MoT projection (ktCO<sub>2</sub>-e)**



**Projections consistent with seeking to achieve greenhouse emissions reduction targets**

The New Zealand government has recently re-confirmed its ambition of achieving net-zero<sup>37</sup> emissions by 2050.

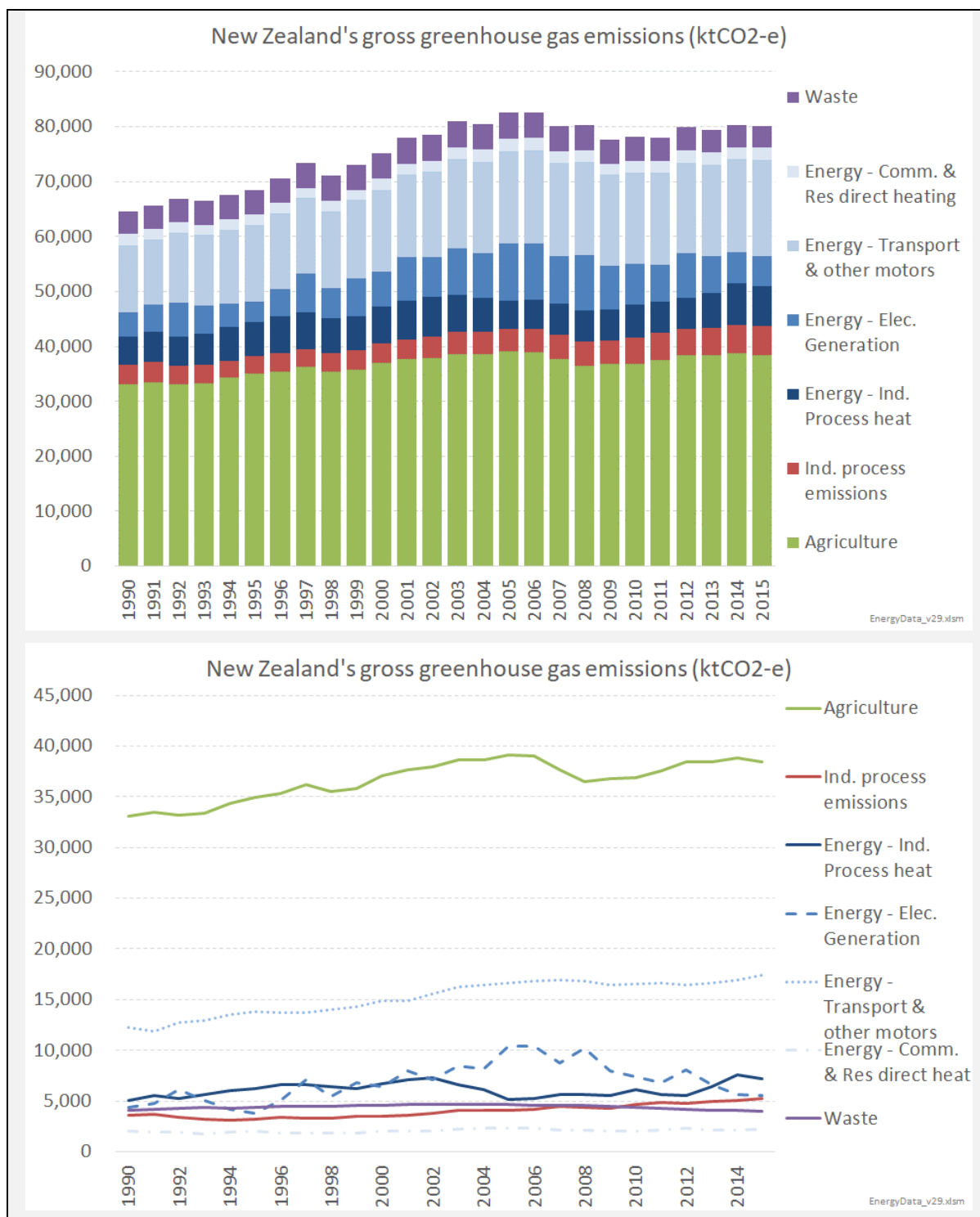
As charts in Box 1 indicate, the scale of current transport emissions are such that achieving this target is going to require a transformation of New Zealand's economy across many sectors. Given the inherent challenges of moving to low-emissions options for many sectors<sup>38</sup>, our New Zealand sectoral emissions models indicate that the transport sector is going to have to deliver some of the greatest reductions.

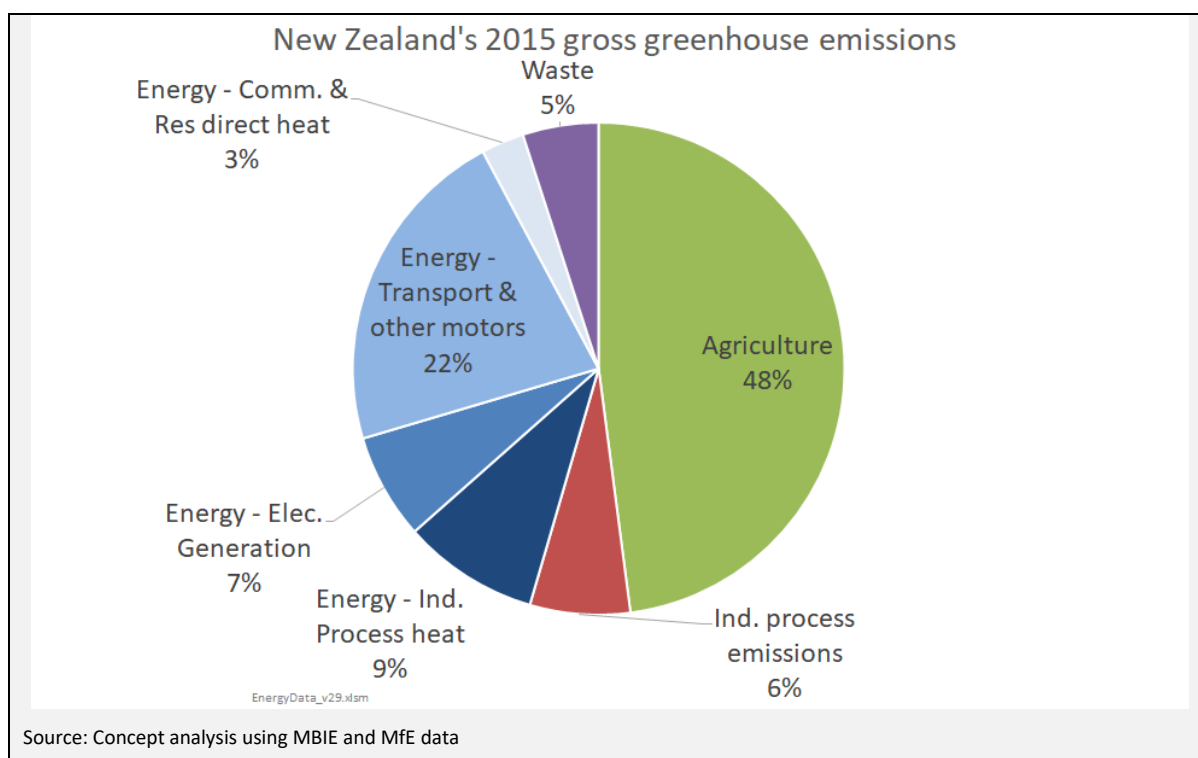
**Box 1: Historical transport emissions as a share of overall NZ GHG emissions**

As the following three charts illustrate, New Zealand's greenhouse emissions have been growing since 1990, with the transport sector being responsible for the majority of the increase in emissions between 2000 and 2015.

<sup>37</sup> 'Net' emissions are calculated as New Zealand's gross emissions, less any sequestration achieved through re-forestation.

<sup>38</sup> For example, there are likely to be inherent limits to the reduction in methane and nitrous oxide emissions from agriculture – other than a complete shift away from dairy and meat farming to horticulture and forestry. Likewise, many industrial process emissions are an inherent feature of the industrial process giving limited options for reduction – other than shutting down the industrial process (which itself will only reduce global emissions if the reduced NZ production is not offset by increased overseas production from a producer with a similar, or greater, emissions intensity).





We have used our models of the New Zealand transport sector, plus our models of whole-of-New Zealand greenhouse emissions, to estimate the level of EV uptake required to meet the target of net-zero greenhouse emissions by 2050.

Our main transport model:

- Projects demand for transport services (i.e. the movement of people or goods) based on:
  - observed historical relationships between underlying drivers (e.g. population growth and GDP) and transport outcomes (e.g. vehicle kilometres travelled ('vkt'))
  - future projections of these key drivers (e.g. population and GDP)
- Projects the costs of outcomes of meeting this demand for transport services from different options, including:
  - 'Mode-shifting' such as: from private vehicles to public transport, or walking & cycling, or car-sharing; heavy freight from road to rail
  - 'Fuel shifting' from internal combustion engine (ICE) vehicles fuelled by petrol & diesel, to alternative low-emissions vehicles such as electric vehicles (EVs).

Our central projections of what is required in the transport sector to meet the net-zero-by-2050 target assume a significant degree of mode-shifting. This is particularly for light passenger vehicles, with the share of trips by cars to meet the demand for passenger transport services dropping by 30% between 2015 and 2050. This will require reversing a significant trend to-date, whereby the proportion of passenger trips by cars has been steadily increasing.

Despite this significant degree of mode-shifting, the majority of transport sector emissions reductions will need to come from fuel shifting. For this projection we have assumed that the vast majority of this fuel shifting will come from EVs. (Plus, some continued improvement in the fuel efficiency of ICE vehicles that continue to be sold).

It is possible that alternative-fuelled technologies such as biofuels or hydrogen may emerge in the future as more cost-effective options for transport. However, our provisional modelling of the economics of these options suggest this is unlikely to be the case, except potentially for hydrogen for heavy-freight vehicles. Further, given that the purpose of this study is to understand the potential electricity sector implications from large-scale EV uptake, it was deemed more appropriate to examine outcomes where EVs are the principal fuel-shifting technology to meet the emissions-reduction targets.

