New Zealand Transition Engineering Retro-Analysis

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NEW ZEALAND TRANSITION ENGINEERING RETRO-ANALYSIS

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Abstract

To meet New Zealand's emission commitments, the government has prioritized the up-take of Electric Vehicles (EVs), as personal transportation is a large consumer of fossil fuels. Extrapolating figures from official sources (Ministry of Transport and Ministry of Business, Innovation & Employment) we estimate that passenger transportation is responsible for at least 30% of New Zealand's fossil fuel consumption. Given New Zealand has a large share of renewable sources (78%) the simple conclusion is that the uptake of EVs would directly reduce carbon emissions, however the interaction of EVs with the power system is complex and requires a comprehensive approach. Transition Engineering (TE) is an emerging field that addresses sustainability in design and management of engineered systems. Within the context of the TE methodology we investigated the implication of EV targets on the New Zealand Energy System and associated Greenhouse Gas Emissions. We utilized a Retro Analysis approach, using the transport activity and grid composition of 2012, superimposing various policy objectives into that system to understand the costs, benefits, consequences and utility of the policy. An energy system model was developed using the Long-range Energy Alternatives Planning System (LEAP). The model incorporated seasonal availability of power plants along with sector specific energy consumption profiles reported in official datasets. We defined a set of scenarios to examine the impact of different EV targets, charging behavior, modal shift, transport behavior and changes to grid composition. The implications of the intermittent nature of renewable resources were explored along with potential demand additions (EV charging) on the power system.

1 Introduction

A recent report from the Intergovernmental Panel on Climate Change stresses a stronger global response is required to mitigate the effects of Climate Change (Intergovernmental Panel on Climate Change 2018). One mitigation pathway is the electrification of transportation, as transport is a large consumer of non-renewable resources. New Zealand appears well-suited for electric vehicles, with a high share (~78%) of renewable power generation. The New Zealand Government has already announced a set of measures to enhance the uptake of electric vehicles including: exemptions on road user charges, information campaigns, innovation programs and research funding (Ministry of Transport 2018a). The latest "Transport Outlook" report from the Ministry of Transport projects that the ownership costs for electric vehicles (EVs) are to reach cost-parity with internal combustion vehicles by mid-2020s. It is expected that this will then drive EV share to 40% of the vehicle fleet by 2040 (Ministry of Transport 2017b).

New commercially available EVs have a driving range of around 270 kilometers (Nissan 2018), which far exceeds the average distance, 31 kilometers, travelled by individuals in private vehicles daily (Stats NZ Tatauranga Aotearoa 2014). For many New Zealand urban commuters, EV's have become a suitable replacement for Internal Combustion Engine (ICE) vehicles. However, the adoption of a large-scale fleet of EVs should be informed by a robust understanding of the technical challenges, economic and environmental implications. According to a 2018 white paper published by Transpower, in the upcoming years, considering added wind, geothermal, hydro and solar generation and a full removal of gas and coal generation, the biggest challenge to solve will be peak load, particularly in dry years and cold winters (Transpower 2018).

This paper uses a retro-analysis based in 2012, as both transport and energy data were available for this year, to provide insight into the impact of EV's on the NZ power system. A retro-analysis imposes changes, such as policy actions or targets, onto a base-year, with confirmed resources, to investigate the impact of those changes without speculating on future demand or availability. A retro-analysis has previously been used to understand the environmental implications of biofuels in New Zealand (Krumdieck & Page 2013). Within the context of this work, a retro analysis is useful for decoupling the effect of added grid resources from the effects of added EV's and to also present what may occur if proposed added infrastructure is not delivered. The model used accounts for the seasonal variability of renewable resources and charging patterns of the EV's. Two levels of EV adoption, to match government policy and projections, are investigated: A 64,000 increase in EV's by 2021 and a 40% light fleet replacement by 2040. Official proposed modifications to the grid are also simulated. Combinations of these scenarios are analyzed for their effect on the performance of the grid, including: reserve margin, peak-power requirements, carbon-emissions and generation costs.

2 Background

2.1 Energy and Environmental Planning Tools

Energy-environmental planning models are based on scenario analysis that estimate energy consumption and Greenhouse Gas (GHG) emissions upon projections of socio economic indicators. Common scenarios are based on long-term energy consumption with considerations for environmental aspects, technology substitution, energy carriers substitution, energy efficiency programs and the implementation of Renewable Energy projects. Models that have a strong transportation component also emphasize on the forecast of Vehicle Population, Traffic Volume and Vehicle Kilometers travelled per capita (VKT) (Sadri, Ardehali & Amirnekooei 2014). Several simulation packages are common for this type of analysis and are widely used by researchers, consultancies, and policy makers worldwide. The Long-range Energy Alternatives Planning (LEAP) System is a scenario based modelling software developed by the Stockholm Environment Institute. It relies on a large database of emission factors. The software integrates optimization solvers that can be used to investigate the cost effective addition of different technologies (Stockholm Environment Institute 2017). The Unified System for Regional Electric Power Planning (SUPER) is a modeling tool developed by the Latin American Energy Organization (OLADE). SUPER can model mid to long term expansion of power and transmission capacity of an interconnected system; it can also optimize cost and minimize energy risk (Latin American Energy Organization 2018). EnergyPLAN is a model developed and maintained by the Sustainable Energy Planning Research Group at Aalborg University. EnergyPLAN simulates the operation of national energy systems (EnergyPlan 2018).

