Transform modelling inputs

Contents

Purpose

Results of the Transform modelling process will include options on how to deal with the effect on the planning and operation of the NZ electricity network. Inputs into the modelling process include three trajectories/scenarios with data on: electric vehicles, solar, heat pump uptake and distributed wind.

Electric vehicles, and associated battery technology, have been focused on as the major source of change to the power system.

Scenario Descriptions

Two scenarios, a central and high uptake scenario have been defined by the Ministry of Business, Innovation and Employment (MBIE) for use in the Electricity Demand Generation Scenarios (EDGS) which are used in the "Base Case" and "Global Low Carbon" scenario[1] respectively. They will be used "as is" for inputs to the transform modelling. The uptake of solar and electric vehicles in the MBIE base case and global low carbon scenarios are based on the IEA "Current policies" and "450ppm" scenarios respectively.

A third scenario which includes higher uptake trajectories of consumer technology called "High Uptake of New Technology" has been created for the Transform modelling process. The scenarios are:

a. **Base case (mixed renewables):** This is a "balanced" renewables scenario reflecting the current views of relative technology costs and expected fuel costs. It has a central solar uptake and moderate electric vehicle uptake.

b. **Global low carbon emissions:** High carbon prices and lower wind generation costs are assumed. Higher solar generation installation (especially residential installations) and higher uptake of electric vehicles is assumed in comparison to the base case.

c. **High Uptake of New Technology:** A scenario in which breakthroughs in battery and electric vehicle technology and costs occur relatively early. Battery costs fall in 2022 allowing electric vehicles and solar to become cost competitive to the mass market, and wide spread adoption follows.

[1] A description of the Global Low Carbon and Mixed Renewables scenarios can be found in the forthcoming EDGS 2014. These scenarios have been updated since the Energy Outlook: Electricity Insight, available here: http://www.med.govt.nz/sectors-industries/energy/energy-modelling/modelling/pdf-docs-library/electricity-insight/electricity-insight.pdf

Basis for "High Uptake" assumptions

The Transform "high uptake of new technology" scenario is largely an exploration of the result of sustained exponential cost reductions in PV and storage technologies, drawn from the work of Tony Seba at Stanford University[2]. Seba's thesis is that the costs of solid state technologies such as solar panels and batteries decline logarithmically and will continue to do so indefinitely. He contrasts this with the observation that the costs of electro-mechanical technologies, such as conventional generation plant fall linearly – reflecting improvements in total factor productivity.

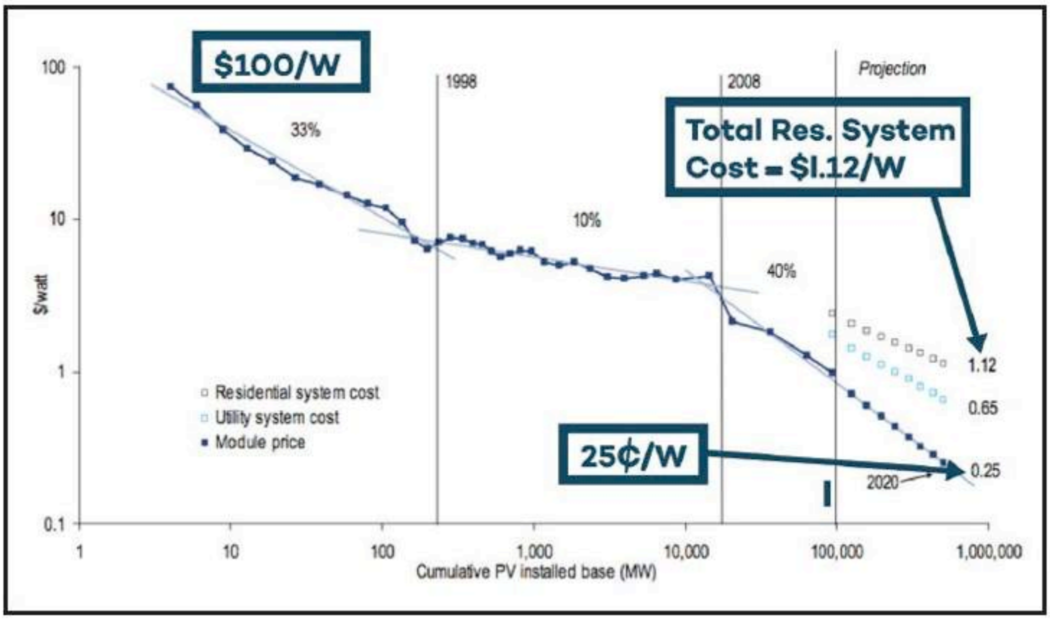


Figure 1 - Solar costs have fallen 154x since 1970 - source Seba

Seba's conclusion is that solar costs will inevitably fall below the cost of mainframe generation net of transport and distribution at which point all new generation will be solar.

Seba's projections for storage costs follow a similar exponential trajectory:

[2] *Clean Disruption of Energy and Transportation*, Tony Seba, 2014

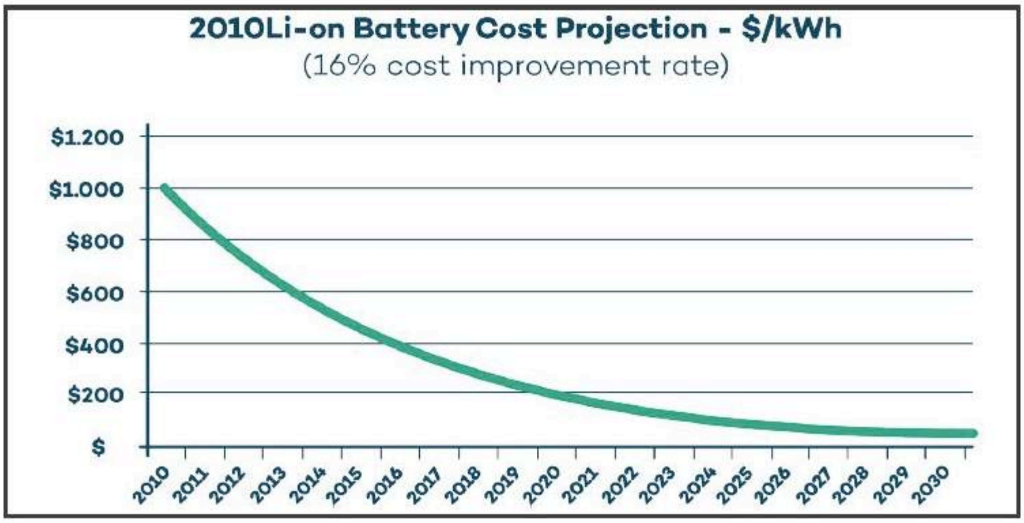


Figure 2 Li-ion battery cost projection $/kWh - Source Seba

Most published scenario work assumes high battery costs sustained for the medium term, reflecting consensus opinions from 2013. We have observed a dramatic fall in analysts' projections for such costs published since Panasonic and Tesla announced the construction of a large-scale battery manufacturing plant known as the "Gigafactory" which is set to double current battery production worldwide[3], and the response to this announcement from competitors.