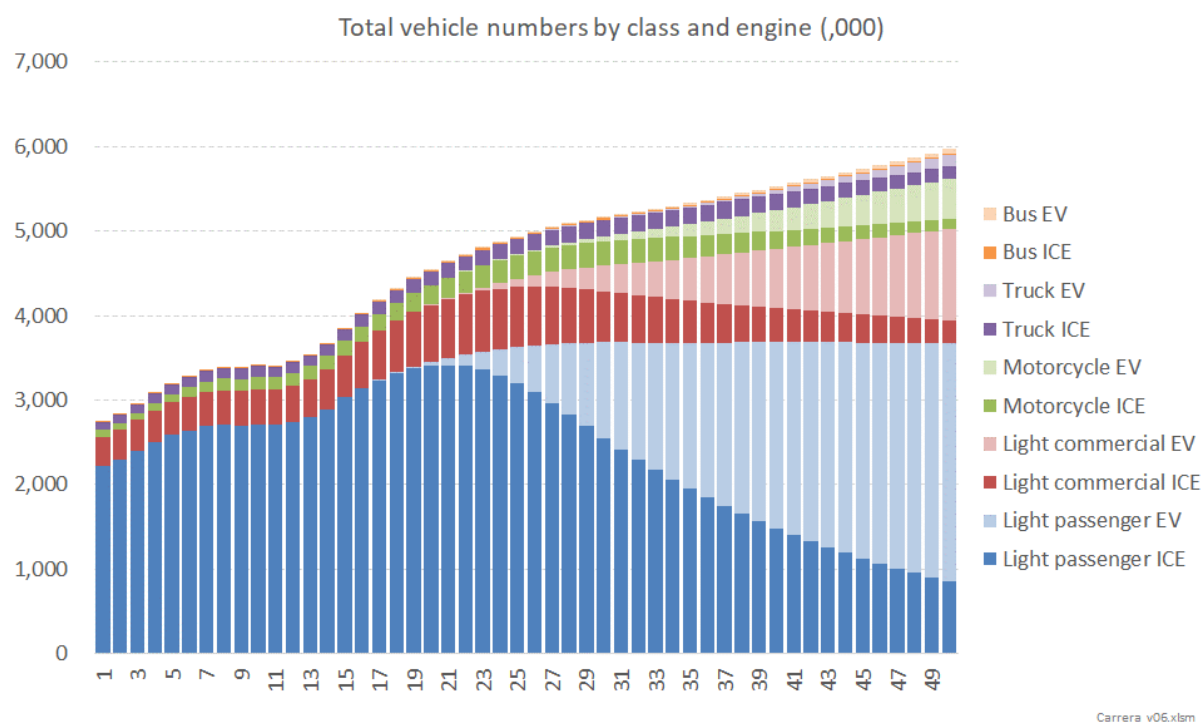
The following series of charts illustrate our central projections of what is likely to be required from the land transport sector to enable net-zero total-NZ emissions by 2050.

They illustrate how rapidly New Zealand needs to transition away from purchasing ICEs to EVs. Thus, in order to deliver the emissions savings required, Figure 23 shows that by 2030 almost all new light vehicles (private & commercial) entering New Zealand will need to be EVs.

The reason why there is a need for such a rapid transformation of vehicle purchasing patterns is because vehicles entering the NZ fleet remain in the fleet for many years: the average age of a vehicle scrapped in New Zealand is 20 years. Thus, an ICE vehicle purchased in 2030 could still be on the road in 2050.

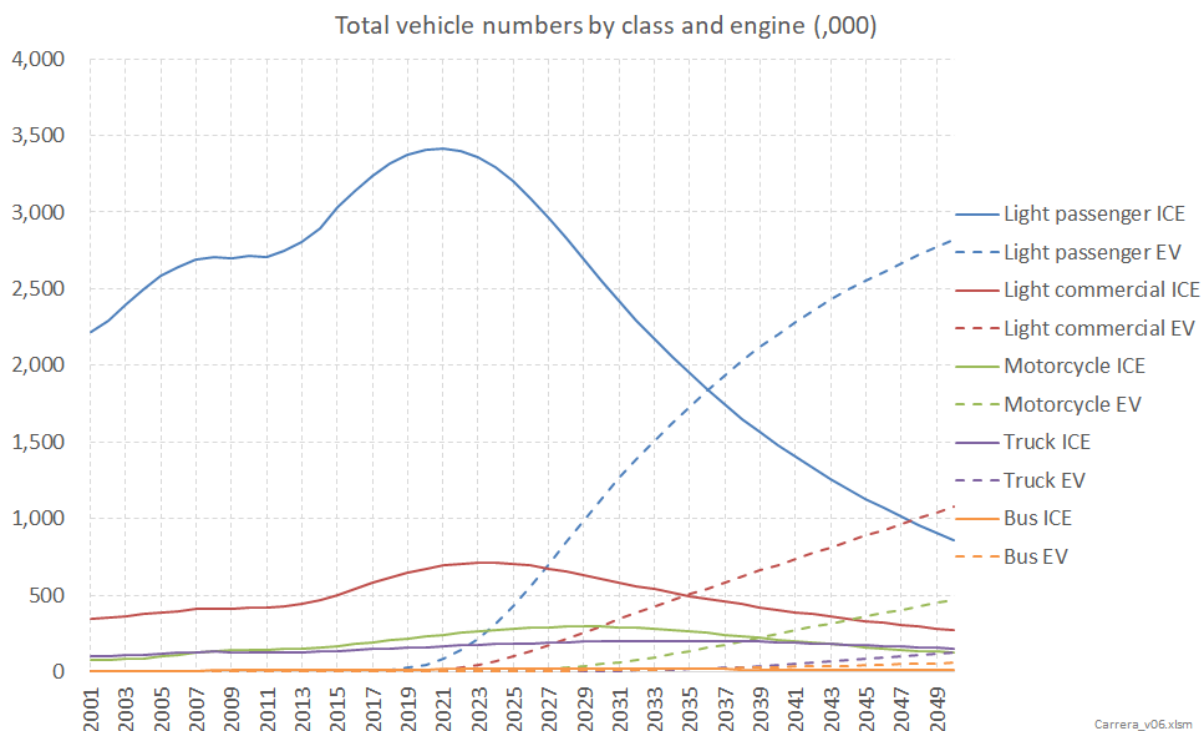
For reference, these projections are consistent with policies in a growing number of other countries, who are implementing policies which will effectively ban new ICE vehicles from around this time. For example: 2025 for Norway, 2030 for the Netherlands, 2032 for Scotland, and 2040 for France and the UK. Other major countries and economies such as China, India and California are also in the process of developing similar policies, with countries such as Austria, Denmark, Germany, Ireland, Japan, Portugal, Korea and Spain having set targets for EV sales.

**Figure 21: Vehicle numbers by class and engine for NZ-net-zero-by-2050 – bar chart (,000)**

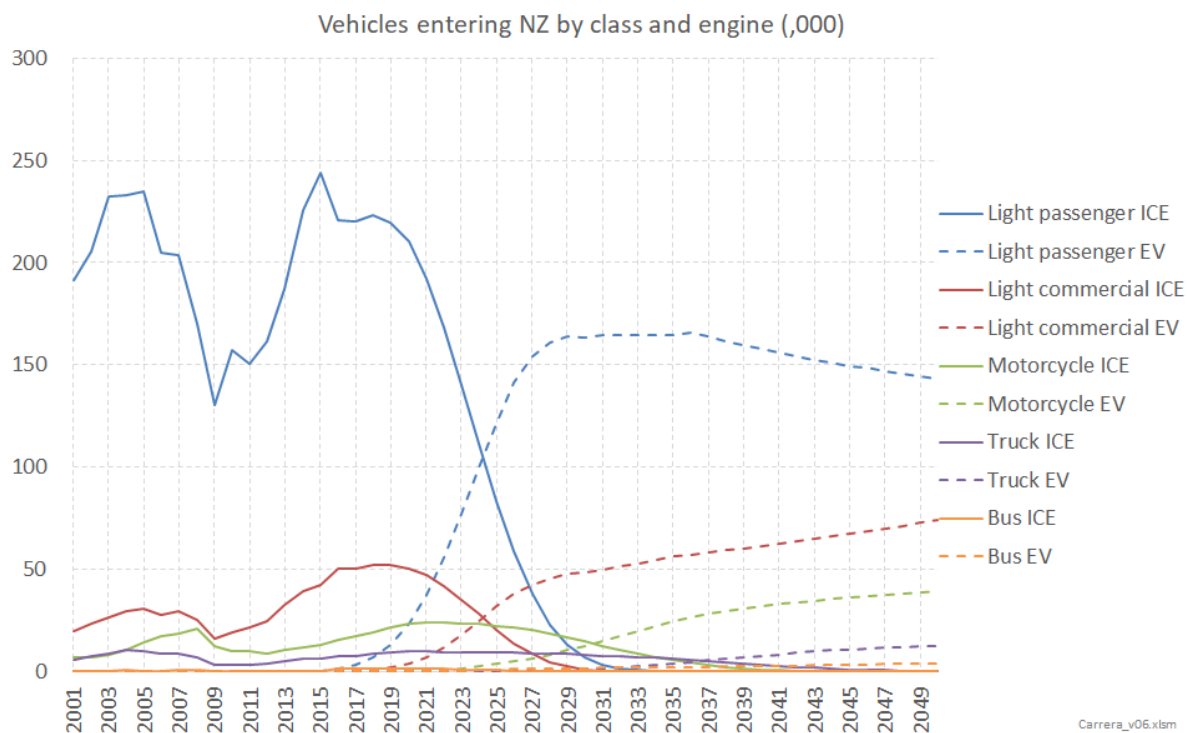




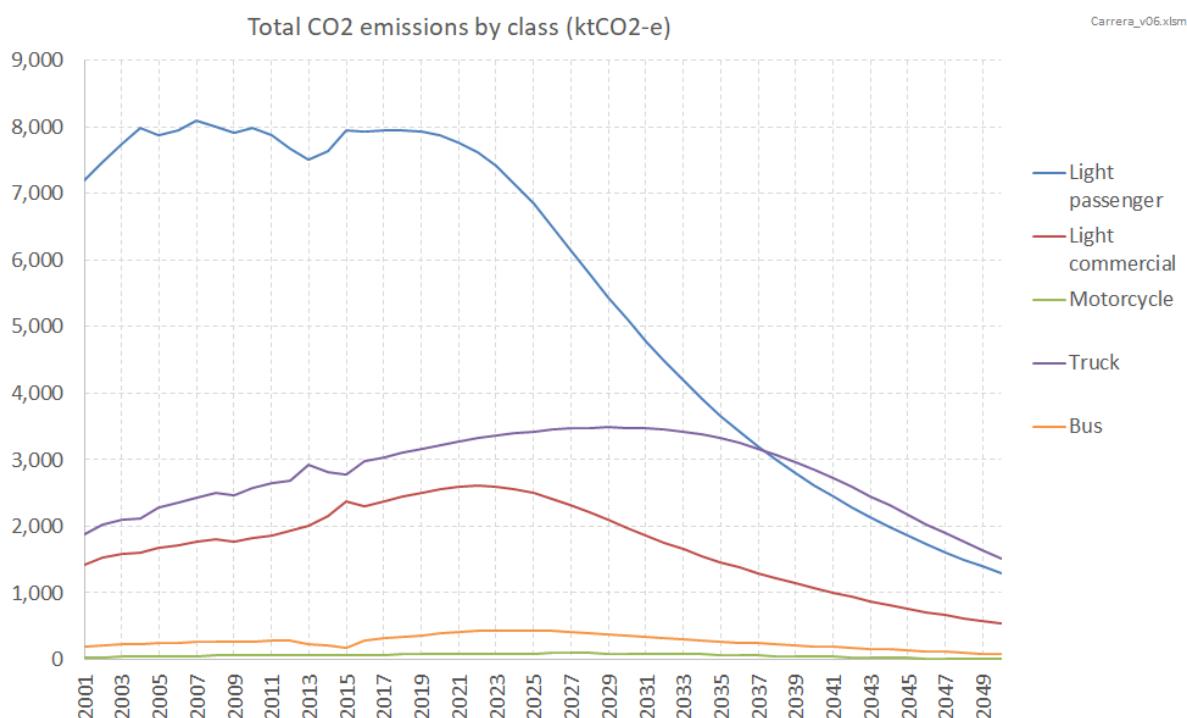
**Figure 22: Vehicle numbers by class and engine for NZ-net-zero-by-2050 – line chart (,000)**



**Figure 23: Vehicle entering NZ by class and engine for NZ-net-zero-by-2050 – (,000)**



**Figure 24: Projected CO2 emissions by class for NZ-net-zero-by-2050 (ktCO2-e)**



### **Projection considering the impact of electricity pricing on rates of EV uptake**

This third projection is based on the second, NZ-net-zero-by-2050, projection, but attempts to simulate the effect of EV-owners continuing to face the predominant current, non-cost-reflective electricity pricing structure. (Whereas the NZ-net-zero-by-2050, projection assumes that this pricing distortion is resolved in the next couple of years).