Suganthi and Samuel (2012) reviewed several forecasting models that have been used to estimate future energy demand. Models covered in the review cover time series, regression, econometric, decomposition, neural networks, grey box prediction (combination of theoretical structure with coefficients derived from data), input-output and genetic algorithms. The article also describes features from energy planning bottom up models. MARKAL (Market Allocation) is an analytical tool that outlines the supply and demand side from an energy system; the program was originally developed as a least cost linear programming model for the International Energy Agency (IEA) (Suganthi & Samuel 2012). Sadri, Ardehali and Amirnekooei (2014) provide a procedure for energy-environmental planning for transportation, addressing transportation data limitations in developed countries. Iran is used as a case study; Population and Gross Domestic Product (GDP) are forecasted up to 2025 through a Grey model applied over historical data for 1997-2008. An important contribution from their work is that the study uses both LEAP and EnergyPLAN, hence allowing to contrast and highlight the capabilities and limitations of each approach (Sadri, Ardehali & Amirnekooei 2014). LEAP has the capability to contrast the performance of different scenarios whereas Energy PLAN treats every scenario as a new project and comparison needs to be carried out outside of the platform. Emodi et al. (2017) use LEAP to run a long-term (up to 2040) scenario based analysis for Nigeria. The scenarios reflect different levels of policy intervention on energy efficiency and renewable energy application. The article also provides a detailed description of the energy consumption, transport stock turnover, transformation (transmission and distribution), and cost calculations that are carried out within LEAP. One of the biggest challenges for Nigeria will be to enhance the consumer's economic accessibility to cleaner technologies; the study also addresses the need to incorporate the impact of climate change on energy supply and demand forecasts (Emodi et al. 2017). Ostergaard (2015) investigates the range of optimization criteria and performance indicators used in EnergyPLAN models reported on peer reviewed journals. According to the review, Primary Energy Supply (PES), GHG emissions, Economic Costs and Excess power generation are the most employed criteria used for optimization/simulation EnergyPLAN models. The article also reports on performance indicators for evaluating the impacts of intermittent renewable generation; basically, these are calculated as ratios between marginal changes in optimization criteria (Ostergaard 2015).

2.2 Electric Vehicle Policy

Many countries are promoting policy to increase the uptake of EV's in order to reduce transportation energy, reliance on imported and non-renewable fuels and emissions. Some policy measures directly support the uptake of EV's, including: subsidizing purchase costs, access to bus lanes or high-occupancy lanes and reducing or exempting fees for toll roads and parking. As of 2017, many countries including: Japan, South Korea, Germany, France and the USA have had direct subsidies and tax credits (Nian, M.P & Yuan 2017). Other incentives include research funding or added charging infrastructure.

Norway are the current world leaders in EV adoption with a long history (>25 years) of EV policy. As of 2015, EV's made up 2.7 % of Norway's total vehicle fleet and 17.1% of new passenger vehicle sales (Figenbaum 2017). A main contributor to their uptake is low electricity prices, renewable generation (96% hydro-power) and high oil-prices. Researchers reported that Norway's EV policy only became effective as large vehicle manufacturers entered the EV market and of the incentives price reductions appear to be the most effective measure, as other European markets with price incentives also have higher shares of EV's (Figenbaum 2017).

Several researchers have investigated the impact of EV policy or EV adoption on countries energy systems, emissions and fuel dependence. For the UK, who have banned the sale of conventional ICE vehicles after 2040, Raugei, Hutchinson and Morrey (2018) performed a life cycle analysis of ICE and EV's to analyze the dependence on non-renewable energy. They found the replacement of ICE vehicles with EV's provided significant reductions to the non-renewable Cumulative Energy Demand (nr-CED). If the added load was met with combined cycle gas turbines the nr-CED was reduced by ~32% and by ~70% if met by renewable sources. Brazilian researchers simulated replacing a taxi-fleet in a Brazilian city with EV's and analyzed the carbon emissions (Teixeira & Sodré 2018). Given the carbon-intensity of the grid, large-proportion hydro-power, the transition reduced carbon emissions between 10 to 32 times compared to ICE vehicles. The analysis only included emissions to run the vehicles, not the manufacture, and grid emission factor remained constant, unlikely for large-scale ICE replacement. Researchers from Thailand used a LEAP model to analyze the total effect on GHG of the countries policy target of replacing 1.2 million ICE vehicles with EV (Winyuchakrit, Sukamongkol & Limmeechokchai 2017). They found, given the current grid composition, a high level of non-renewable generation, the GHG emissions would increase 7% and a similar increase was found even when renewable energies made up 20% of generation. The LEAP model did not include the lifecycle (manufacturing) emissions, but did include the impact on the grid with the addition of the EV's. The simulated results for ICE to EV replacement generally appear positive, particularly when just looking at the on-going energy consumption and emissions. The results appear strongly linked to the emission factors for generation and a higher efficiency drive-train. However, the results look less positive, or reverse, when the life-cycle (higher embedded energy in EV's) is taken into account or the impact of the added EV load and time of use on the grid are taken into account. This highlights the need of a LEAP type model as EV's can present a challenging power addition to the grid, which may require higher use of non-renewable energies.