Seba's projections have recently been supported by an independent review of battery cost estimates reported between 2007 and 2014.

[3] http://www.teslamotors.com/blog/panasonic-and-tesla-sign-agreement-gigafactory

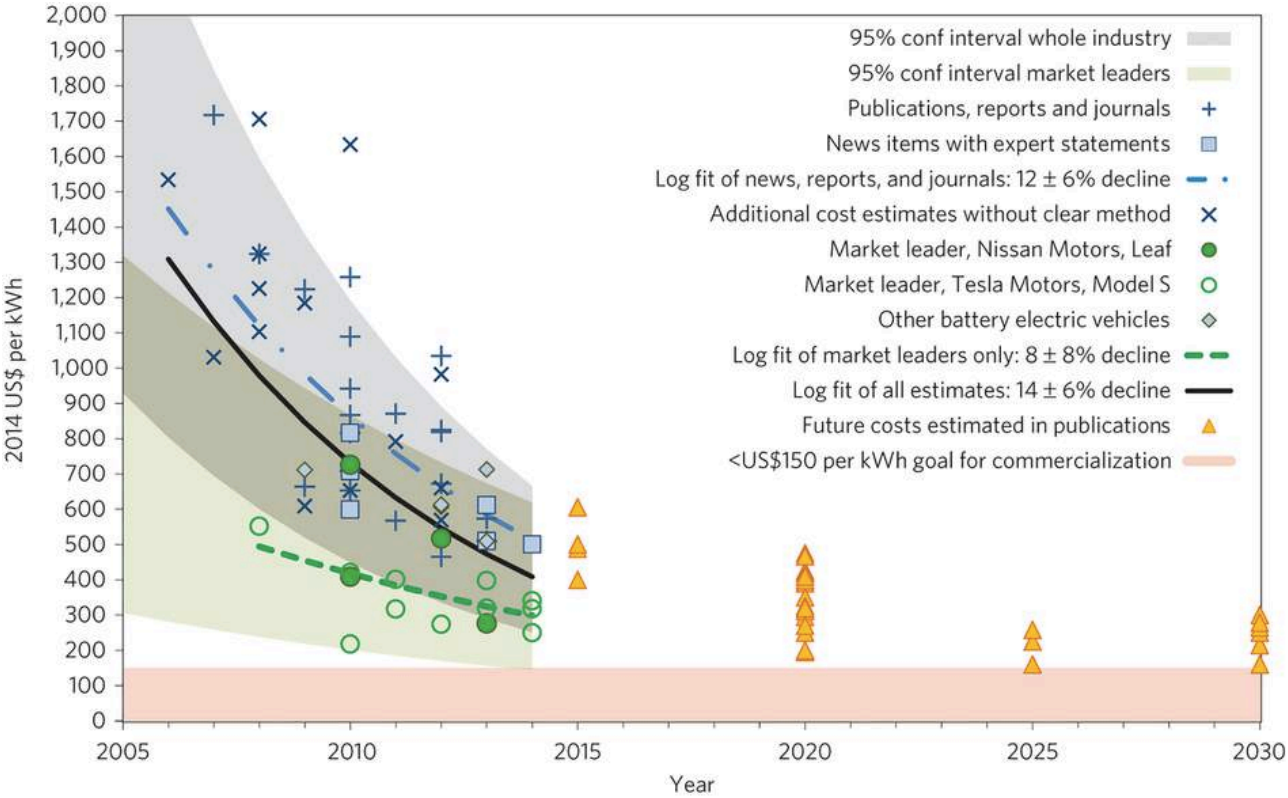


Figure 3 Cost of Li-ion battery packs - Source Nature Climate Change

The study concludes that the costs of Li-ion battery packs continue to decline and that the costs among market leaders are much lower than previously reported. This has significant implications for the assumptions used when modelling future energy and transport systems.[4]

Electric Vehicles are an extreme example of the effect of multiple exponential technologies in a single consumer product, where like-for-like costs will be lower than electro-mechanical equivalents but their consumer utility and performance will be vastly greater – much as a smartphone is not only cheaper than a landline telephone but it does more – integrating location, data communications, movement sensing and so on to support functions that are more useful than untethered voice communication alone. The compound effect of these technology capabilities and cost improvements explains the logarithmic uptake of mobile and smartphones in contrast to landlines:

[4] Rapidly falling costs of battery packs for electric vehicles, Nature Climate Change, March 2015

