THE UNIVERSITY OF NEW SOUTH WALES
SCHOOL OF PHOTOVOLTAIC AND RENEWABLE ENERGY ENGINEERING

Renewable Energy Powered Electric Transport Options for Rarotonga, Cook Islands

A feasibility study on electric vehicle and electric bike and an overview of the technologies

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Abstract

Rarotonga is completely dependent on import fuels for transport and the majority of the electricity generation on the island is using large diesel plants. The resulted problem is fuel supply risks and price fluctuations for the transport and electricity sector. The aim of the study is to investigate the potentials of using electric vehicles (EVs) and electric bikes (E-Bikes) as the main forms of transport option on Rarotonga in order to reduce the reliance on import fuels. It is also important to identify the cost effectiveness of using solar energy to power the electric transport options due to the current high electricity prices on the island. The methodology includes finding suitable electric transport technologies to be used on the island, collect relevant data and perform feasibility studies. The results would be analysed and one of the key findings is that the use of a 2kW household solar system is extremely affordable due to the current grid incentive policy on Rarotonga, which avoids individuals to spent additional investment cost on battery storage. Nevertheless the electric vehicle is not a feasible transport option without the grid incentive policy. In addition, they are commonly charged during night time which increases the load of the diesel power plants on Rarotonga and result in higher diesel use. On the other hand, the electric bike is found to be the most attractive transport option due to its relatively low capital cost and a minimum impact on the current electricity network.

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1 Introduction

The Cook Islands is a group of 15 small islands in the South Pacific Ocean, to the North East of New Zealand (See Figure 1.1). It has a small population of around 12000 and most people live on the capital island Rarotonga. The electricity on the island is produced using large diesel generators and the transport is completely dependent on imported fuels. Due to the geographic isolation of the Cook Islands, it is exposed to high fuel costs and supply risks. Moreover, tourism is their main industry and the use of fossil fuels can damage the natural environment and the economy. As a result, the aim of this study is to access the potentials of using renewable energy powered electric vehicle (EV) and electric bike (E-Bike) as the main forms of transport options in Rarotonga, aiming to reduce the dependence on imported fuels.

Figure 1.1: World Atlas for the Cook Islands (Worldatlas, n.d.)

The project will start from investigating the transport and electricity sector on Rarotonga and an overview of the electric transport technologies. The model of electric vehicle (EV) and electric bike (E-Bike) that is suitable to be used on Rarotonga would be selected and compared against the conventional transport options through feasibility studies. As the main objective of the study is to reduce the reliance on import fuels, a solar system would be designed to power the electric vehicle (EV) and the electric bike (E-Bike). The results from different transport options would be discussed and analysed and the most feasible transport option will be proposed in the end.

2 Background

2.1 Transport Sector in Rarotonga

The main forms of transport for the local residents on Rarotonga are motorbikes, followed by motor vehicles (H. Duo, pers. comm., 26 Aug. 2015). For tourists, they have the options to use taxi, island buses, as well as rental services for bicycles, motorbikes and motor vehicles as transport options (Jarvy Web, 2015).

The Cook Islands is heavily dependent on imported fuels for transport. In 2009, around 12.7 million litres of diesel, 4.2 million litres of petrol and 9.7 million litres of kerosene were imported into the country, with a total cost of $US 57.8 million (reegle, 2012). The usage pattern shows that 43% of the total imported fuel is used by transport, 30% by aviation and 27% by electricity (MFEM 2011). The diesels are mostly used for electricity generation while kerosene and petrol are used for transport and aviation. The large proportion of the transport sector in the consumption of imported fuels shows the benefits of using EVs and E-Bikes as the main forms of transport on Rarotonga.

2.1.1 Electric Vehicle

An EV is a motor vehicle that uses rechargeable batteries as the main fuel source to power the electric motor instead of using petrol. The main benefits of the EVs in comparison to conventional vehicles are listed below:

1. The electricity used for charging the EV can be sourced from renewable energy.
2. Environmental friendly and reduces import fuels.
3. No engine noise and fewer moving parts to service.
4. Longer vehicle life in an island environment as EV does not require intake of air for engine combustion. The intake of salty air can damage the inner parts of the vehicle.

The two main types of EV include the plug-in hybrid-electric vehicle (PHEV) which uses both battery and petrol as the power source, and battery-electric vehicle (EV) that use battery only. The study will focus mainly on EVs instead of PHEVs as it allows the transport sector to transform to 100% renewable in the long term.