Another driver for the adoption of EV's is the added flexibility of the grid with flexible charging and exporting back to the grid. However, EV's are more constrained than stationary batteries as they must meet transportation needs and do not maintain a connection with the grid. Mills and MacGill (2018) explored the optimization of EV's as a distributed energy resource in a Sydney Australia case-study. They found that universal access to charging infrastructure (chargers at work, schools, shopping malls etc.), required a significant expense, to effectively utilize EV's as a distributed resource for the grid, particularly to balance a mid-day solar-power peak.

3 Methodology

The model reported in this paper follows the hierarchical structure of LEAP. Key Assumptions, Demand, Transformation and Resources are the main modules. All branches and technologies are defined under *Current Accounts.* Scenarios are defined through assumptions on changes of activity, share, population or energy intensity. The sources of information, fundamental assumptions, and scenarios are described in the following sections.

3.1 Model setup and Data

2012 was selected as the base year as sectorial electricity consumption data-sets were available. The demand module was organized into four subfolders for the Transport, Industry, Commercial, and Residential sectors, respectively. The transport module had a higher level of detail as our study particularly focused on the impact of policy on energy consumption and GHG emissions from this sector. The first level of disaggregation considered passenger and freight subfolders. Vehicle Kilometers (VKTs) and vehicle occupancy were used to calculate passenger kilometers (PKMs) that were further allocated to the household light, motorcycle, heavy bus and light commercial sub-categories. VKTs from heavy trucks were excluded from the road passenger category, as they were accounted for in terms of Tonne Kilometers (TKM) within the road freight category. Fuel consumed by Cruise liners and Interislander Ferries were not accounted for within the passenger category. The Freight subfolder is entirely based on transport activity and modal shares (i.e. road, rail and coastal shipping) reported on the National Freight Demand Study (Deloitte et al. 2014). Fuels used within the passenger and freight categories include Diesel, Petrol, Electricity, Residual Fuel Oil and Jet Kerosene. Other fuels like LPG were not included in the analysis, as they are not representative within the New Zealand transport sector (approximately 0.4% share). Data used within the transportation branch along with the corresponding sources are summarized in Table 1.

Description	Sources
VKTs by vehicle and fuel type	Annual vehicle fleet statistics report (Ministry of Transport 2017a)
Vehicle occupancy	Transport Indicators (Ministry of Transport 2018b)
Aircraft PKMs	Air travel statistics and modeling (Cross & Wang 2014)
Rail passenger activity	Transport Indicators (Ministry of Transport 2018b)
Freight activity and modal shares	National Freight Demand Study (Deloitte et al. 2014)
Energy intensities	(Tiwari & Gulati 2013; V. T. T. Technical Research Centre of Finland Ltd 2017)

Table 1 Transport Data and sources

In the Transport Branch, energy intensities were specific to each technology. The definition of Industry, Commercial and Residential sectors followed a different approach. Aggregate energy intensities were defined at the top level of each of these categories. Each category contains a set of fuel branches, and a share was assigned to each one of them. Sectoral Energy Intensities were expressed in terms of energy use per unit of gross product. Data on GDP breakdown by industry for New Zealand was obtained from Figure.NZ (figure.NZ 2016). Sectoral energy use, fuel shares and installed power capacities were obtained from online documentation on energy statistics published by the Ministry of Business, Innovation and Employment (MBIE) (Ministry of Business Innovation and Employment 2015). A novel feature of our model is that it utilizes energy load shapes to derive electricity consumption profiles for different sectors. The profiles employed in the model were taken from an online dataset containing half-hourly readings of electricity consumption for different sectors (Electricity Market Information 2018).