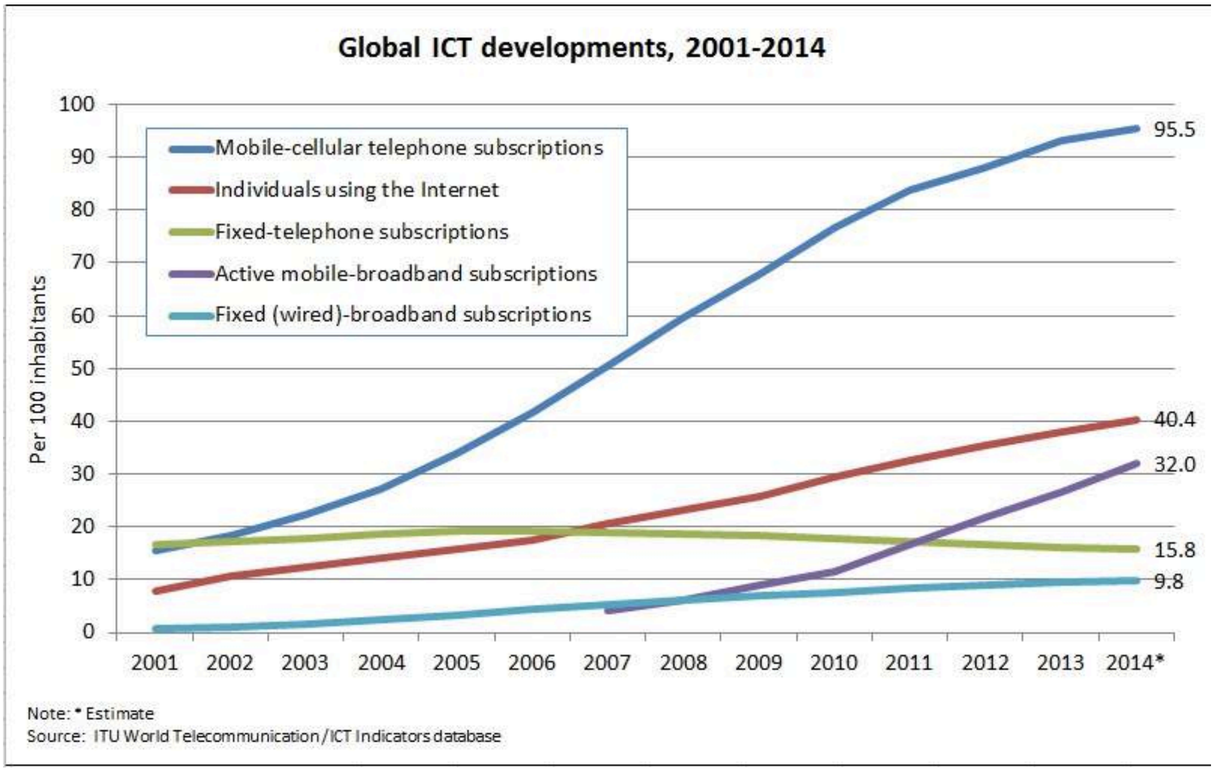


Figure 4 Relative market share of telecommunication technologies – Source International Telecommunications Union

Data Summary

Table 1: Data summary

	Heat Pumps	Electric Vehicles	Solar PV	Wind (distributed)
Notes	Domestic only	Residential and Commercial vehicles	Residential Solar PV	Total plant build
% Existing buildings	*	Yes[†]		
% New buildings	*	Yes[†]		
Domestic	Yes			
Commercial	Yes			
Trajectory 1	Yes	Yes	Yes	Yes
Trajectory 2	Same as T1	Yes	Yes	Yes
Trajectory 3	Same as T1	Yes	Yes	Same as T2
Home Charge Slow		Yes		
Work Charge Slow		Yes		
Home Charge Fast		Yes		
Work Charge Fast		Yes		
HV			No	Yes
MV			No	Yes
LV			Yes	Yes

* Unnecessary as entered directly as number of heat pumps

[†] For the percentage of new and existing buildings, these were estimated from household numbers.

Electric Vehicles

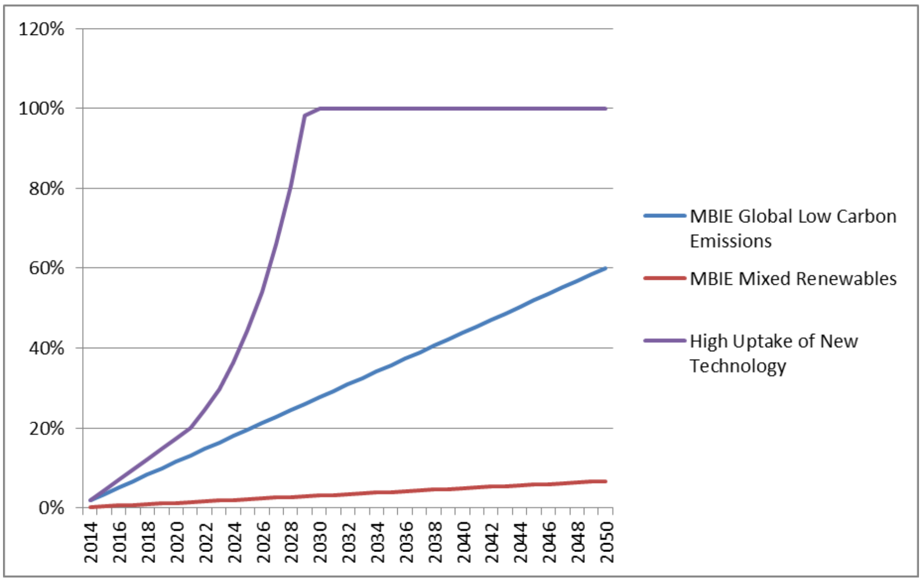
MBIE scenarios

The MBIE scenarios use fleet projections from the Ministry of Transport's Vehicle Fleet Model (VFM)[5]. The main input into the VFM is the uptake rate, the percentage of electric vehicles (both new and used) entering the fleet annually.

The uptake rate projections for the Base Case and Global Low Carbon Emissions are a medium and high case respectively. The uptake rates are informed by the IEA World Energy Outlook[6] and IEA Energy Technology Perspectives[7]. Growth in the vehicle fleet is driven by population growth. For the medium and high EV uptake projections it is assumed that the percentage of **new vehicles** entering the vehicle fleet that are electric increases in a straight line until it reaches 4.9% and 43.8% (respectively) in 2040.

The percentage of **used vehicles** entering the fleet that are electric is the same as for new vehicles, but with a five year lag.

Figure 5: Uptake percentage of electric vehicles (% of new imports that are electric)



High Uptake of New Technology scenario

A separate passenger fleet model was constructed to model the electric vehicle fleet in the high uptake of new technology scenario. As in the MBIE scenarios the model is population driven but allows changes in rates of vehicle turnover in an attempt to model a step change in vehicle purchasing.

[5] For more detail see http://www.med.govt.nz/sectors-industries/energy/pdf-docs-library/energy-data-and-modelling/technical-papers/Energy-Outlook-2013-Technical-Modelling-Guide.pdf
[6] Base case refers to World Technologies Perspective 2012 cost data
[7] Global low carbon emissions refers to IEA Electric Vehicle Roadmap 2012

Projections for EV uptake are a direct function of the exponential fall in battery costs assumed in the "High Uptake" scenario more widely: by 2025, if battery prices fall to $75/kWh, the EV equivalent of a new Toyota Corolla will be cheaper than one with an internal combustion engine.

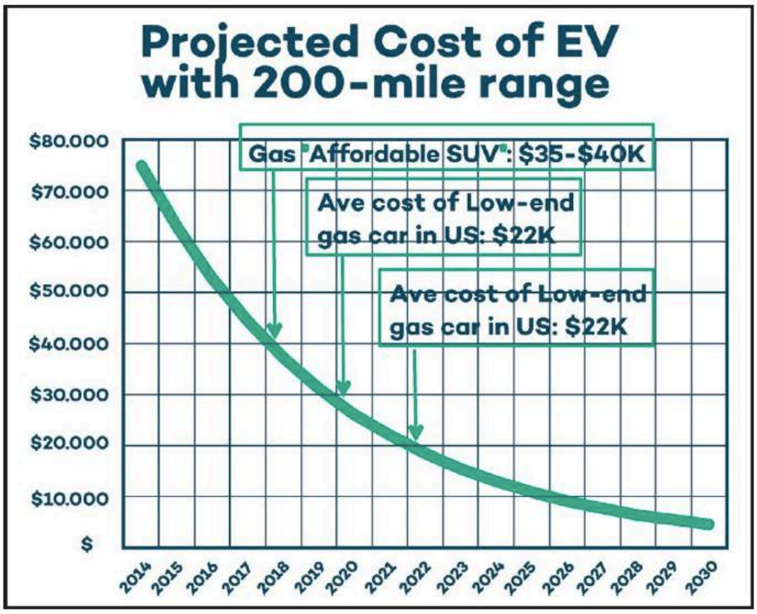


Figure 6 Projected costs for an EV with 200 mile range - source Seba

This trajectory has been modelled in 3 phases:

- **2015-2021** Electric vehicles are mainly limited to the higher end of the market in New Zealand but gain moderate market share. The uptake rate (% of vehicles imported (new and used) into New Zealand that are electric) increases slowly to 20% in 2021. Growth in vehicle fleet is driven by population growth.
- **2022-2030** Electric vehicles are cost competitive with low-end internal combustion engine cars (e.g. Toyota Corollas) in 2022[8] and uptake increases exponentially. By 2030, all new vehicles are electric. A greater percentage of vehicles imports are new are due to electric vehicles (1% additional from 2022 to 2035). A five year delay is applied to imported used vehicle uptake compared with new vehicles.
- **2030 onwards** Electric vehicles with self-driving technology become dominant in the vehicle fleet. Vehicles owned per capita increases (20% to 0.72/person) to represent this. Scrappage rates of ICEs rise in 2030 and remain at 165,000 for the duration of the projection. Once all ICEs are cycled out of the fleet (2044) market saturation is reached and growth in electric vehicle numbers slows.

[8] Based on graph presented by Seba T., 2014, Auckland presentation titled: Clean Disruption of Energy and Transportation.

Figure 7: Electric Vehicle Fleet

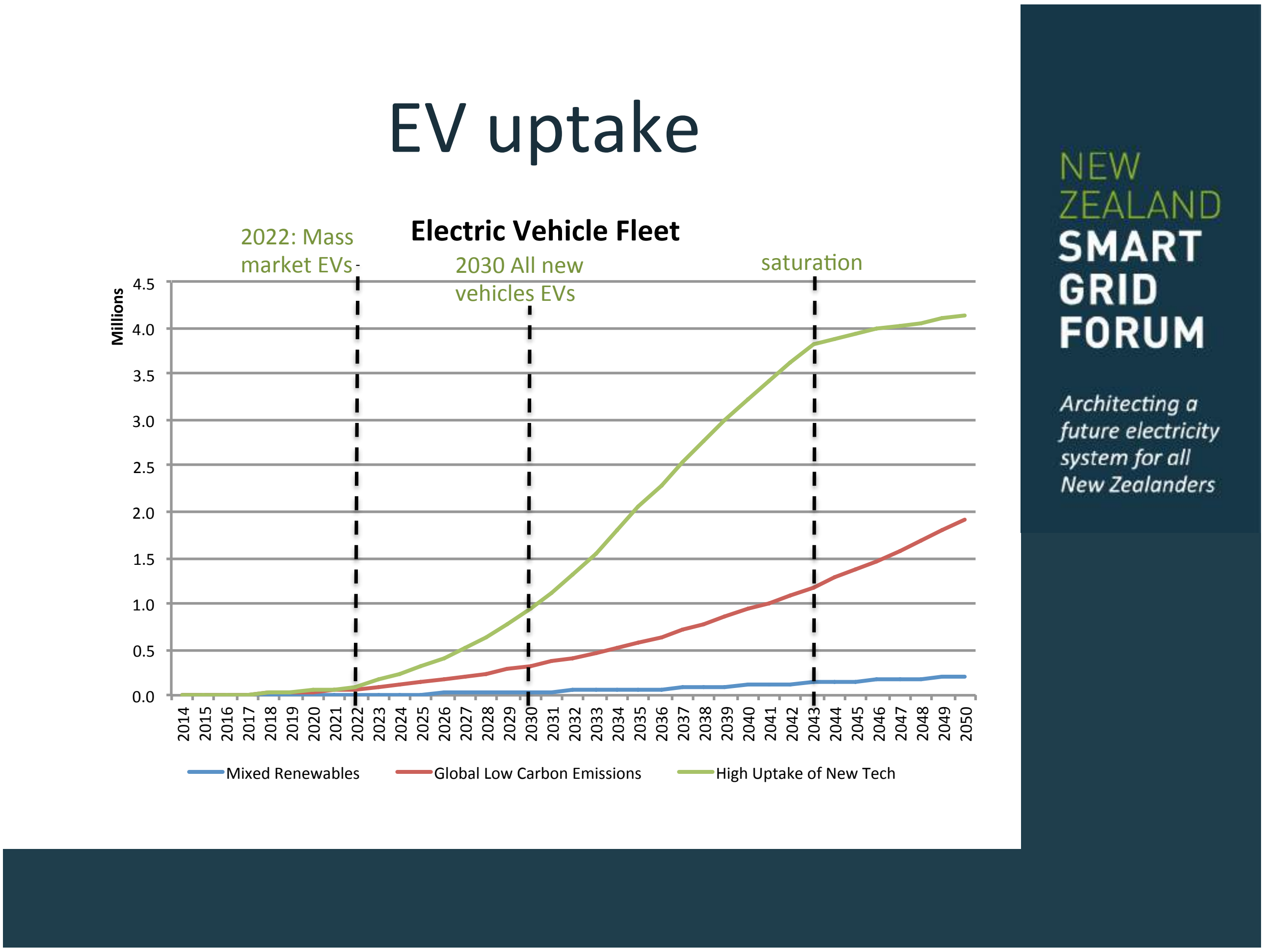
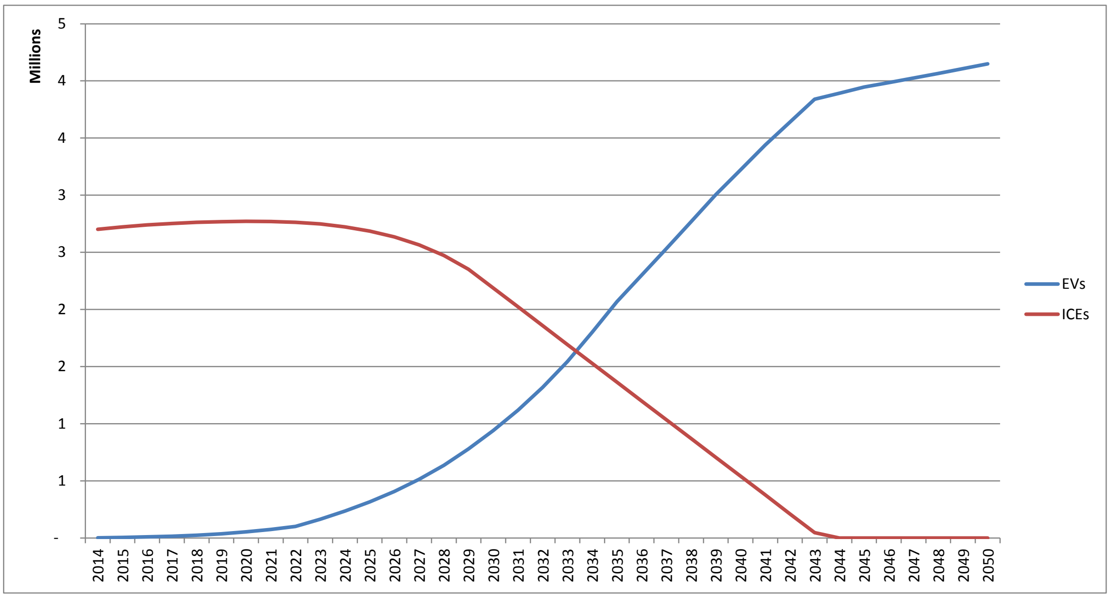