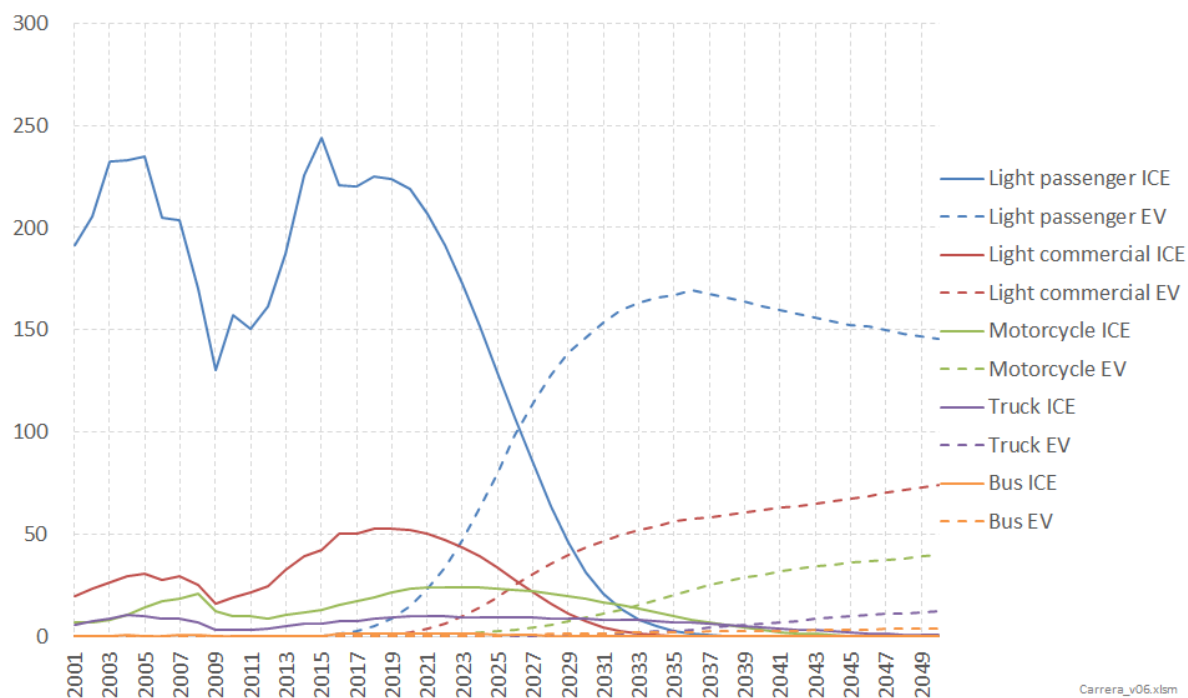
As illustrated in Figure 11 on page 22 of the main report, a continuation of non-cost-reflective electricity pricing structures for consumers will result in EV-owners paying significantly more for charging their EVs than would be the case if they charged their vehicles overnight and paid the 'true' economic cost of meeting such overnight demand.

The approach taken to estimating the impact of non-cost-reflective pricing on rates of EV uptake was as follows:

1. Estimating the scale of battery cost reduction and CO<sub>2</sub> price increase that would be consistent with moving EV uptake rates from the base MoT projection to the net-zero-by-2050 projection, and the consequent impacts on the relative total-cost-of-ownership of EV and ICE vehicles.
2. Calculating the impact of non-cost-reflective pricing on the total cost of ownership of an EV
3. Factoring the rates of EV uptake due to a continuation of non-cost-reflective pricing in proportion to the factors derived in step 1 in terms of reductions in the relative total cost of ownership of EV and ICE vehicles.

Thus, while there is inherently a significant degree of uncertainty over these figures, the estimates of the impact of non-cost-reflective pricing are considered broadly consistent with the underlying projections produced by MoT and the net-zero-by-50 scenario.

**Figure 25: Vehicle entering NZ by class and engine for scenario considering impact of non-cost-reflective electricity prices (,000)**

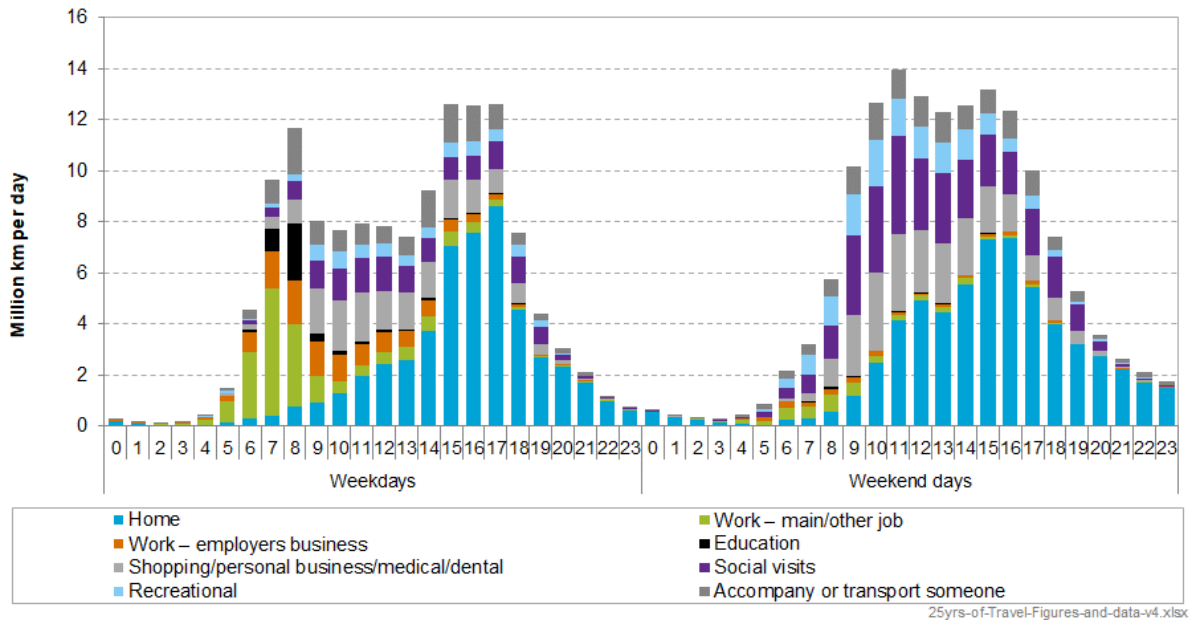


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## Appendix B. What pattern of ‘passive’ EV charging at residential properties is likely to emerge based on current electricity prices?

Figure 26 shows the pattern of travel for private cars in terms of time-of-day and destination. The blue-shaded bars show the travel where the destination is ‘Home’.

**Figure 26: Average distance per day by purpose and time of day (2010-2014)**



Source: Concept analysis based on MoT Household Travel Survey data

This graph shows a strong proportion of journeys with Home as the destination occur in the late afternoon / early evening – the time of existing electricity system peak demand.

If everyone plugs-in their vehicle as soon as they arrive home, there is the potential for a significant increase in demand at such times – particularly if people use dedicated chargers which draw a higher kW demand.

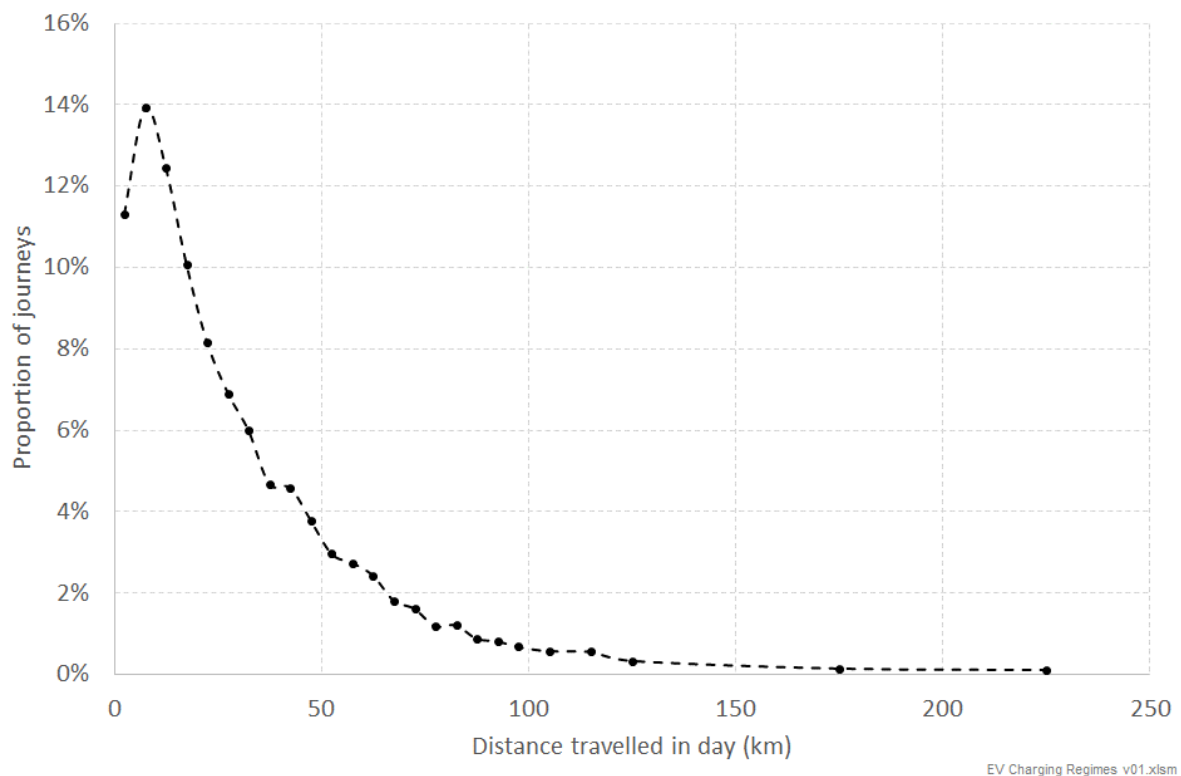
Such a plug-in-as-soon-as-you-get-home charging approach is likely in situations where consumers face no difference in electricity price at different times of day – and indeed this charging pattern has been observed overseas and in New Zealand.