Energy Transmission and distribution, Electricity Generation, Oil Refining, Natural Gas extraction and Oil Extraction define the transformation module. In regards to the Electricity Generation branch, the model incorporates “availability shapes” to describe the fraction of time a plant is available in each of the time slices considered in the analysis. This is also a novel feature of ours and proved to be important in regards to assessing the effect of peak power requirements along with intermittent renewable generation. These profiles were derived from monthly datasets containing half-hourly readings for different power plants in New Zealand (Electricity Market Information 2018). The information was aggregated into daily time slices as displayed in Figure 1. An additional one hour length slice was added to account for the year's peak event. Remaining data on costs and technical features for electricity generation were obtained from official reports and scientific literature (Dagher & Ruble 2011; Electricity Authority 2014; Kachoee, Salimi & Amidpour 2018; Kale & Pohekar 2014; Ministry of Business Innovation and Employment 2016; Organisation for Economic Co-operation and Development, International Energy Agency & Nuclear Energy Agency 2015; Park, Yun & Jeon 2013). Table 2 provides a summary of data entered in the electricity generation branch. Annual summary statistics from the MBIE website were used to define the losses, historical energy production, exogenous capacity, and availabilities within the Oil Extraction, Natural Gas Extraction, Oil Refining, Transmission and Distribution branches (Ministry of Business Innovation and Employment 2015).

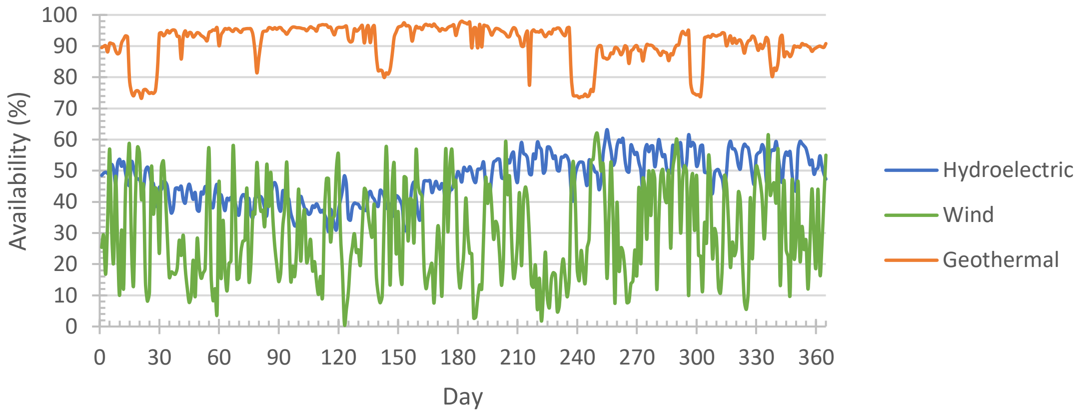

Figure 1 Average Daily Availability of Renewable Generation in 2012

Technology	**Capital cost (NZD/kW)**	**Fixed O&M (NZD/kW)**	**Variable O&M (NZD/MWh)**	**Process efficiency (%)**	**Availability (%)**	**Lifetime (Years)**
Hydroelectric	4395.30	6.73	33.18	100	Variable	50
Onshore Wind	2601.90	54.83	21.30	100	Variable	20
Geothermal	5909.40	102.84	16.63	11.5	Variable	30
Thermal Coal	3924.90	60.92	10.04	38	95	30
Thermal Natural Gas	1177.47	21.14	12.52	35	95	30
Thermal Diesel	970.20	15.29	9.69	40	95	20
Cogeneration NG	1969.80	34.40	10.85	40	95	30
Cogeneration Wood	2822.40	38.15	10.85	24	50	30
Thermal Biogas	6468.00	29.40	76.63	40	50	30
Solar PV	5189.10	68.41	19.45	100	30	30

Table 2 Cost and technical data of electricity generation

3.2 Scenarios

Seven scenarios were simulated to measure the effects of EV uptake and charging strategies, transportation mode shift, transport reduction and grid composition on the performance of the power system, carbon emissions and electricity generation costs, listed in Table 3.

Four scenarios (**EV2, EV40, MT40** & **AC40**) are based on a retro-analysis exploring different levels of EV technology uptake (**EV2 and EV40**), modal shift to bus transportation (**MT40**), and adaptation of transport behavior (**AC40**). The retro approach imposes these changes, with confirmed resources, to investigate their impact without speculating on future demand or availability. The base year was 2012, as it was the most recent year where both transportation and energy datasets were available. Each of these scenarios maintain both light vehicle fleet VKT's at 2012 levels and the grid resources at 2012 composition, including that years' confirmed seasonal availability of renewable technologies (Wind, Geothermal and Hydro), Figure 1. The costs and benefits of EV's will be closely tied by future grid composition. Consequently, two additional scenarios are simulated (**MR** & **MR-EV40**) which impose the “mixed-renewables scenario” grid composition outlined in the 2016 MBIE report: "Electricity Demand and Generation Scenarios (EDGS)”. According to this plan, it is expected that over 3 GW of installed capacity will be added between 2012 and 2040, as shown in Figure 2.