Figure 8: High Uptake of New Technology Internal Combustion Engines vs. Electric Vehicles



Split between Fast & Slow charging

The Transform Model relates fast and slow charging to the technical specifications of the batteries used for the charging process. Broadly, for slow charging the Transform Model uses batteries of ≈3kW (≈8hr to full charge) whereas for fast charge it uses ≈7kW (≈3.5hr to full charge). The Transform Model uses different charging profiles for fast and slow charge.

Split between Work & Home charging

The EV charging profiles in the Transform Model are based on real-world customer field trials. The work charging profiles reflect a combination of the charging of the employee's own car during the day and fleet vehicles in the evening/overnight. The home charge has generally two peaks, i.e. morning and evening after the usual journeys.

For the two MBIE scenarios a flat scalar was applied to all years.

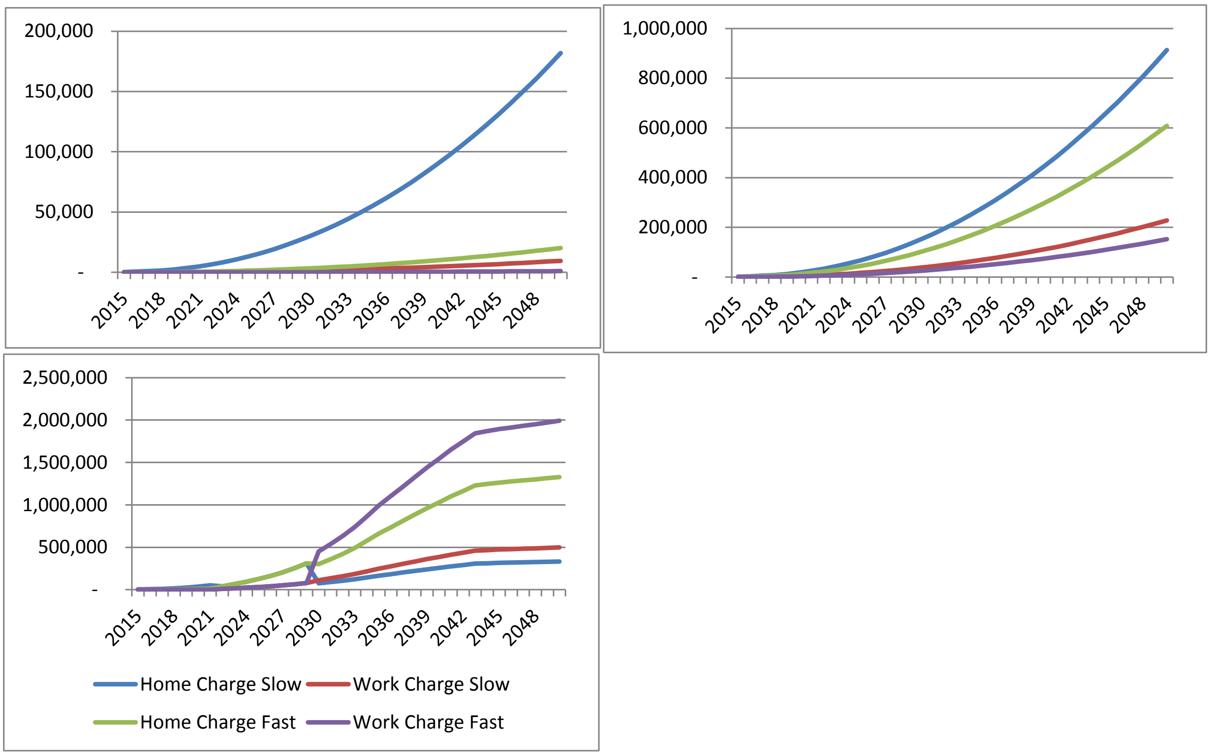
The majority of charging is assumed to occur at home and at slow charge in the MBIE base case. In the Global low carbon emissions scenario we have assumed higher work and fast charge rates.

In the High Uptake of New Technology scenario, we have assumed much higher work and fast charge rates once the post 2030 phase is reached. Table 2, shows the scalars applied, to give a wide range of spread between scenarios and charging type and time.

Table 2: Electric vehicle split rates

		Slow	Fast	Work	Home
Base case		90%	10%	5%	95%
Global Low Carbon Emissions		60%	40%	20%	80%
High Uptake of New Technology	2015-2021	80%	20%	10%	90%
	2022-2030	50%	50%	20%	80%
	Post 2030	20%	80%	60%	40%

Figure 9: Electric vehicles split by work/home and fast/slow, from top left clockwise: base case, global low carbon and High Uptake of New Technology



Solar

MBIE scenarios

The Ministry has developed a "central projection" for solar uptake based on a number of assumptions. A financial model, split into three separate time periods, is used to calculate the cost of solar. The decision for households whether it is economic to install solar is calculated using MBIE data on regional electricity tariffs. A discounted cash flow model finds the Long Run Marginal Cost (LRMC) required to provide an economic return over the modelled period. Assumptions on uptake rate are then applied to work out the capacity of installed solar. A more detailed description is available on MBIE's website[9].

The uptake assumptions are summarised in Table 3. When installation of solar PV becomes financially positive for a particular region of the country, it is assumed that 15% of the existing housing stock installs PV, and that 30% of all new homes install PV. In addition to this it is assumed that 0.17% of homes install solar PV even when it is not optimal from a pure cost comparison perspective. After 2035 a continuation of the uptake rate for 2026 to 2035 is used based on a linear function.