To establish the likely extent of peak demand increase from a plug-in-as-soon-as-you-get-home charging approach, Concept has developed a model which takes data from a number of different sources.

The first source was the Household Travel Survey (HTS) data represented in Figure 26. From this, Concept developed a simple model which made the time at which people started charging their vehicles proportional to the number of people travelling ‘Home’ in the previous hour.

The next step was to estimate how empty EV batteries will be when vehicles arrive home, and thus how much charging will be required. For this, Concept sourced more detailed HTS from MoT officials, with the key data represented in Figure 27

**Figure 27: Distribution of light private vehicle distances travelled in a day**



Source: Concept analysis based on MoT data

This graph indicates that most private vehicles travel less than 50 km during a day. Indeed, Table 4 below indicates that the median distance travelled is approximately 23.5 km.

**Table 4: Daily distances travelled by light private vehicles (km)**

	mean	median	p75	p90	p95
All NZ	39.6	23.3	47.2	84.1	127.1
Akl	35.3	23.4	43.4	68.9	95.1
Chch	31.7	21.0	36.3	60.3	83.0

EV Charging Regimes v01.xlsm

Source: MoT based on household travel survey data

We undertook some modelling which estimate that approximately 75% of the energy for all these journeys can be satisfied by charging at home.<sup>39</sup> This gives a mean 'home-charged' distance of 30 km. (Lower than the 39.6km mean of all distances).

The average fuel efficiency of an EV is estimated to be approximately 0.2 kWh/km. This means that a vehicle which travels 30 km will consume  $30 * 0.2 = 6$  kWh.

<sup>39</sup> This assumed that all daily trips of 80km would be satisfied by home charging. Although most current EVs have ranges of at least 120 km on a full charge, with future EVs projected to have higher ranges, we believe that many people will chose to 'top-up' their vehicles during the day for many longer journeys, even if they should have sufficient charge to last the day.

The duration taken to re-charge this 6 kWh will be a function of the capacity of the charger. Four main types of charger are emerging as being used to re-charge EVs at home. These are illustrated in Table 5.

**Table 5: Typical types of residential EV charger<sup>40</sup>**



	Standard 8a	16a 'Blue Commando'	Dedicated AC Slow	Rapid AC
Installed Cost	~\$	~\$200	\$1000	+\$2500
Capacity	2.3kW	3.9kW	7.9kW	22kW
Equivalent	Small Hot Water	Large Hot Water	2 Clothes Dryers	10 Heat Pumps

Source: Powerco

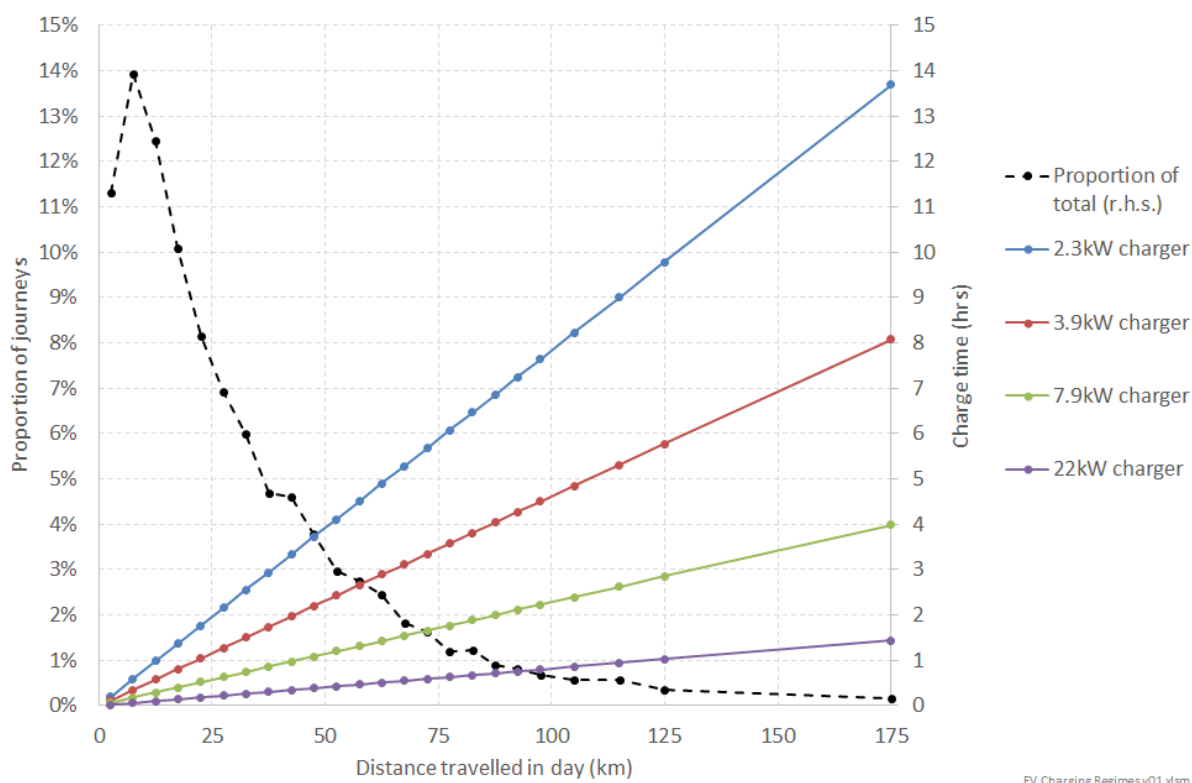
Figure 28 develops Figure 26 by adding lines which show how long to re-charge a battery for an EV that has travelled a certain distance using different chargers.<sup>41</sup>

<sup>40</sup> It should be noted that although the dedicated and rapid chargers have greater kW capacities, the per EV kW capacity will be limited by the maximum power a vehicle can draw. For example, the Nissan Leaf can only draw up to 6.6 kW. Thus, these higher kW rated chargers are only likely to be needed by households who wish to charge multiple vehicles at the same time, or who purchase high performance EVs (e.g. the high spec. Tesla) which have much larger battery and charging capacities. Upgrade to the houses wiring may also be needed with these chargers.

<sup>41</sup> In reality, the charge times are not as straightforward as indicated here due to the fact that the charging rate for most EV batteries significantly drops off once they get above 80%. In some cases, it can take almost as long to get from 80% to 100%, as it takes to get from 0% to 80%! However, we have not modelled this particular effect because it is second-order in nature for this analysis.

Further, a very large number of vehicle owners set their cars to default to only charge up to 80% - given that charging above 80% can, over time, reduce the useful life of the battery. This behaviour will mean that the effect is not apparent for the majority of vehicle charging situations.

**Figure 28: Distribution of vehicle distances travelled in a day and associated EV re-charge times using different chargers**



As can be seen, it would take 2 hr 36 mins to re-charge an EV that had travelled 30 km using a standard 2.3 kW charger, whereas it would only take 13.75 minutes using a 22 kW charger.

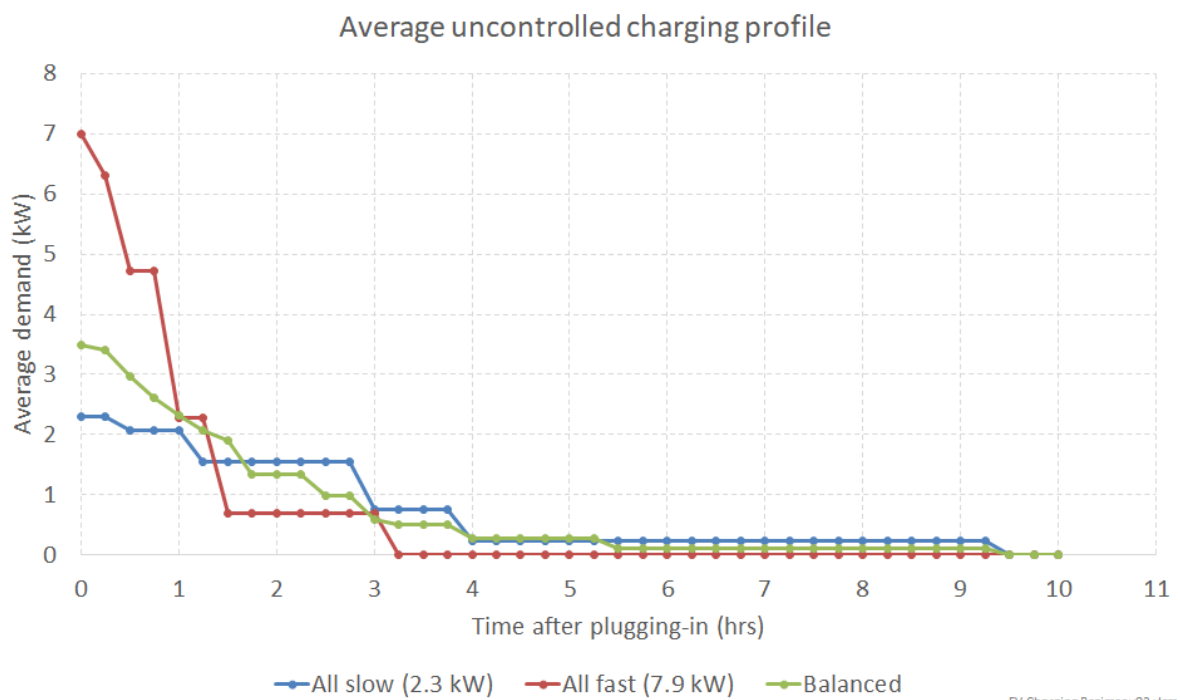
The next dimension to this analysis was simulating outcomes from vehicles being charged with different chargers:

- A scenario where all vehicles were charged with the standard 2.3 kW charger (“All Slow”)
- A scenario where all vehicles were charged with a 7.9 kW charger (“All Fast”)<sup>42</sup>
- A “balanced” scenario which has a mix of 2.3, 3.9 and 7.9 kWh chargers

The variation in the level and duration of charging for different distances travelled for these different charger types is shown by Figure 29 below.

<sup>42</sup> The actual rate of charging was limited to 7 kW, given the issues identified above about the ability of EVs to actually draw high levels of power.

**Figure 29: Average charge profile for a population of EVs having travelled a typical range of distances during the day, but all starting charging at the same time<sup>43</sup>**



In simple terms, if all vehicles charge with a 7.9 kW charger, the initial demand will be very high. However, this will very quickly start to drop off as those vehicles who only travelled during a short distance during the day reach full charge. Only the very few vehicles who travelled 120 km during the day (the maximum distance in this sampling approach) will continue charging for several hours – finishing just after 2 hrs 45 min).