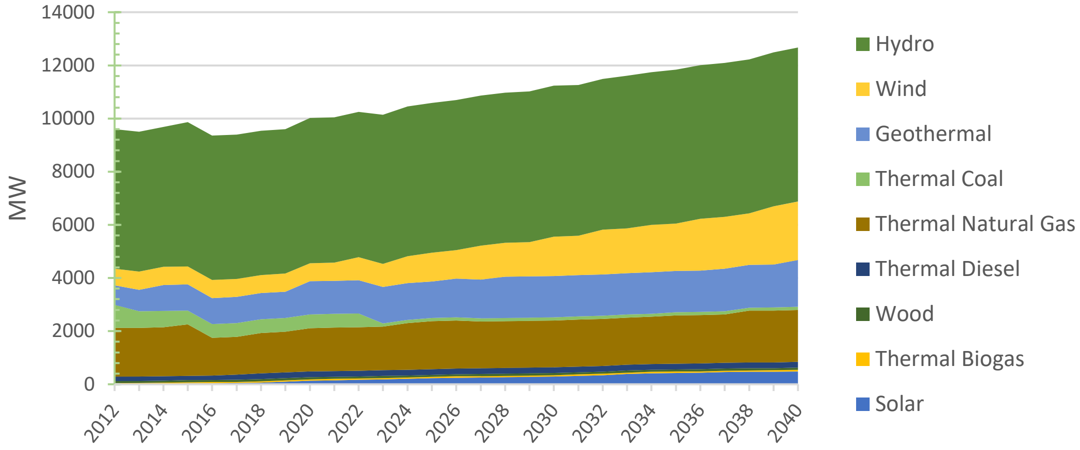

Figure 2 Change in Electricity Capacity, EDGS Mixed Renewables Scenario (Ministry of Business Innovation and Employment 2016)

Two Levels of ICE to EV replacement were considered, 2.3% and 40%, in-line with NZ government targets and projections (**EV2** & **EV40**). The NZ government targets 64,000 additional EV’s by 2021 (2.3% of light vehicle fleet) and the Ministry of transport projects a 40% replacement of ICE vehicles by 2040 (Ministry of Transport 2017b). For analysis, the EV’s are considered to be Nissan Leafs (Nissan 2018). The charging load is calculated given the Nissan leaf’s energy consumption (150 Wh/km), a round trip charging efficiency (ratio of amount of energy put in to amount of energy retrieved from storage) of 80% (Homer Energy 2018), an average daily travelled distance of 33.6 kilometers and an average vehicle occupancy of 1.58 (Ministry of Transport 2018b). As the operation of the power system changes with time, two charging strategies (**8h** & **3h**) are considered. The first charging strategy distributes the charging load of the whole EV fleet over eight off-peak hours (11pm – 7am). The second distributes the charging load over three off-peak hours (11pm-2am). Both scenarios are somewhat optimistic as they do not align with residential or commercial peak power times, however it is likely that many vehicles will be charged overnight so we view this as a reasonable assumption to test the performance of the grid. As faster EV charging becomes available, the aggregate peak load and instantaneous peak loads may increase and could have significant effects on the performance of the power system.

The adoption of EV’s will require significant investments, for both the vehicles and infrastructure. The benefits of EV’s should be put in the context of other means to reduce transportation energy and the associated emissions. To do this a transportation mode shift (**MT40**), a 40% shift of private transportation PKM’s to buses, and transportation reduction (**AC40**), a 40% reduction in PKM’s due to changes in behavior, were simulated. The buses are modelled as ICE vehicles, while electric mass-transit systems could be used the ICE buses are proven technologies with little associated infrastructure costs and serve well to benchmark the benefits of EV’s. Adaptive Capacity is used to justify the transportation demand reduction scenario. It captures the latent potential for the adoption of less energy intense means of transportation by changes in behavior, without changes in infrastructure. It has been proposed as a metric to assess maximum car travel demand reduction without reducing participation in essential activities (Krumdieck 2011). Watcharasukarn, Page and Krumdieck (2012) assessed the current adaptive capacity of commuters using Christchurch as a case of study and they estimated that the passenger activity, associated to car trips from general staff workers, could be reduced by approximately 40%. The respondents in their study reduced their fuel use through changes in destinations (e.g. shopping at local shops), changing transport mode, chaining trips, and using active means of transport (e.g. walking, cycling) (Watcharasukarn, Page & Krumdieck 2012).