In recent years more and more EV models are becoming available and each of them has a different maximum distance that they can travel before recharging. The main factors that affect the maximum travel distance include the battery size, driving style and road conditions. EVs can be charged at home by installing a special charging station or using public charging stations. Currently the capital costs of EVs are still expensive. However, they are expected to become more affordable as battery technology improves and having mass production of EVs.

The required battery charging time for the EV from empty to full charge is depended on the battery size and the maximum power of the charging equipment. The different types of charging equipment include a standard general power outlet, a specially designed home charging station or quick charging stations on the road. A comparison of charge times based on a 23kWh battery charging using different equipment are shown in the table below (chargepoint, n.d.).

Table 2.1: Comparison of battery charge times with different charging equipment

	General Power Outlet	Home Charging Station	Quick Charging Station
Voltage	240V	240V	440V
Power (Max)	2.4kW	3.6kW	44kW
Approximate Time	10 hours	6 hours	30 minutes

2.1.2 Electric Bike

An E-bike is similar to a regular bicycle with an electric motor. It has a battery and a control panel that is used to turn on the E-bike function, monitor the battery level and control power levels. The rider can either pedal the bike or utilise the power from the battery which makes riding easier and allow the rider to travel a longer distance. The benefits of E-Bikes are similar to EVs as discussed above, environmental friendly and reduces the reliance on import fuels. But in addition, the user can still use the E-Bike when the battery has run out, and their capital cost and maintenance cost are a lot lower in comparison to EVs.

The developments of E-bikes have a long history. The first generation uses the throttle mode, which is similar to the operation of a motorcycle where the motor provides power and propels the bike forward. It does not require the user to pedal the bike.

The second generation uses the pedal assist mode. The motor will be activated upon pedalling the bike. The design includes a magnet being attached to the pedals and a cadence sensor that pick up the movement of magnet. The level of assistance from the motor is proportional to the speed of the cadence sensor. However, this technology has its limitations. As you ride uphill and pedalling slows down, the cadence sensor tells the motor to give less power, which is opposite of what you need.

The third generation torque sensor helps to resolve this problem by measuring how hard you are pressuring on the pedals, and the motor power increases if the pressure is high. The combination of a torque sensor and a cadence sensor allows the motor controller to fully understand how the bicycle is riding, which result in smooth performances (The New Wheel, 2015).

The range of the E-Bike is heavily depended on how much pedal assist you apply and the battery can be recharged with a standard wall socket at home or at work. The charging time is based on the battery size and the type of charger. The most common types of batteries are lead acid, nickel metal hydride or lithium ion batteries. Lead acid batteries have the lowest price and the lithium ion battery is about twenty times more expensive (INSG, 2014). However, lithium ion batteries have a longer life span and the cost is expected to decrease as battery production increases.

2.2 Electricity Sector in Rarotonga

The section above discussed the electric transport options which have the potential to reduce the reliance of import fuels. However, the electricity used to charge the battery need to be sourced from renewable energy generations. Otherwise the electric transport options would act as additional loads to the electricity network. Thus it is necessary to investigate the progress of renewable energy in electricity sector.

2.2.1 Supply of Electricity

The electricity supply on Rarotonga is mainly the responsibility of the government owned utility Te Aponga Uira (TAU). Their roles include the generation, distribution and retailing of electricity. The power utility provides about 90% of the Cook Islands electricity demand (TAU, 2015).

On Rarotonga, nine large diesel generators with a nameplate capacity of 12.3MW are used to produce electricity on the island. Due to the aging and ongoing de-rating of the engines, the actual available capacity is 9.5MW in 2012 (See Table 2.2). The estimated end of life shows that approximately 62% of the generators need to be replaced between 2017 and 2020.