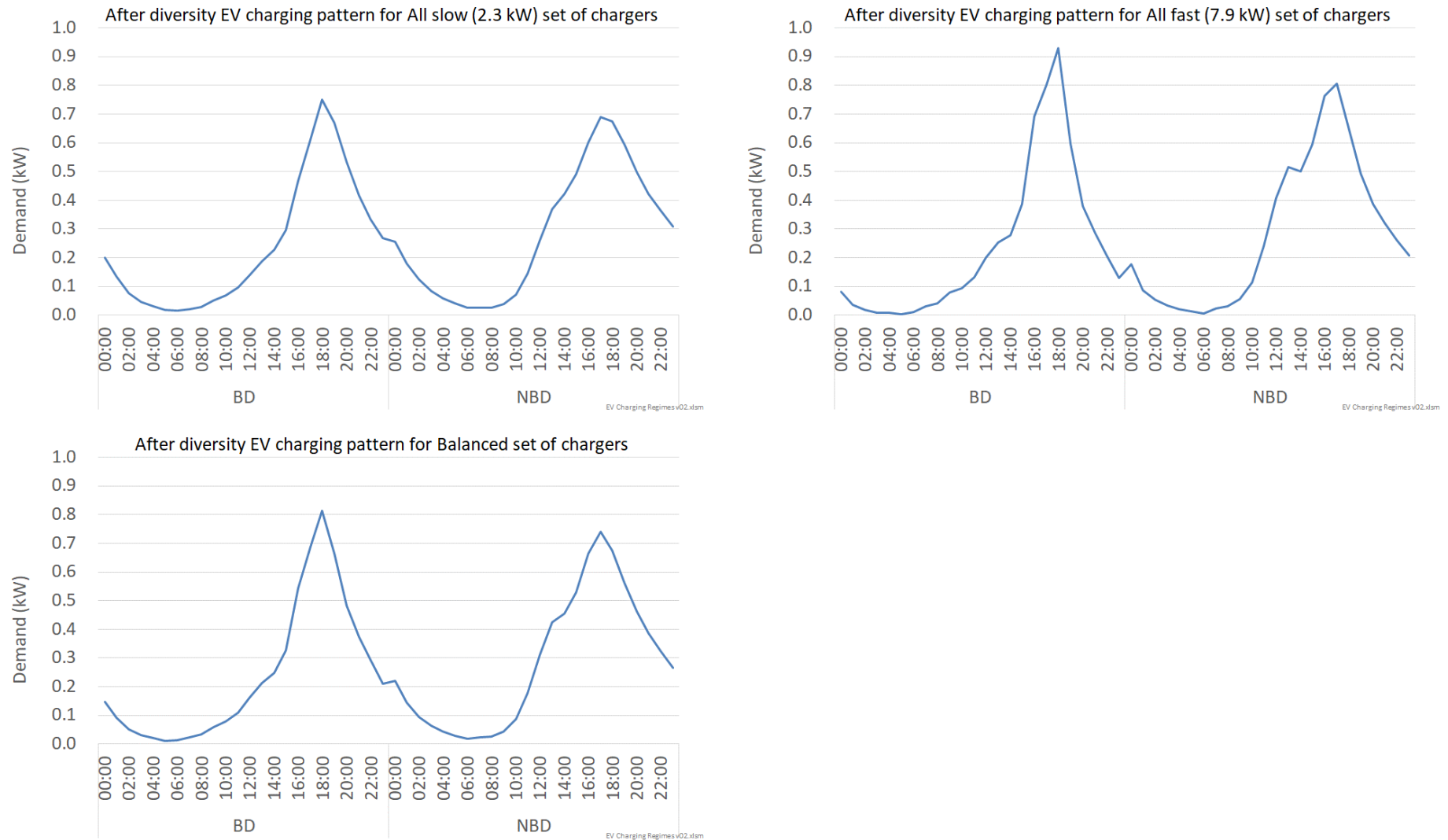
Conversely, if all vehicles charge with a 2.3 kW charger, the initial demand will be a lot lower, but will continue for a lot longer – finishing in 9.5 hrs for those vehicles who travelled 120 km.

The final piece of the modelling involved combining all these different representations to estimate the likely after-diversity charging profile for EVs which are plugged-in as soon as they arrive home. This is shown in Figure 30 below.

<sup>43</sup> The 'lumpy' step-change nature of this graph is because a very simplified probability distribution of distances travelled was used, corresponding to 5<sup>th</sup>, 25<sup>th</sup>, 50<sup>th</sup>, 75<sup>th</sup>, and 95<sup>th</sup> percentiles along the distribution represented in Figure 26.



**Figure 30: After-diversity EV demand impact per EV for a ‘passive’ (i.e. plug-in-when-get-home) charging pattern, for different types of EV charger**



The pattern of demand shown in is the after-diversity average per EV.

The overall scale of impact on a network will be driven by how many residential consumers have an EV.

If only 50% of residential consumers in a network have an EV then the average impact on after-diversity peak residential demand will be half of that shown in the above graphs – i.e. approximately 0.4 kW per household in a network area, assuming a balanced mix of charger capacities.

However, if every household in a network had an average of 1.75 EVs (being the national average number of vehicles per household), the kW impact per household on peak residential demand would be 1.75 times that shown in the graph – i.e. approximately 1.4 kW per household.

This compares with current after-diversity peak residential demand of approximately 2.25 kW per household<sup>44</sup>. Converting the fleet ‘overnight’, and with consumers charging when they get home, would therefore likely increase residential peak demand by approximately 62%. Section 2.3 addresses the likely cost implications of this pattern of charging.

### Can networks rely on diversity?

The key potential concern with EVs is the very high kW demands an individual EV may place on the network (a 7.9 kW fast-charger is a very large load to add to a residential house), and the fact that people may all start charging at roughly the same time (i.e. early evening when they get home from work) or at the start of a low rate TOU period.

However, the above analysis indicates that there are significant diversity benefits associated with charging EVs:

- Diversity of when people arrive home. Figure 26 indicates that, although most people arrive home between 4.30 and 7.30 pm on weekdays, this is actually quite a long period of time when combined with the second diversity factor:
- Diversity of travel distances (and hence battery charging requirements).

This combination gives rise to the effect shown in Figure 30, whereby the after-diversity peak demand if all EVs were charged with a 7.9 kW charger is only 25% greater than if all EVs were charged with a 2.3 kW charger. Thus, with dedicated chargers, many EVs will have finished charging before new EVs are plugged-in.

While this may be true for large numbers of EVs, it is important to consider whether this holds for the number of ICPs on an LV network – typically of the order of 50 ICPs.

Analysis on current (non-EV) residential diversity effects suggests that this is likely to be the case.

For example, Box 2 below shows an extract from Orion’s design standard for the capacity required for building new LV networks. This indicates the diversity effects are significant, even for relatively small numbers of consumers.

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<sup>44</sup> This is a high-level national estimate. There is material variation between networks due to factors such as climate, and the proportion of heating undertaken by electricity versus gas or wood-fuels.

## Box 2: Orion design standards for LV networks with small numbers of houses<sup>45</sup>

### 6.4 DIVERSITY FACTOR

Where less than 30 residential consumers are connected to a substation or feeder, the ADMD must be increased by a diversity factor shown in the following table:

Table 6-1: Diversity Factors

No of Houses	Diversity Factor	No of Houses	Diversity Factor
1	4.00	16	1.19
2	2.50	17	1.18
3	2.00	18	1.17
4	1.75	19	1.16
5	1.60	20	1.15
6	1.50	21	1.14
7	1.43	22	1.14
8	1.38	23	1.13
9	1.33	24	1.13
10	1.30	25	1.12
11	1.27	26	1.12
12	1.25	27	1.11
13	1.23	28	1.11
14	1.21	29	1.10
15	1.20	30	1.00

Given that the same patterns of human behaviour drive the pattern of non-EV residential demand, including the drivers of peak demand (i.e. getting home from work at roughly the same time, turning on the lights, cooking, heating etc.), it seems likely that the diversity effects observed for residential non-EV demand are likely to also hold for residential EV demand.

That said, there are potentially special situations where peak residential EV demand for certain locations may be significantly greater than the above analysis suggests:

- Firstly, it is potentially the case that the average distance driven by people living in the outer-suburbs of cities may be materially greater than the average distance for other groups of people. It is not known whether this is the case (given that the data shown in Figure 27 also includes those people living in rural locations who may drive longer distances on average), and/or whether there is greater diversity in return times which might partially offset such increased charging requirements.

However, to the extent that there are clusters of houses with high distance daily travel, this would tend to put greater peak demand pressure on their local networks, than the averages estimated above.

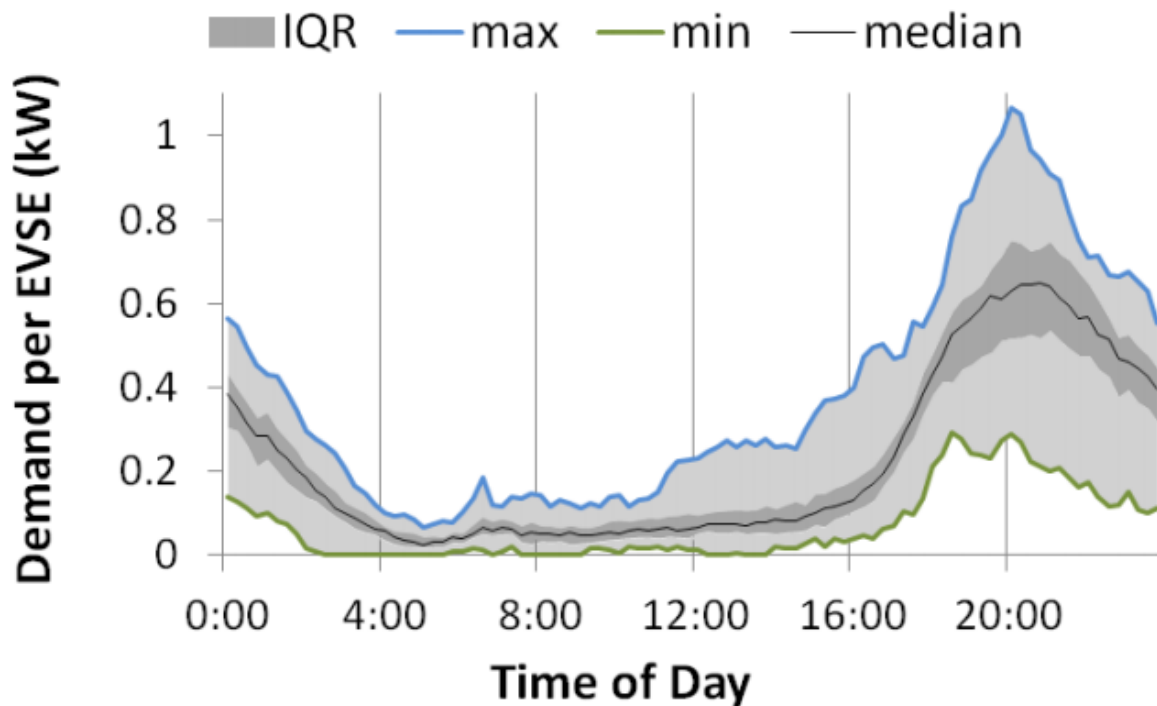
- Secondly, some holiday locations may have extreme peaks in demand coinciding with the start of public holidays. For example, places like Whangamata in the Coromandel, or Ohakune in the Central North Island, may have sudden influxes of EVs arriving at the start of a public holiday, and all having relatively empty batteries. This could give rise to peak demand requirements many times above the 'normal' levels seen on other days.