[9] http://www.med.govt.nz/sectors-industries/energy/energy-modelling/modelling/electricity-demand-and-generation-scenarios/stakeholder-workshop-21-april-2015

Table 3: Solar uptake assumptions for central projection

Group	Uptake rate
Existing households	15% of existing households where solar is economic
New households	30% of new households where solar is economic
Commercial uptake	18% of the household installed capacity

Commercial and small and medium enterprise currently contributes 18% of the existing installed solar capacity. It is assumed this percentage is constant to 2050. This projects PV capacity to reach around 248 MW by 2050.

High Uptake of New Technology scenario

For the High Uptake of New Technology case capacity grows at a similar rate to the global low carbon scenario until 2022. In 2022, batteries cost reduce, doubling the number of households where it is economic to install PV.

We also assume 80% of the existing housing stock installs PV from 2017 and that 80% of new homes install PV where it is economic. This gives almost 1 million households, 39%, with solar PV installed by 2050.

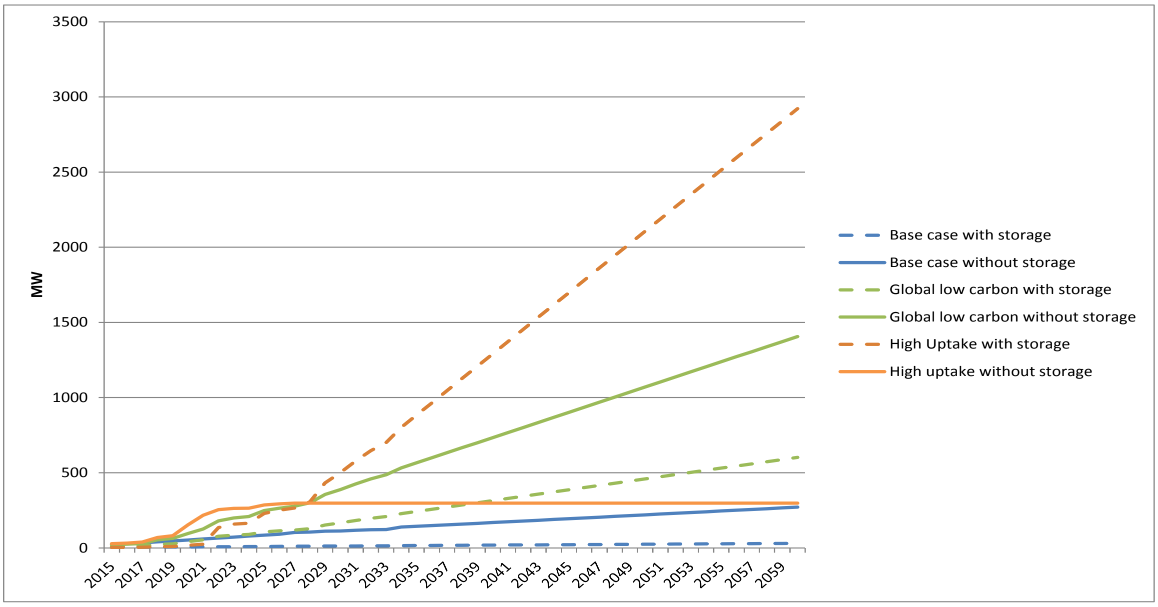
Storage assumptions

The storage assumptions are shown in Table 4 below. Storage assumptions were not explicitly considered in the MBIE scenarios. Additional assumptions were made for the purposes of this work. In the Base Case and Global Low Carbon Emissions scenarios we assume a conservative uptake of battery systems in line with current trends. In the high uptake scenario we assume reductions to battery costs apply to household battery storage systems. From 2023 the majority of solar systems are installed with batteries, and from 2028 onwards all solar systems are installed with batteries.

Table 4: Scale factors applied to solar generation

			With storage	Without storage
Mixed Renewables			10%	90%
Global Low Carbon Emissions			30%	70%
High Tech uptake	**2015-2022**	**2022**	10%	90%
	2023-2028	**2028**	75%	25%
	2028 on	**2051**	100%	0%

Figure 10: Solar export to grid



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High Tech uptake	**2015-2022**	**2022**	10%	90%
	2023-2028	**2028**	75%	25%
	2028 on	**2051**	100%	0%

Figure 10 shows the proportion of solar in each scenario with and without storage –the greater volume of solar export without storage in the “Global low carbon” scenario reflects the assumption that 70% of installations do not have storage – in contrast to the higher storage assumptions for the “High uptake” scenario.

Impact of storage on net grid demand

EA Technology’s “Transform” model does not consider battery storage as a specific modelling input: we have reflected the effect of lower battery costs within the projections of Solar PV uptake in the “high uptake” scenario. This considers the circumstance where the battery is charged from excess solar. However, it does not consider the circumstance where the household can charge their battery from the grid. The grid demand outcomes would be quite different in this circumstance, and this is something that will be looked into in future work.

Solar/storage profiles

Two demand profiles have been used:

1. Winter profile –weighted average household winter profile from actual NZ network data
2. Summer profile –weighted average household summer profile from actual NZ network data

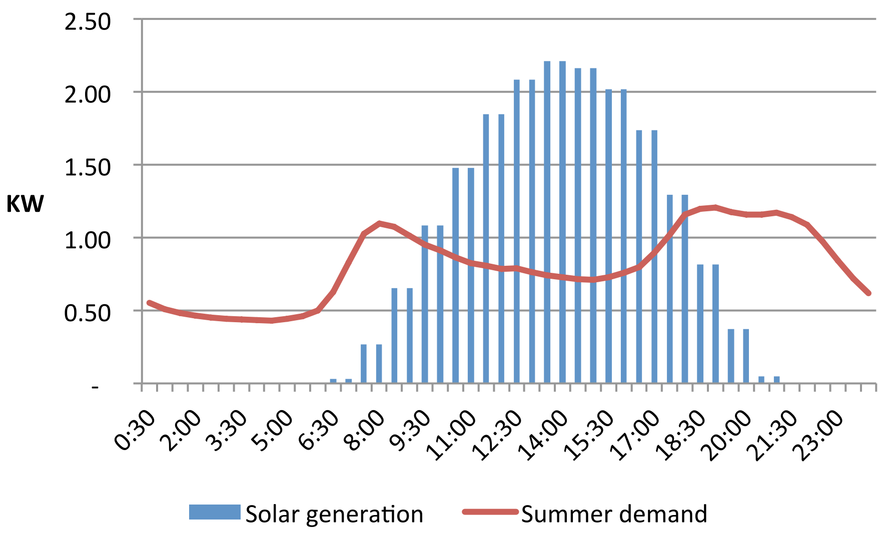
Solar PV and Energy Storage Characterisation

- Solar -3 kW panel
- Battery -3 kW battery (i.e. can draw 3 kWh from the network per hour) with a storage capacity of 11 kWh. Battery storage size assumed to be 11 kWh based on information provided by members of the Smart Grid Forum. Members mentioned that if smart appliances and energy efficiency solutions are integrated in the future that battery size may be smaller in the future. Since we were primarily concerned with how much we could store in the battery it seems to be reasonable to assume the battery size is a bit larger than might actually be the case. As we note above, in this situation we are not considering grid charging to the battery, only charging from surplus solar generation.
- The model used was a single day model and assumed that there was no storage at the start of the day and that the household tries to use stored solar during the day in the same day.