Table 2.2: Generator capacity on Rarotonga (Government of the Cook Islands, 2012)

GENERATOR	BRAND/Type	RATED (kW)	DE-RATED (kW)	ESTIMATED END OF LIFE
1	Duvant Crepelle/12V26N	2000	1500	2020
2	Duvant Crepelle/12V26N	2000	1500	2020
3	Mirrlees Blackstone/MB275-8	1600	1200	2019
4	Lister Blackstone/ETSL	600	400	2000
5	Lister Blackstone/ETSL	600	400	2000
6	Mirrlees Blackstone/ESL 16 Twin bank	1200	900	2010
7	MAN B and W/L9-27/38	2700	2000	2036
8	Cummins/KTA50-G3 (temporary installation)	800	800	2017
9	Cummins/KTA50-G3 (temporary installation)	800	800	2017
TOTAL		12300	9500	

2.2.2 Demand of Electricity

In 2012, the electricity demand profile for the Cook Islands showed that the two major end-use sectors are the residential and commercial sectors (See Figure 2.1). The day time peak loads are mainly air-conditioning and lighting for commercial end-users. Another peak load is during the evening due to residential sector activities such as lighting and cooking. The annual electricity demand is approximately 28.8GWh on Rarotonga (Government of the Cook Islands, 2012).

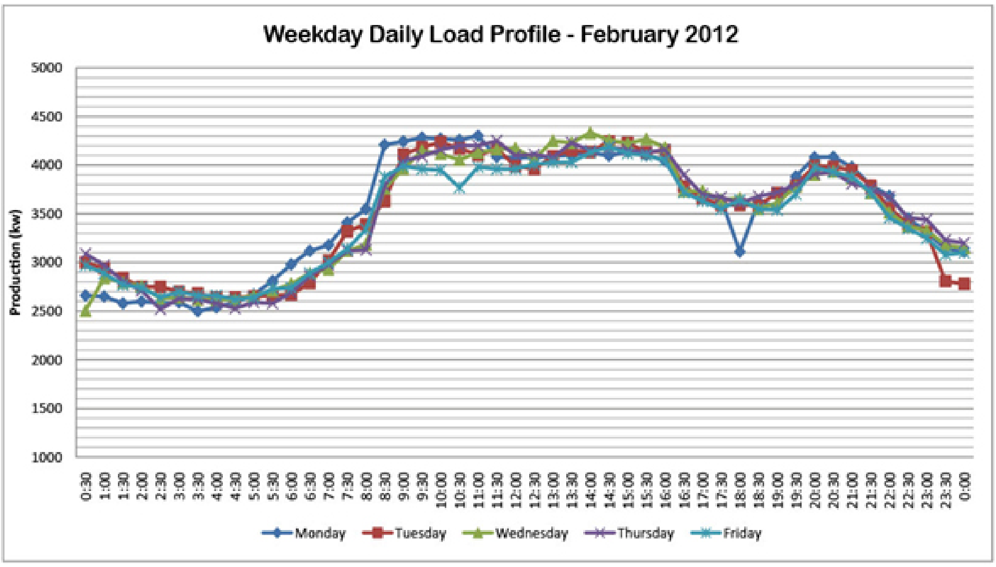


Figure 2.1: Weekday load profiles for Cook Islands (PEEP2, 2015)

2.2.3 Retail of Electricity

The electricity tariff on Rarotonga is shown in the table 2.3. It can be seen that the domestic electricity tariff is extremely high for energy usages above 300kWh per month, at a rate of $84c/kWh.

Table 2.3: Electricity Tariff from TAU in 2011 (PEEP2, 2015)

Domestic	Rate	Commercial	Rate	Demand	Rate per	Dual Tariff	Rate
First 60 kWh/Month	@ 57c	All	@ 81c	kWh used	@ 72c	First 60 kWh/Month	@ 57c
61 to 300 kWh/Month	@ 80c			Peak/kW	$30.00	61 to 240 kWh/Month	@ 80c
Balance	@ 84c			Shoulder /kW	$26.00	Balance	@ 84c
		Service charge	$5.00	Service charge	$20.00	Service charge	$10.00

2.2.4 National Renewable Energy Programme

Due to the high electricity prices, the government of the Cook Islands decided to launch a National Renewable Energy Programme in 2010, which plans to transform the electricity sector to use 50% of renewable energy by 2015 and 100% by 2020 (MFEM, 2011).

2.2.5 Renewable Energy Options in Rarotonga

The government of the Cook Islands published a Renewable Energy Implementation Plan in 2012 and the table below summarise the main types of renewable energy options discussed in the plan.