<sup>45</sup> ADMD = "After-diversity maximum demand"

## Comparison with overseas

A US study “A First Look at the Impact of Electric Vehicle Charging on the Electric Grid in The EV Project”<sup>46</sup>, looked at EV charging in the United States to understand the likely pattern of charging that would emerge. Figure 31 below (Figure 21 in the report) shows the observed after-diversity average per-EV charging profile. The following text is taken from their study, explaining the implications from the results:

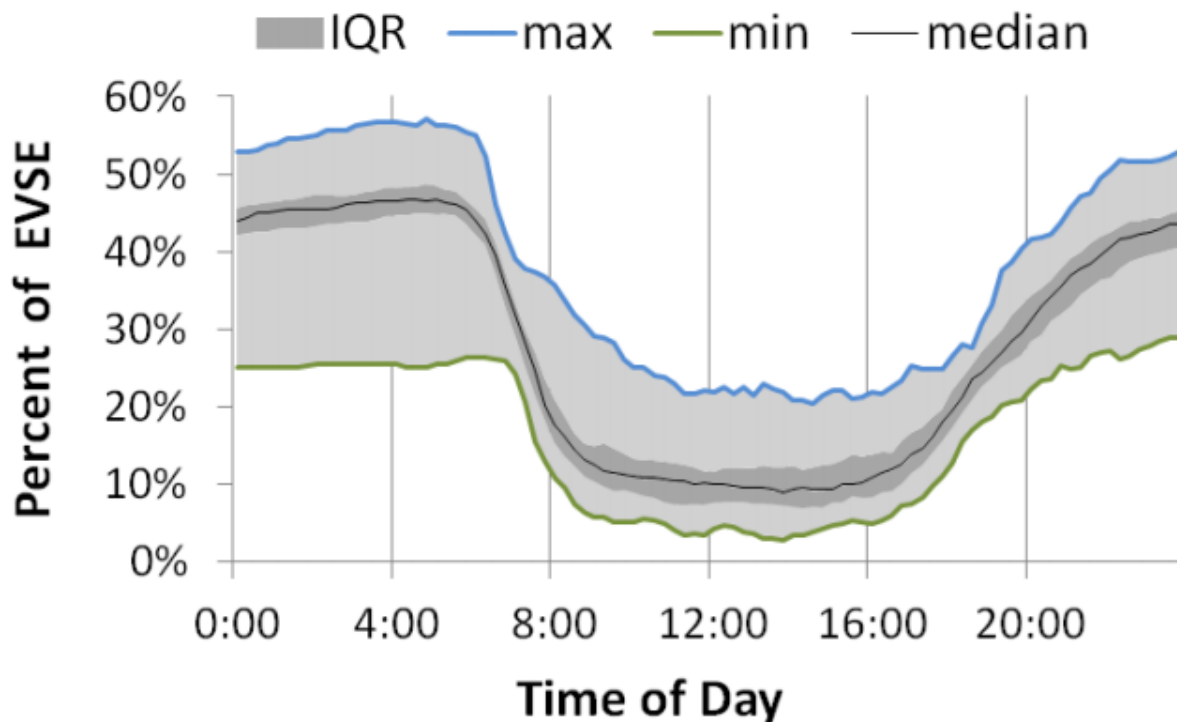
**Figure 31: REPORT FIGURE 21: Weekday time-of-day charging demand for Nashville**



On first glance, it may appear that the charging demand magnitude in these figures is too low. After all, a single Nissan LEAF draws about 3.3 kW during steady-state charging, yet the charging demand time-of-day plot never exceeds 1 kW. Note, however, that the percent of EVSE connected to a vehicle never exceeds 60%, as shown in [REPORT] Figure 14 [below].

<sup>46</sup> [https://energy.gov/sites/prod/files/2014/02/f8/evs26\\_charging\\_demand\\_manuscript.pdf](https://energy.gov/sites/prod/files/2014/02/f8/evs26_charging_demand_manuscript.pdf)

Figure 32: REPORT FIGURE 14: Weekday time-of-day charging availability for Nashville<sup>47</sup>



Thus, the normalized charging demand per EVSE will never exceed 60% of the maximum possible demand for one vehicle. Furthermore, not all vehicles that are connected to EVSE are drawing power. At any given time, a fraction of the vehicles connected have full battery packs and have ceased drawing power from the EVSE. The charging demand plots show the resulting demand of EVSE with vehicles connected and drawing power, normalized with respect to all EVSE in the data set.

Thus, in Nashville, [REPORT] Figure 21 [above] shows an increase in the weekday demand curve from 16:00 to 20:00 corresponds to the increase in the charging availability curve over the same time period shown in [REPORT] Figure 14. In this region, most users do not program their vehicles or EVSE to begin charging at a scheduled time. Instead, the vehicles begin to draw power from the EVSE immediately after they are plugged in. Because people arrive home or otherwise choose to plug in their vehicles at home at different times throughout the evening, charging demand increases gradually. This charging diversity leads to relatively low peak demand and smooth changes in demand.

#### Summary

In summary, we have calculated that flat rate pricing will on average lead to an after diversity peak load contribution per EV on the road of approximately 0.8kW.

<sup>47</sup> [This graph shows how many vehicles are physically plugged-in to their home chargers at any moment in time – irrespective of whether they are drawing power or not.]

## Appendix C. Electricity system costs of meeting EV-driven demand growth

### Network cost impacts

A significant proportion of network costs are driven by electricity consumption by consumers.<sup>48</sup>

However, such costs are not driven by the *volume* of kWh that are transported across the network. i.e. there are no material network operational costs driven by the volume of kWh flowing across a network at any moment in time.

Instead, those network costs which are driven by demand are driven by the *peak kW* demand on the network:

- Each network has a level of peak capacity it can supply.
- If peak demand on a network steadily increases, at some point that capacity limit will be breached.
- Network companies seek to prevent capacity limits from being breached by investing in additional capacity ahead of time.

Thus, over time, as peak demand increases, network companies will need to make capital investments to increase the capacity of their networks.

Figure 5 previously indicates that if EV users adopt a ‘passive’ charging approach, EV charging will be heavily weighted towards periods of peak demand – and thus drive an increased need to make capacity investments.

The costs of meeting an increase in peak demand will vary significantly according to where such increases occur. In particular:

- Whether the increase in peak demand is in a part of a network with
  - relatively little spare capacity (in which case investment in new capacity could be required almost immediately); or
  - lots of spare capacity (in which case no investment requirement may result – even over a period of decades)
- What is the voltage level of the network the investment is required in. i.e. the low-voltage (LV) network, 11 kV high voltage (HV) network, sub-transmission (sub-trans) network, or at the transmission network level.<sup>49</sup>

<sup>48</sup> Orion estimate that, in the long-term, 50% of its costs are driven by growth in electricity consumption.

<sup>49</sup> The transmission network is owned and operated by Transpower, and comprises the very high voltage wires (110 kV and above) which transport electricity across the country from the main power stations, to the various regions of the country.

Distribution companies (e.g. Vector in Auckland, Orion in Christchurch, etc.) distribute this power to end consumers within their region. They will take power from the transmission network (at so-called grid exit points, GXPs) and distribute it at progressively lower voltages throughout their region, with transformers stepping the voltage down at each transition point. Their sub-transmission networks (typically operating at 33 kV) will take the power directly from the transmission network and distribute it over longer-distances to various main locations within their networks. Their 11 kV network will then distribute it within these main locations to groups of customers, who are then served by low-voltage networks operating at 400 V. Typically, 50-100 customers will be connected to an individual LV network.

- Whether the network is in an urban or rural environment, and whether there are particular factors in each area which could materially increase the cost (e.g. remote and challenging terrain for rural environments, or the need to underground the network in an urban environment.).

Despite these significant variations in the costs of meeting peak demand growth for specific situations, on average over the whole of New Zealand and over time, it estimated that the cost of peak network demand growth is comprised as follows:

- Distribution = \$100-150/kW/yr
- Transmission = \$60-70/kW/yr

The distribution cost is based on information published by Orion in its pricing methodology on the peak-demand driven costs its network (which it estimates to be \$105/kW/yr), plus published numbers from Australian networks as to their costs of meeting peak demand (ranging from NZ\$90 to NZ\$185/kW/yr).

The transmission cost is a very simple estimate based on average Transpower interconnection prices over the past ten years (which are approximately \$100/kW/yr, adjusted for inflation) and applying a simple factor that assumes that in the long-run 65% of transmission costs are due to peak demand growth – compared with the 50% factor estimated by Orion for distribution costs.

It should be noted that the Orion number relates principally to the costs of peak demand growth causing capacity upgrades on its high-voltage (HV) networks. i.e. the large substations and cables which distribute the power at high voltage (11kV or above) around the network region.

Orion's peak-demand-driven LRMC calculation assumes there is no need to retrospectively increase capacity on its low voltage (LV) networks. i.e. the small local substations and 240-volt lines which take the power to individual customers. Each line (or 'network') typically serving 50-100 customers.

This assumption in Orion's pricing methodology is because generally, LV networks have been built with significant surplus capacity based on historical levels of peak demand per ICP. This 'building-with-surplus' approach is due to the economies of scale associated with network investment, and the fact that retrospectively increasing capacity on an LV network is generally much more expensive than building a network with room to grow.

It is potentially the case that significant EV uptake could cause capacity to be exceeded on these LV networks. In particular, voltage issues could emerge from individual large loads (such as an EV being fast-charged) at the end of lines. Such effects may reduce the benefits of diversity.

It is beyond the scope of this report to analyse whether such LV capacity exceedance outcomes are likely to emerge. However, there does appear to be a risk of such outcomes occurring. In this it should be appreciated that some LV networks have much less 'spare' network capacity than others. Further, it is likely that uptake of EVs will not be evenly spread, with clusters of EVs emerging in particular locations. As such, to the extent that issues start to emerge on LV networks, there is a high likelihood that the effects will be varied with some networks experiencing problems much sooner than others.