Scenario	Designation	Description	Grid	Vehicles	Charging
Base	BASE	2012 Base year	2012 base	-	-
2.3% EV	EV2-8h	64k EV shift	2012 base	2.3% EV	8 hours
	EV2-3h				3 hours
40% EV	EV40-8h	40% EV shift	2012 base	40% EV	8 hours
	EV40-3h				3 hours
40% MT	MT40	40% PKM shift from ICE vehicles to bus transportation	2012 base	40% PKM shift to MT	-
40% AC	AC40	40% reduction of PKM's due to adaptive capacity	2012 base	40% PKM reduction	-
MR-40% EV	MR-EV40-8h	40% EV shift with grid modified to the 2040 mixed renewable strategy	2040 mixed renewables	40% EV	8 hours
	MR-EV40-3h				3 hours
MR-ICE	MR	Grid modified to the 2040 mixed renewable strategy without added EV's	2040 mixed renewables	-	-

Table 3 Summary of retro-analysis scenarios to be analyzed

4 Results and Discussion

Table 4 provides a summary of the total effect of the different scenarios from the Retro Analysis. Including different EV target levels, charging behaviour, transportation modal shifts, adaptive capacity and electricity generation composition. The next sections provide detailed observations regarding key results.

Scenario Designation	Reserve Margin (%)	Peak Power (MW)	% from BASE	Energy Demand (PJ)	% from BASE	GHG Emissions (MT CO_{2e})	% from BASE
BASE	-2.3	6,696	-	540	-	33.02	-
EV2-8h	-2.5	6,710	0.2%	539	-0.3%	32.98	-0.1%
EV2-3h	-2.5	6,710	0.2%	539	-0.3%	32.98	-0.1%
EV40-8h	-7.0	7,030	5.0%	510	-5.6%	31.97	-3.2%
EV40-3h	-13.6	7,573	13.1%	510	-5.6%	31.97	-3.2%
MT40	-2.3	6,696	-	516	-4.5%	31.35	-5.1%
AC40	-2.3	6,696	-	501	-7.4%	30.18	-8.6%
MR-EV40-8h	13.2	7,030	5.0%	510	-5.6%	22.36	-32.3%
MR-EV40-3h	5.1	7,573	13.1%	510	-5.6%	22.36	-32.3%
MR	18.8	6,696	-	540	-	24.73	-25.1%

Table 4 Retro Analysis Results: Reserve Margin, Annual Peak Power Demand, Annual Energy Demand, Annual Direct and Indirect GHG Emissions

4.1 Reserve Margin and Peak Power Requirements

Reserve margin is the excess generation capacity at the peak power demand, and is expressed as a percentage of system capacity. Many scenarios, including the base year (-2.3%), have a negative reserve margin, demonstrating that the power system is already stressed. This is currently dealt with by load shedding, where electricity users agree to shut down operations. The 2021 target, a 2.3% shift to EV's, has minimal impact on the reserve margin (-2.5%, a 0.2% decrease from the baseline). Suggesting this level of EV's will be well tolerated given the current grid resources. The 2040 target, a 40% shift to EV's, has a significant impact of reserve margin, in the 8 hours charging case it drops the reserve margin to -7%. In addition, the reserve margin is highly sensitive to the charging strategy. Under the critical charging strategy (3 hours), the reserve margin drops to -13.6%. This highlights significant challenge EV charging timing may present to the grid. Further, as capacity is added to the grid, the reserve margin sensitivity increases, with an 8.1% difference in reserve margin between the two charging scenarios (MR-EV40-8h & MR-EV40-3h). This reflects the challenges of a higher share of intermittent generation such as wind power, which increases 142% under the proposed "mixed renewables" grid. With the added generation capacity, a 40% shift to EV's results in a reserve margin or 5.1% for the worst-case scenario, the critical charging strategy. Showing the 40% addition may be well handled with the proposed modifications to the grid. However, the peak loading requires a large addition of capacity to manage, meaning a significant infrastructure cost.

Grid operators and government entities appear to have a high level of confidence on the future prominence of distributed generation, demand response and storage to manage the demand volatility. It has been claimed that smart grid technology encompasses some of these expected advantages. In contrast to existing electrical grids, they are based on a digital structure that enhances the integration of additional renewable capacity, EV's and distributed generation (Bayindir et al. 2016). Nevertheless, at present, smart grids cannot offer this level of flexibility and there are still critical economical and technical barriers to overcome. On the technical side, there are several research challenges implied by the dependence of the intelligent grid on information and communication infrastructure. There are also concerns on the design, deployment and maintenance of smart meters; conduction losses, high temperatures in components, harmonic injections and failure diagnosis. These are key problems in power electronic interfaces (Colak et al. 2016). From a power system perspective, a higher penetration of renewable technologies will imply dealing with a system whose behavior will be quite different from the behavior from current centralized arrangements. Renewable generation technologies lack the ability to deliver the required inertia that is enhanced by rotating masses from synchronous generators, meaning that, it will be challenging for the new system configuration to provide immediate frequency responses to inequalities in the overall power balance (Tielens & Van Hertem 2016). Aside technical issues, the implementation of smart grid technology will need the support of effective economic and regulatory mechanisms to establish the level of grid ownership on a distributed context and control pricing schemes that account for capacity and energy costs (Poudineh & Jamasb 2014). There is an inherent risk in the energy outlook for New Zealand as it heavily leveraged on the success of yet to be proven technologies.