Table 2.4: Renewable Energy Options in Rarotonga (Government of the Cook Islands, 2012)

Options of renewable energy	Description
Solar	Technically viable, cook island has abundant solar resource, relatively simple, highly scalable.
Wind	Technically viable. Higher risks of mechanical failure, requires proactive management for cyclonic winds, relatively greater maintenance, can be challenging to repair.
Hydro	High implementation costs
Pumped hydro	Requires extensive research on its feasibility and the potential site locations.
Battery storage	Technically viable, simple. Expensive, requires active management.
Biogas	Using green waste and agricultural waste (appropriate waste disposal), fuel currently more expensive than diesel, require continuation of fuel supply infrastructure (e.g. manually collect manure from animals).

The implementation plan also includes a study on the levelised generation cost for different types of energy generation on Rarotonga (See Figure 2.2).

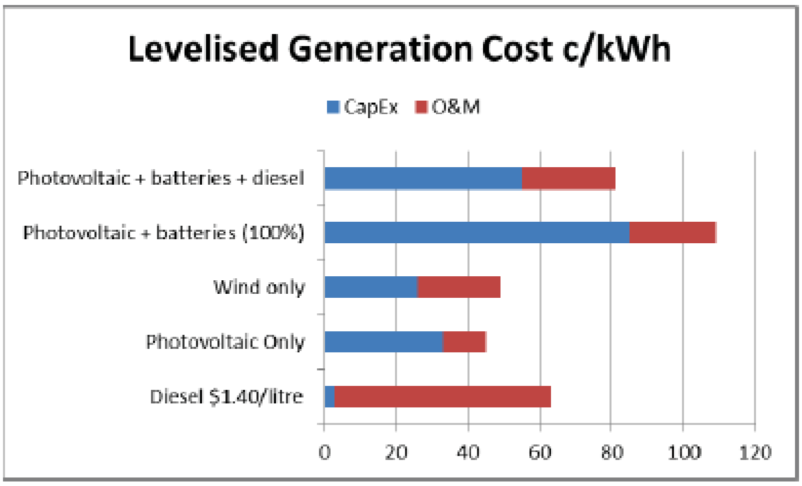


Figure 2.2: Levelised Generation Cost on Rarotonga (Government of the Cook Islands, 2012)

The results show that the least cost technologies are wind and solar energy. However, this is only true up to a certain level of renewable penetration into the grid, as wind and solar energy does not provide firm capacity and their power output fluctuates depending on the weather patterns. For example, cloud cover can cause a sudden drop in solar output, but there is a limitation on how quickly a diesel plant can increase its output to match the loss of renewable generation due to its mechanical constraints. The mismatch between electricity supply and demand would eventually leads to grid instability. As a result, variable renewable output cannot replace firm capacity generations totally without sufficient energy storages. Although there will be extra costs, it can ensure a more robust and reliable electrical network. This is extremely important as the network on Rarotonga is isolated and the failure of the grid would cause immediate blackout of the island.

The most effective way storage facility with the current technology is in the form of battery storage (Government of the Cook Islands, 2012). However, a combination of photovoltaic and battery requires significant scale up of the panels and batteries. As a result, the most viable option is the use of photovoltaic, battery and diesel back up as shown in Figure 2.2 above.

In 2012, the maximum level of renewable penetration to the network is determined to be 600kW (Government of the Cook Islands, 2012). Since then TAU has reinforce the grid to maintain the current standards of reliability and quality of supply while preparing for the uptake of renewable energy in the grid.

1. Transforming the mechanical controls of existing diesel power plant to automation controls
2. Installation of new modern fast acting diesel engines along with technologies such as flywheels which will provide temporary storage
3. More 11kV cables will be installed to provide a second ring main of HV cable network around the island to facilitate the integration of RE generators that may be remote from the existing network

However, even with all the upgrades, current studies suggest the maximum RE penetration level into the grid is limited to be 3.3MW, which achieves around 16% of energy production on Rarotonga (TAU, 2014).

Although battery storage can solve the problem of grid stability in the short term, given Rarotonga's environment they are not feasible over the long term. This is because large scale solar and battery development requires recycling of spent batteries at the end of their lifecycle. Alternatively, biogas plant and pumped hydro schemes can be used to provide the firm capacity and energy storage. The benefits of low operating cost in the long term can offset the initial capital cost over time.