Solar profiles without storage

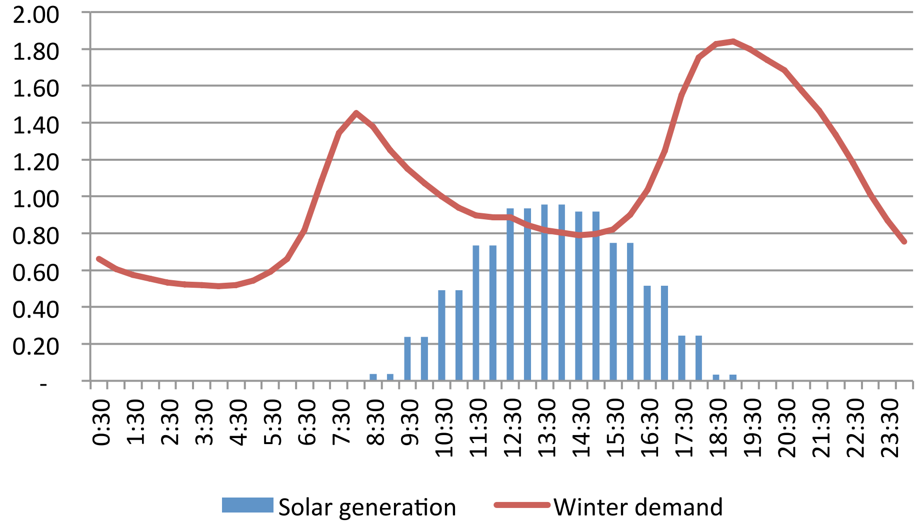
Without storage –typical summer's day

- An average solar profile over the 3 months December through February has been taken
- Without storage surplus solar is lost.



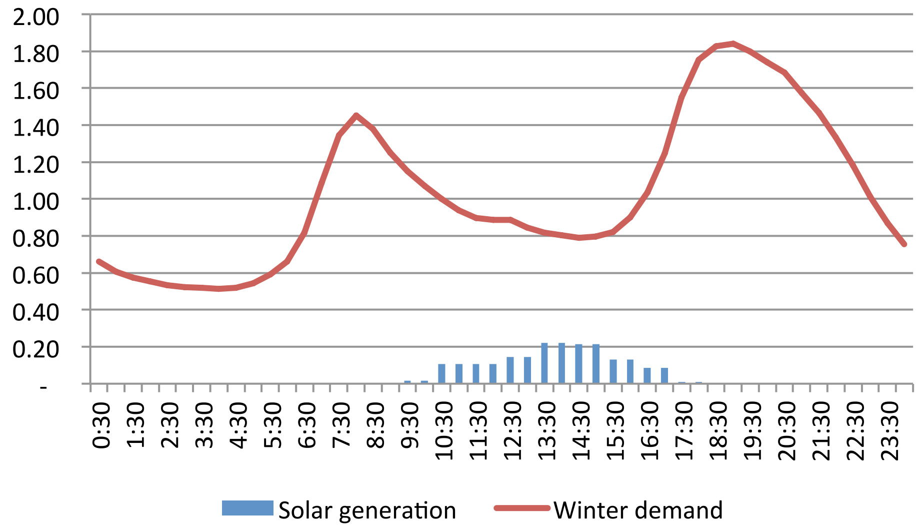
Without storage –typical winter's day

- An average solar profile over the 3 months June through August has been taken
- No surplus generation on a typical winter's day.



Without storage –particularly bad winter's day

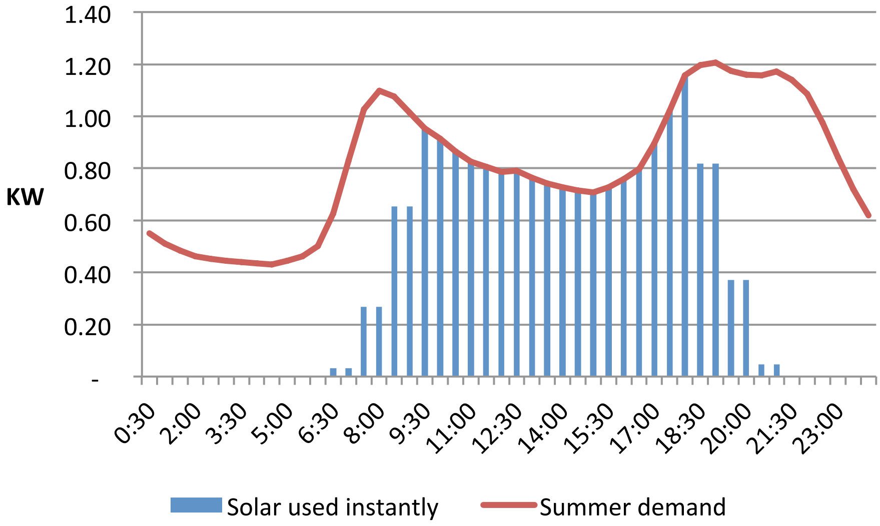
- A particularly bad winter's day was picked from the time series of daily solar profiles through winter.
- In a particularly bad winters day solar generation doesn't met very much of the households electricity demand



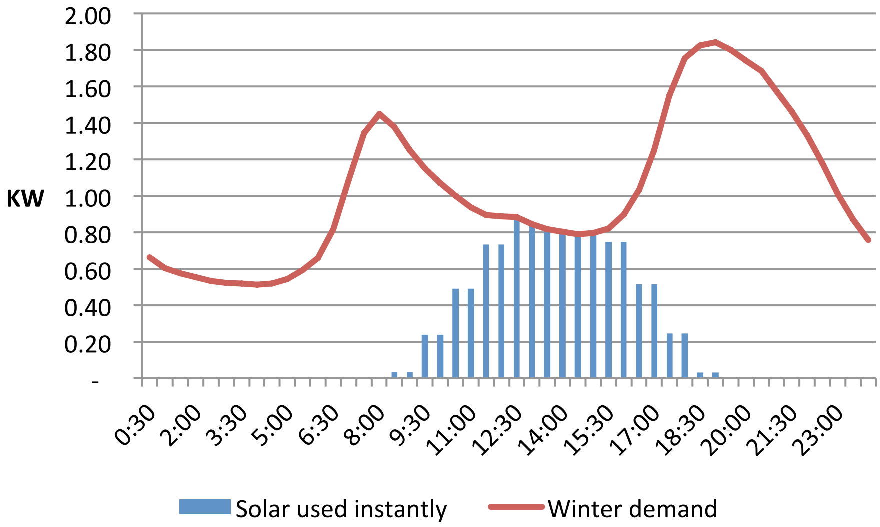
Solar profiles with storage

With storage –typical summer's day

Surplus solar is able to be stored in the battery. See energy storage characterisation below.