Orion have provided an estimate of what it would cost should they need to increase capacity on their LV networks. This estimate is that such capacity upgrades would cost approximately \$40/kW/yr. However, it is understood that some other networks (particularly Wellington and Dunedin) may face higher costs because voltage correction measures available to some networks may not be available in these areas because of the signal frequency at which their hot-water ripple signalling systems work.

Given all the above, there is a reasonable degree of uncertainty as to the level of network costs that would arise from increases in residential peak demand.

## Generation cost impacts

Whereas the demand-driven component of network costs are almost entirely driven by peak kW demand, generation costs are strongly driven by kWh demand. i.e. each extra kWh of demand requires an extra kWh of generation to supply it.

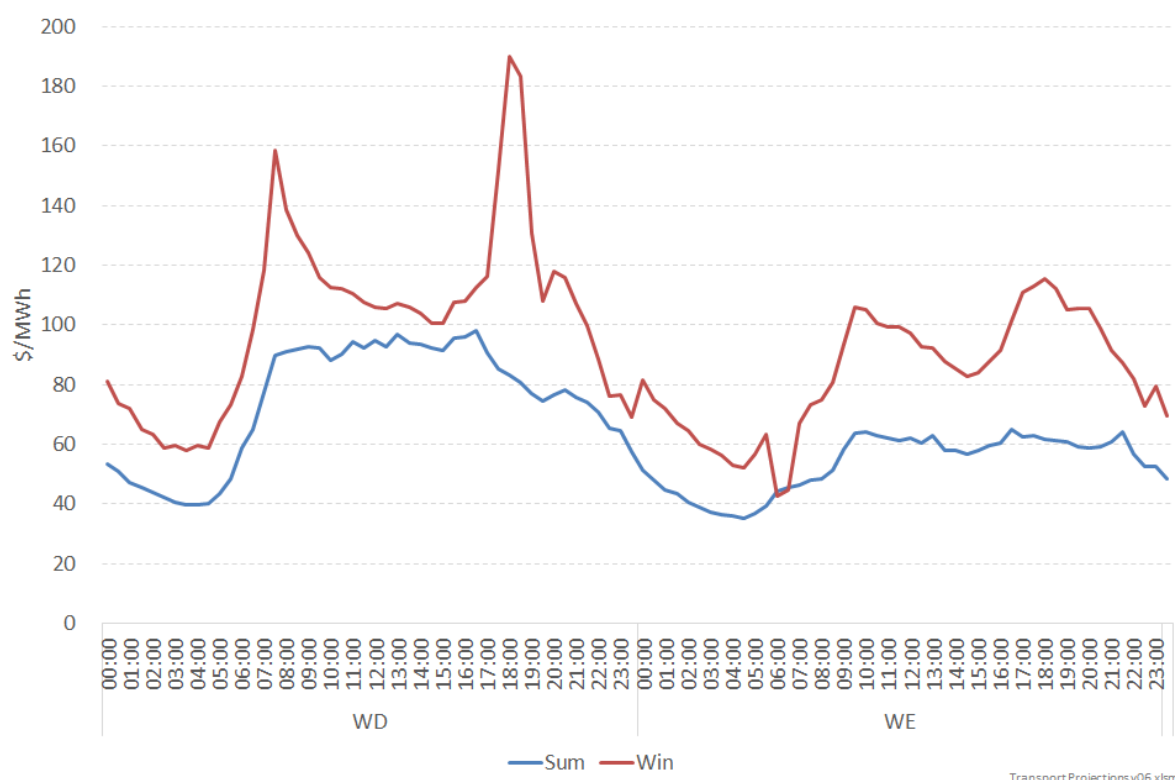
However, the cost of generation to meet demand varies significantly according to the time of year and day such demand occurs.

Put simply, at times of high demand (e.g. winter versus summer, or morning / evening peaks versus overnight) prices are much higher as there is a need to call upon infrequently-used generators that are not used at other times. Prices at these times are higher to reflect the fixed and capital costs of such infrequently-used generators being recovered over a relatively small amount of generation.

In other words, generation costs have both an energy and capacity element within them.

For the purposes of estimating the generation costs of EV charging, the following wholesale price shape was used. This was based on historical observed price shapes, normalised to give a time-weighted average price of \$80/MWh.

**Figure 33: Assumed shape of wholesale prices**



As can be seen, a demand profile which is heavily focussed towards the peak periods (as is the case for the evening-focussed 'passive' EV charging profile) will give rise to substantially greater generation costs than a 'smart' EV charging profile which is predominantly overnight. Using the price shape shown in Figure 33, the average generation cost of meeting

- A 'passive' EV-charging profile would be approximately \$90/MWh
- A 'smart' EV-charging profile would be approximately \$70/MWh



## Appendix D. Commercial and Heavy freight EV impacts, and public charging

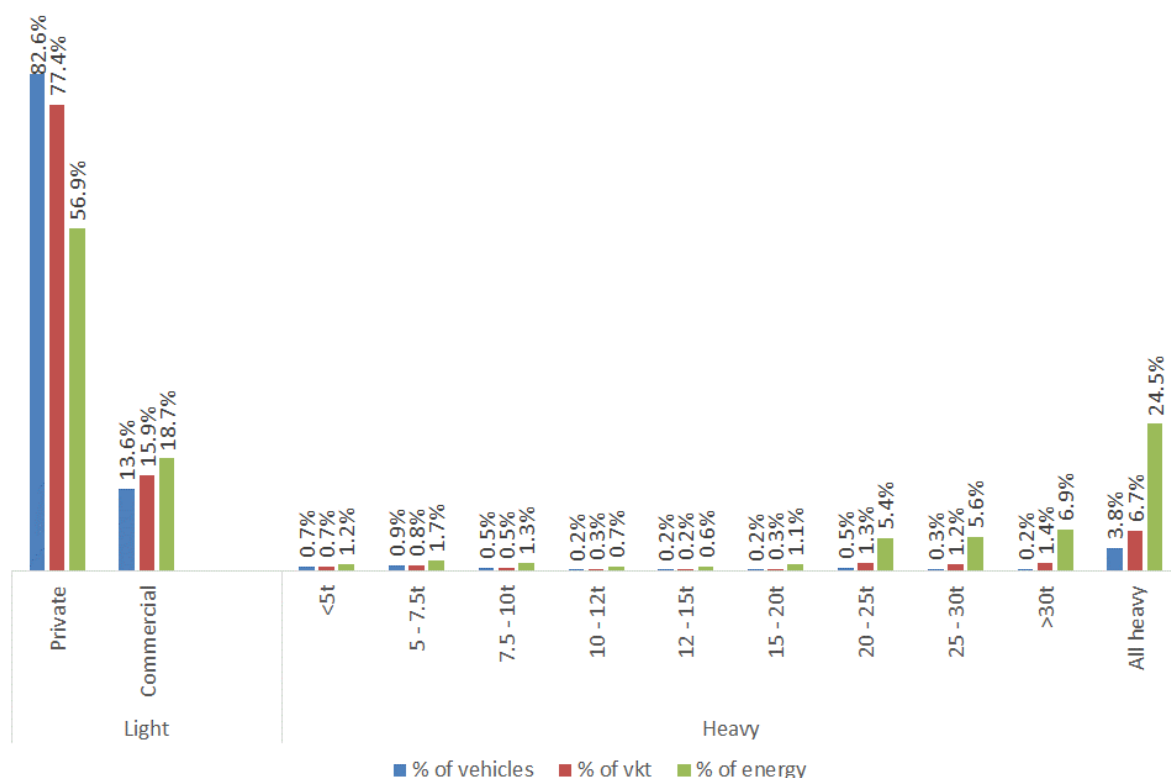
In the course of undertaking this study, Concept also sourced data on New Zealand's commercial and heavy freight transport fleet.<sup>50</sup> This was used to help get a feel for the extent to which electrification of this section of New Zealand's transport fleet may cause material electricity supply cost impacts.

Figure 34 shows a proportional breakdown of New Zealand's land transport fleet by three key metrics:

- Number of vehicles
- Distance travelled (vkt<sup>51</sup>)
- Energy consumed

This split is between light private vehicles, light commercial vehicles, and heavy goods vehicles. This latter category is split between the different heavy goods weight classes.

**Figure 34: Breakdown of New Zealand's land transport fleet**



Simple heavy and commercial fleet analysis\_v04.xlsm

The key take-away from Figure 34 is that heavy freight vehicles – particularly the heaviest vehicles – tend to be driven a lot further per vehicle than light vehicles, and consume significantly more energy per km than light vehicles.

<sup>50</sup> This data was from a mix of different sources, of varying degrees of quality. This has required estimation to 'fill in the gaps' in a number of cases. Where we have done this we have tried to sanity-check through comparison with a variety of other data points to ensure the estimations are reasonable. As such, despite the data gaps, we believe the analysis provides reasonable first order approximations of the nature and scale of commercial and heavy fleet energy requirements.

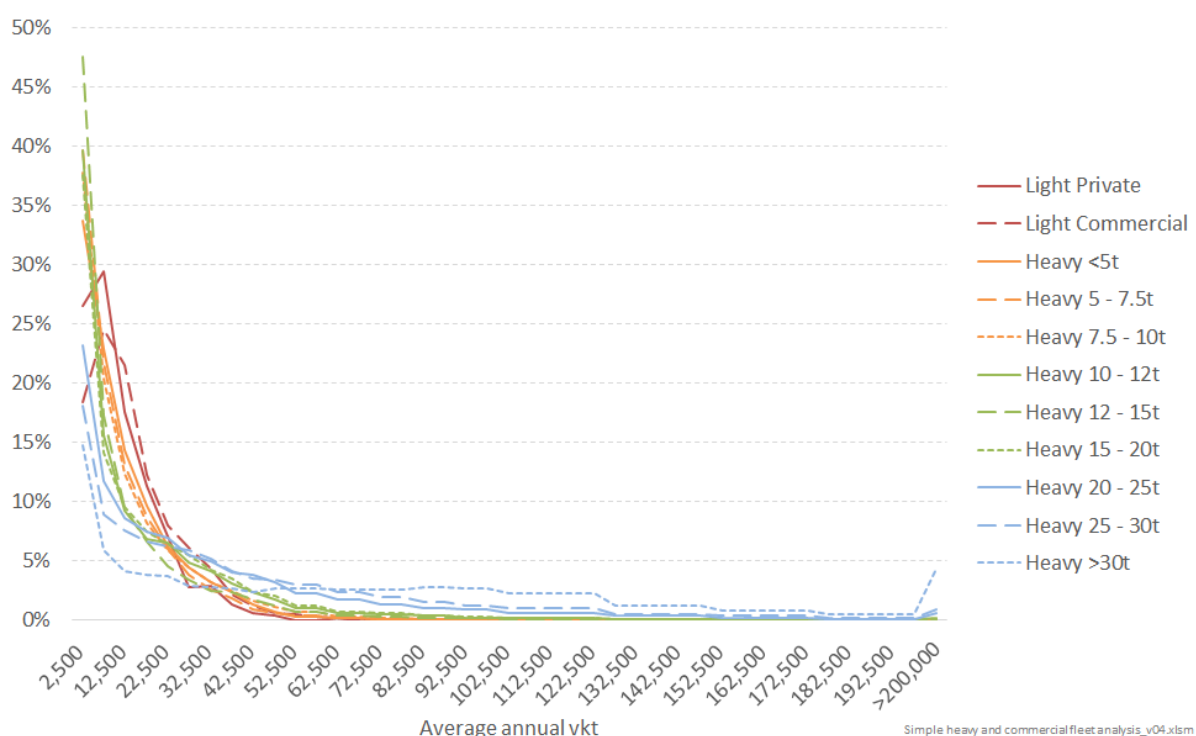
<sup>51</sup> vkt stands for 'vehicle kilometres travelled'

This means that the electrification of light commercial and heavy goods vehicles will have almost as much of an electricity system impact as the electrification of light passenger vehicles.