4.2 Energy Demand and GHG Emissions

According to our results, GHG emissions from the energy sector accounted for a total of 33 million tonnes of CO2e in the BASE scenario, which fits the 31.5 million tonnes of CO2e reported under the New Zealand's Greenhouse Gas Inventory (Ministry for the Environment 2018). For total energy demand, there is only a 0.4% relative difference between the BASE scenario and the 542 PJ reported in the National Energy Balances (Ministry of Business Innovation and Employment 2015).

The 40% shift of EV's without modifications to the grid reduces carbon emissions by 3.2%, the charging strategy makes little difference to the emissions. With modifications to the grid (i.e. added renewable generation and partial removal of thermal power plants) this reduction increases to a substantial 32.3% reduction. However, the modifications to the grid alone provide a 25.1% reduction, and so in this best case scenario, the 40% shift to EV's are only responsible for a 7.2% decrease in emissions. This shows that the efficacy of EV's for emission reductions are highly dependent on the added capacity and that modifications to the grid are far more effective at driving down emissions than the significant shift to EV's, a large extend of the reductions coming from the residential and commercial sectors, as shown in Figure 3. Figure 3 also illustrates that the transportation sector remains highly carbon intense even with the addition of EV's. This analysis did not take into account the large embedded energy of EV's and their batteries. The IVL Swedish Environmental Research

Institute has published a report of the greenhouse gas emissions from lithium-ion batteries and found that 150-200 kg Co_{2e} per kWh are required in the current manufacture of these batteries (Romare & Dahllof 2017). For a 40% ICE to EV replacement in New Zealand, considering a 10 year battery replacement and current battery options for the Nissan Leaf, between 0.37 and 0.61 million tonnes of CO_{2e} would be produced in maintaining the batteries for the EV fleet. This is equivalent to 1.1% and 1.8% of total annual emissions, a significant figure compared to the CO2 reductions reported in Table 4. It should be noted that the combination of the grid modification and the shift to EV's (a 32.3% reduction of total emissions from 2012 levels), represents only 7% reduction of energy related emissions from 1990 levels (Ministry for the Environment 2018).

Other strategies considered (MT40 and AC40), reduced emissions 5.1% and 8.6% respectively, without increasing peak demand and requiring intensive modifications to the grid. This highlights that these strategies should not be overlooked as they do not have a strong dependence on the electrical power infrastructure and avoid significant expenses associated with EV's (EV's, batteries and charging infrastructure). For the vehicles alone, assuming the current price of a commercial EV (approximately 25,000 USD) and a discount rate of 5%, the replacement of 40% of the light passenger fleet would represent annual disbursements of 2.7 billion USD from 2012 until 2040.

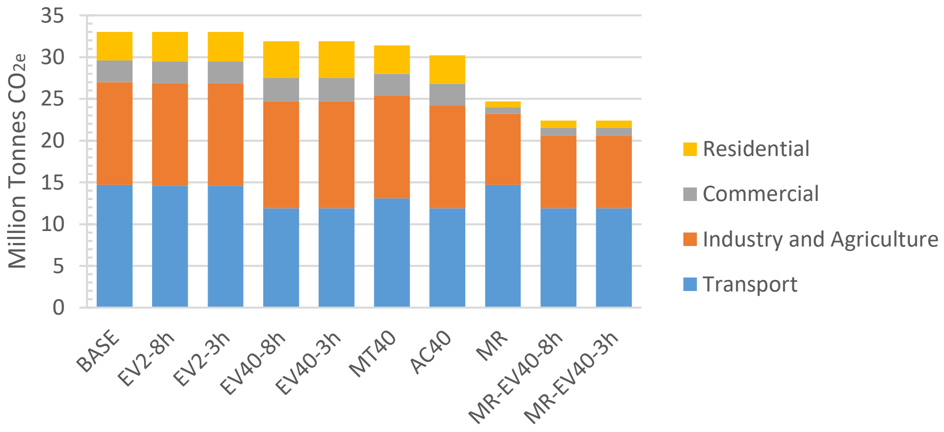

Figure 3 Annual Direct and Indirect GHG Emissions disaggregated by sector

4.3 System Costs

Figure 4 shows the transformation and resource costs. Transformation include maintenance and capital related costs whereas resources include petrol and diesel costs from the transport sector and natural gas to run thermal power plants. Results from different scenarios show an evident tradeoff between capital for investment in renewable energy technologies and fuel required to run thermal power plants. The analysis is based on 2012 fuel costs so the differences will be highly sensitive to future changes in oil price. The costs for the base scenario appear relatively higher to other scenarios. This observation can be interpreted as the cost of not taking future interventions. The MR scenario appears as the most costly given the substantial investment needed for wind generation. There is an observable tradeoff between the costs of building new infrastructure to run EVs with renewable electricity and the costs to keep running cars on oil derivatives. Policy initiatives that account for an optimal balance between technological interventions and commuter behavior are essential, specially when electric public transport may better serve the population.