With storage –typical winters day



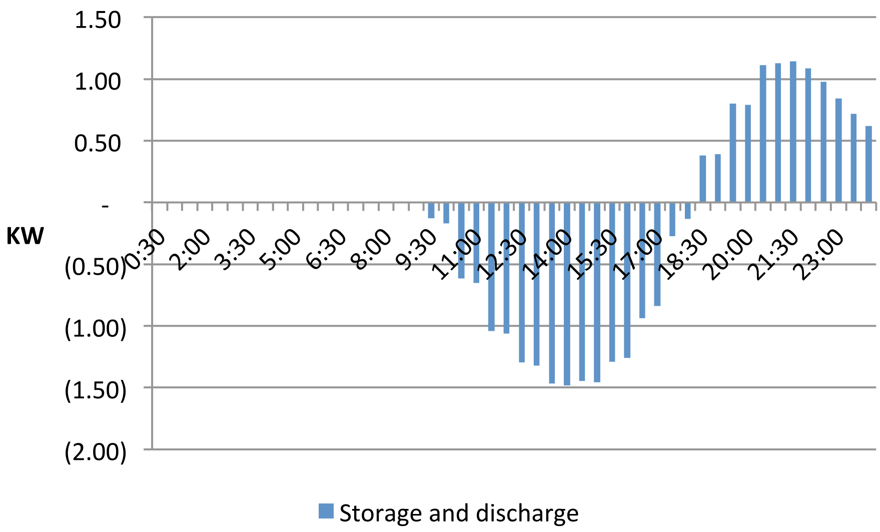
With storage –particularly bad winter's day

Since there is no excess solar in a particularly bad day in winter, the profile is the same as that without storage (see above).

Energy Storage Characterisation

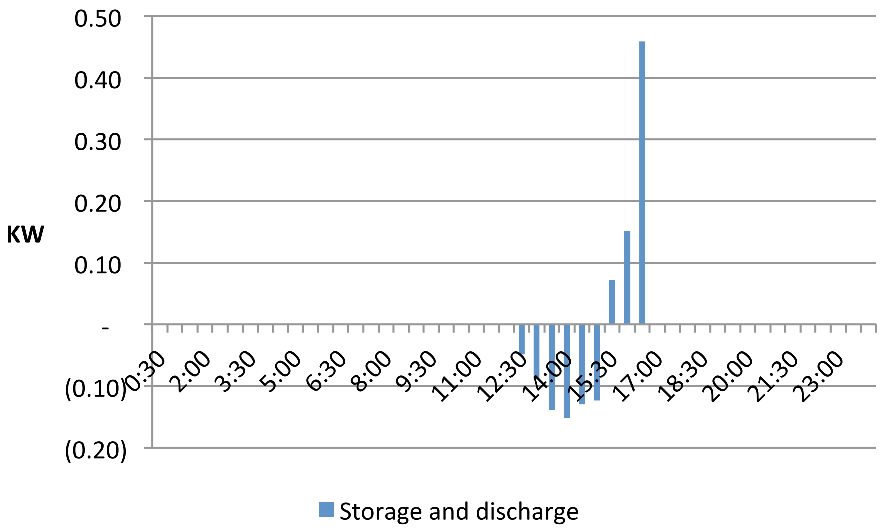
With Storage –typical summer's day

Storage is represented by the negative flow, and discharge is represented by the positive flow.



With Storage –typical winter's day

Since there is no surplus solar on a typical winter's day there is no battery storage.



With storage –particularly bad winter's day

Since there is no surplus solar on a particularly bad winter's day there is no battery storage.

Wind

MBIE Scenarios

The Generation Expansion Model (GEM) was used to determine the optimal build profiles in the two MBIE scenarios. The electricity price forecasting model determines a wholesale electricity price indicator based on the long run marginal cost (LRMC) of new generation built in GEM. Taking into short run marginal costs a least cost optimisation is carried out to determine plant build to 2050.

Capital and operating costs are inputs into the model. The wind capital costs were based on a MIBE commissioned report by Parsons Brinkerhoff (PB): *2011 NZ Generation Data Update* (PB generation cost update).[10] Since then, wind capital costs were reviewed, and due to decreases in the cost of wind turbines, prices compared with other possible generation available to GEM were reduced by 10% (Based on information from Bloomberg New Energy Finance (BNEF)[11]). Specifically, the foreign component of capital costs for wind plant were reduced.

The same wind plant are available to be built in both MBIE scenarios. To reflect a world of higher carbon prices and more focus on renewable technology wind costs were reduced by a further 10% in the global low carbon emissions scenario.

The GEM modelled wind, in which transmission embedded wind projects are included, were allocated to high and medium voltage. A 90% to 10% split is assumed between high voltage and medium voltage wind plant build.

To determine the low voltage wind, MBIE's model of distributed, non-grid connected generation was used. This is a basic model based on flat growth assumptions in each year. We have modelled a small amount of low voltage wind as an estimate of distributed generation (171 MW by 2050).

High Uptake of New Technology

No wind scenario has been modelled. The same trajectory as the Global Low Carbon Emissions scenario has been used.

Heat pumps

Transform was originally developed for Great Britain where the government has provided decarbonisation incentives for heat pump installation. In New Zealand, there is little data available on heat pump uptake. Only one trajectory based on residential heat pump historic uptake has been provided.

It is considered that heat pump uptake in existing buildings has mostly peaked in New Zealand. A largely stable prediction of residential heat pump uptake is given, where post 2022, there is no heat pump growth due to existing buildings.

To estimate commercial building heat pumps numbers EECA heat pump sales data was used. It was assumed that of all heat pumps sold, all those that were not single split were sold as commercial (3%). This percentage was then applied to the total number of domestic heat pumps.

New and Existing Buildings

The number of new and existing buildings is used to bias solar, heat pump and electric vehicle data to different areas of the network. As the data available for heat pumps already included new and existing buildings this was not necessary.

Data on commercial buildings is not readily available; the number of new and existing households was provided as an indication.

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[10] Refer to http://www.med.govt.nz/sectors-industries/energy/energy-modelling/technical-papers/2011-nz-generation-data-update.
[11] Refer to http://about.newenergyfinance.com/about/.