Figure 35 shows the distribution of travel by the different vehicle classes. Understanding such travel patterns is important as it will give insights as to

- the proportion of energy which can be supplied to vehicles by charging overnight at their 'base' (people's homes for light private vehicles; office buildings, depots, factories and the like for commercial and heavy vehicles), and
- the proportion which will need to be supplied during the day, including from away-from-base charging facilities.

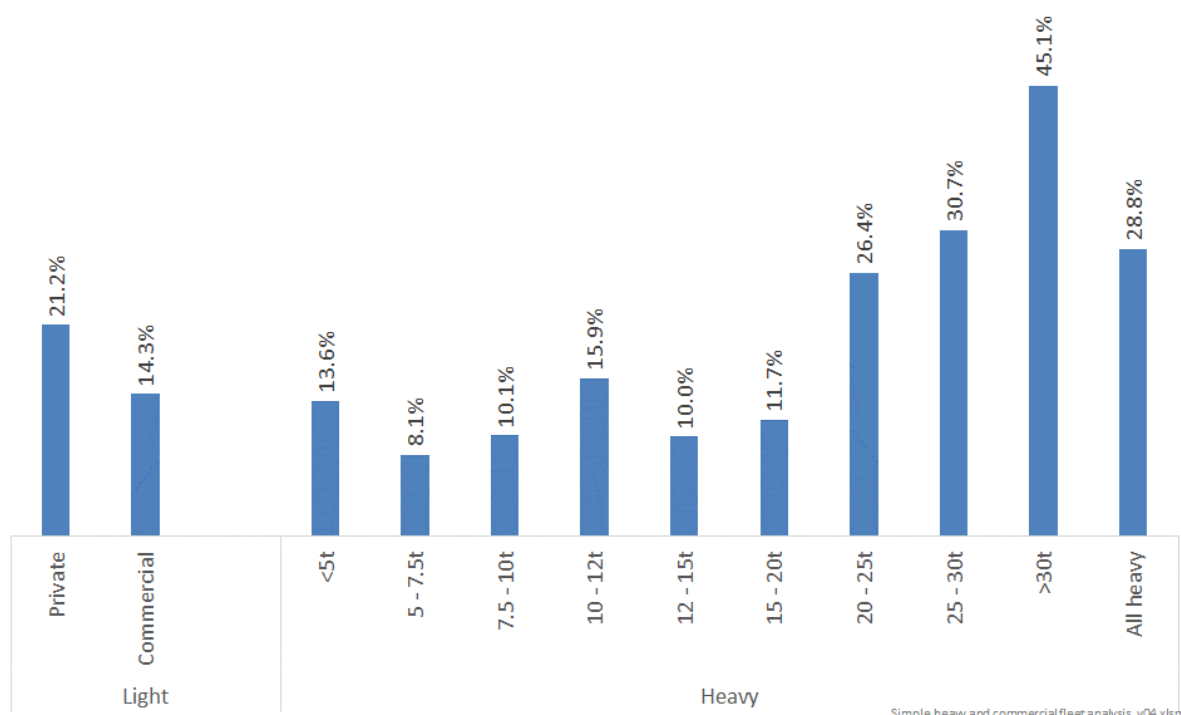
**Figure 35: Distribution of annual distance travelled by vehicle class**



The key take-away from Figure 35 is that the heaviest vehicles tend to travel the longest distances, with some of the very heaviest vehicles travelling extremely long distances each year.

The data in Figure 34 and Figure 35 was combined in a simple model to provide a first-order approximation of what proportion of energy could be supplied overnight for each class of vehicle, and what proportion would need to be supplied during the day. The results are shown in Figure 36 below.

**Figure 36: Estimated proportion of energy required from day-time charging**



Due to data limitations this analysis is necessarily high-level, and thus subject to some margin of error.

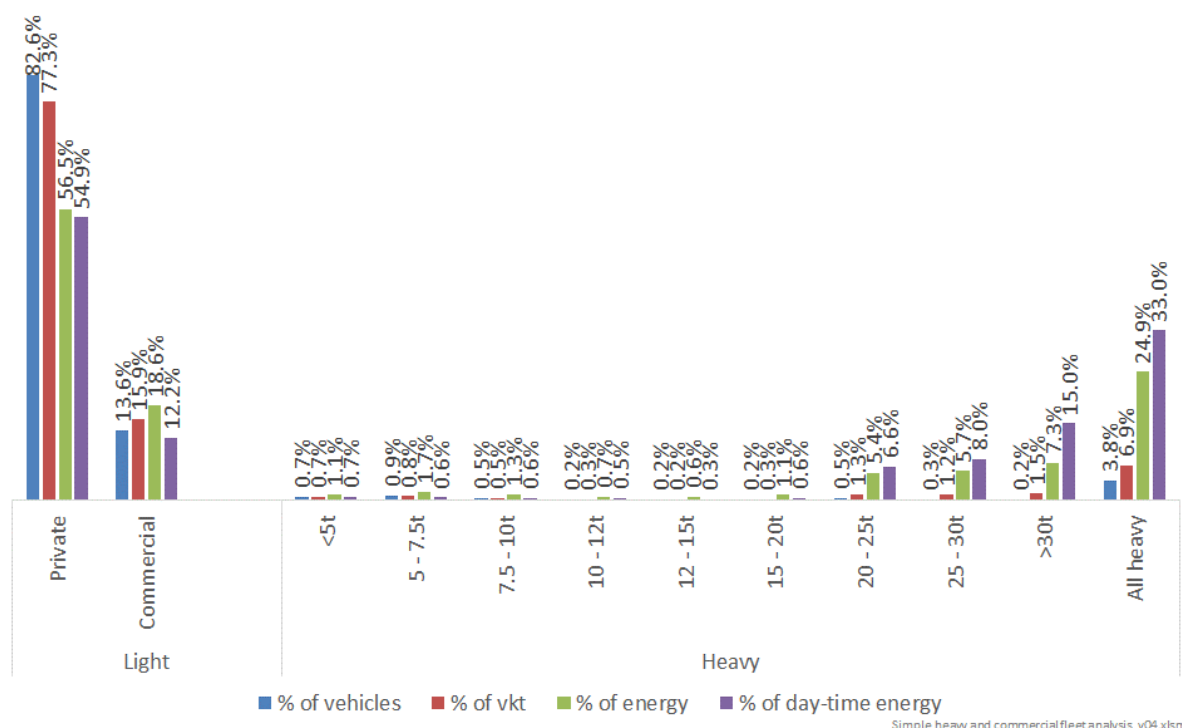
Further, it is an estimation of what is likely to be technically feasible in terms of overnight base charging – and thus what daytime charging will probably be required. It is possible that some drivers may choose to ‘top-up’ their vehicles during the day for convenience (e.g. if a public car-park building or office car-park building comes with a charging port) and/or to address range-anxiety issues. As such, it is potentially the case that this may be an underestimate for some classes – particularly private vehicles.

However, directionally it is considered that the key take-away from this analysis is sound: namely that heavy vehicles are likely to require a significant proportion of their energy from charging during the day.

Further, a relatively greater proportion of commercial and heavy goods charging will likely be on weekdays rather than weekends.

Overall, this analysis indicates that if all of New Zealand’s transport fleet were electrified, approximately 20% of the energy required to charge these vehicles would need to be from daytime charging, with such daytime charging being dominated by heavy vehicles. This is illustrated in Figure 37 below which develops Figure 34 previously, through the inclusion of an estimate of day-time energy required by each class of vehicle.

**Figure 37: Breakdown of New Zealand's land transport fleet – including day-time charging requirements**



This will have some electricity system cost implications, particularly if a significant proportion of this 'day-time' charging were to occur during peak system demand periods (i.e. early evenings on cold winter's weekdays).

No analysis has been done on the extent to which this is likely to be the case, and there are different factors which could drive outcomes:

- On the one hand, vehicles are likely to have emptier batteries towards the end, rather than the beginning of the day.
- On the other hand, re-charging of vehicles is likely to be strongly affected by the timing of when vehicles will anyway be stationary. Thus, heavy goods vehicles may choose to top-up several times during the day while they are picking-up or delivering goods – particularly vehicles with return-to-base modes of operation. Likewise, private vehicles spend the majority of their time away from home stationary in car parks. This stationary time gives ample opportunity for a significant proportion of this within-day charging to be done away from early evening periods – and spread-out.

This last point indicates that patterns of within-day charging have the potential to be smart from an electricity system perspective – i.e. avoiding peak periods, and spread-out during the day. However, the extent to which such outcomes occur will be driven by the incentives on parties to charge this way – i.e. on what basis will they be charged for electricity.

No analysis has been done on this, but it is likely that many of the same considerations as were discussed in section 3 for incentivising smart home-charging behaviour would also apply to incentivising smart away-from-base charging.

That said, it is likely that there will be less opportunities to smooth-out much of this within-day charging, compared with the ability to spread home-charging over an eight hour night-time period. For example, a truck that is only stopping for 20 minutes will not want to be delayed further through needing to charge its battery. Likewise, many commercial and private vehicles on long journeys may

not want to stop for longer than five minutes to re-charge their vehicle. This has implications for the capacity of charger required – particularly those for large heavy goods vehicles.

There are already over sixty 50 kW chargers installed in New Zealand and three 120 kW charges, and it is likely that even larger chargers are going to be developed in the near future. For example, a 350 kW charger has been developed and is being trialled in California.

For comparison, the energy delivery capacity of a petrol pump for light vehicles is estimated to be approximately 15 MW, and a diesel pump for trucks (which deliver the fuel about 4 times as fast) approximately 60 MW.

Given that electric motors are approximately 3.5 more energy efficient than combustion engines, an EV charger equivalent capacity to deliver the required energy at the same rate as petrol / diesel pumps would need to be approximately 4.25 and 17 MW, respectively.

These would be very significant loads to place on networks. For comparison, 450 kW is equivalent to the demand of Dunedin airport.

While at a transmission grid level there would likely still be a lot of diversity from such chargers, at an HV level (such chargers would not be suitable for LV networks) these could cause significant issues.