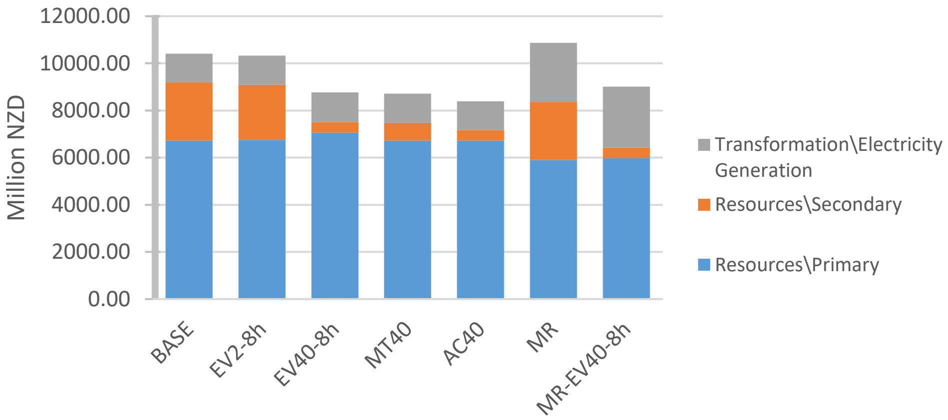

Figure 4 Annual Electricity System costs

5 Conclusions

This model analyzes the impact of EV's and EV policy on New Zealand's power system. The 2021 policy target, a 64,000 vehicle shift to EV's appears to have minimal impact on the power system and should be well tolerated, however it does add a burden to an already stressed power system. A 40% shift to EV's, without modifications to the Grid, significantly increases peak power demand and drives the reserve margin down to between -7% and -13.6%, which may cause significant problems to the functionality of the power-system. The shift also has minimal impact on carbon emissions (-3.2%). With grid modifications, the risk to the power system of the added EV's is reduced (reserve margin >5.1%) and the combination gives a significant reduction of carbon emissions (-32.3% total emissions), although the majority of this reduction comes from added renewable generation capacity. Mass transportation and adaptive capacity are promising pathways that should be explored. They provide significant reductions in carbon emissions (5.1% and 8.6% respectively) without the expenses and technological barriers associated with EV's and added grid capacity.

Currently LEAP lacks storage modeling capabilities, which forced us to disregard the assessment of a decentralized system made up by EV batteries or pumped hydro storage as potential tactics to resolve the intermittency problem. LEAP has the capability to use optimization to calculate a least cost capacity expansion. It was our desire to deliver an optimal expansion plan and contrast it against the one proposed by the MBIE. In our model, the uptake of EV's was reflected by the increase in electricity demand from the residential sector; therefore, we had to define load shapes for each demand device (i.e. fuel technologies within every sector). This feature proved to be a limitation as the software only allows executing optimization given a load shape for the entire system. Additionally, the precision of the results is sensible to the resolution of the time slices. In our case, we were particularly interested in peak power requirements and reserve margin, so we defined an additional time slice to reflect the year's peak hour event. Nevertheless, the calculated emissions might be slightly underestimated for days with high power requirements (i.e. winter days) as the time slices correspond to daily averages of energy demand and power plant availability. Our retrofit approach does not extrapolate future economic activity or population growth. However, this is not a software limitation, and this analysis is possible since additional assumptions can be added to the analysis.

In this paper, we assumed that a power plant's availability was defined by reported historical performance. Nonetheless, it is important to acknowledge that the power dispatched by the system also depends on economic and technical matters. From the perspective of the generators, it would be desirable to dispatch power when the unitary price of energy is higher. Also, power plants may experience temporal pauses due to planned or unplanned maintenance. The real resource availability may be higher than the one used in the model.

Future research should explore the costs associated with added grid and EV charging infrastructure, so the full costs of these policy decisions may be evaluated. There are ongoing efforts to support electric mass transport systems in New Zealand, for instance, the extension of rail electrification to Pukehoke is considered as a priority investment under the Auckland Transport Alignment Project. Similar initiatives should be investigated to give perspective to the costs of an EV based mass transportation system. Strategies involving multiple pathways (EV's, electric rail etc.) should be combined and analyzed to explore what multi-pronged solutions have the best fit for NZ. One key issue that should be addressed are the risks associated with a large share of highly variable generation (wind), as is proposed. Particularly the capacity to handle over-generation and rapid swings in supply, along with an unknown volatile power demand from EV charging. Additionally, wind generation does not reliably help to mitigate peak power demands.

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