Currently TAU is working on feasibility study of the establishment of a 500kW waste to energy plant on Rarotonga (TAU, 2015). They are also asking for bid and engaging expertise in pumped hydro schemes to visit Rarotonga for conducting a screening assessment of the pumped hydro potential of the island. The main tasks include a prefeasibility and technical study, and to identify potential pumped hydro sites on Rarotonga, the size of the plant and its benefit in terms of providing grid reliability and the growth of renewable energy (TAU, 2014). The success of these large scale storage projects could provide a stepping stone towards the integration of renewable energy in Rarotonga.

2.2.6 Implementation of Solar Energy on Rarotonga

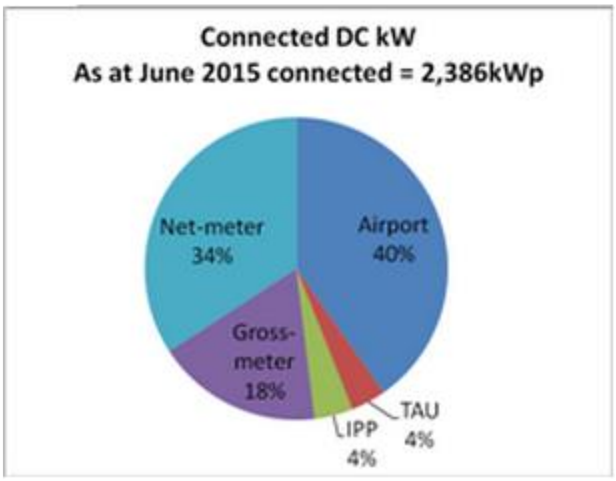


Figure 2.3: Solar energy on Rarotonga (TAU, 2015)

In June 2015, the total installed capacity of solar power on Rarotonga is about 2.4MW. This is approximately four times the level in 2013 and accounts for 10% of TAU's electricity generation (TAU, 2015). The rapid increase is due to several reasons below.

Firstly, TAU have been preparing for renewable energy integration into the network by upgrading modern generator controls at the Avatiu power station, which improved voltage and frequency management as well as response times to fluctuations in generation.

Secondly, TAU's Net-Metering Policy is attractive to the public as customers with solar may export up to 2kW of unused electricity into the grid and receive energy credit for it (TAU, 2015). The customers can then use this energy credit when the solar system is not producing energy at night. As a result, customers can use the grid as storage instead of spending additional cost on a battery system. It allows customers to remain connected to the TAU grid and generate a percentage of their energy using renewable sources. The energy credits will be accumulated for a period of up to 12 months and the consumer will lose any unsure credits afterwards. There will not be a direct payment to the consumer for any excess energy exported to the grid.

Thirdly, gross metering and independent power producers (IPP) were introduced from December 2013.Gross metering allow customers to sell all the electricity generated by a solar system of up to 21kW into the grid at a specific tariff rate (TAU,2015). They would then import energy from the grid using a separate meter. This policy allows customers to better quantify the investment returns of their solar system. For PV systems over 21kW they are considered as independent power producers.

Finally, a solar farm with installed capacity of 960kW was set up near the Rarotonga airport on October 2014 (TAU, 2015). The project costs $3.3 million with 3000 solar panels. It accounts for 40% of the solar installation on the island and it is expected to provide 5% of Rarotonga's total energy needs, reducing diesel consumption by approximately 400,000 litres a year.

3 Research Methodology

3.1 Comparison of Electric Vehicle with Conventional Vehicle

3.1.1 Electric Vehicle Nissan Leaf

The project will start from investigating the current electric vehicle (EV) technology options. The selection criteria of the vehicle is based on the feasibility and suitability to be used on Rarotonga. The island of Rarotonga is shown in figure 3.1 below and it has a circumference of 32km. The maximum distance that the EV can travel must be at least greater than this value.

Figure 3.1: The Rarotonga Island (Raising Explorers, 2014).

In addition, it would be preferable if the EV is available in New Zealand. This is because Cook Islands is dependent on New Zealand in terms of aids and exports (New Zealand Foreign Affairs and Trade, n.a.). To provide an example, New Zealand is a major donor in terms of funding solar projects to allow Cook Islands to achieve its 100% renewable energy target by 2020 (M. Dornan, J. Spratt, 2014).

The model selected for the EV is Nissan Leaf. This is mainly because it's the world's first mass produced electric vehicle at a relatively cheap price. In June 2015, it remained as the bestselling EV around the world with 180,000 units sold (RENAULT NISSAN, 2015). Nissan Leaf is a medium sized vehicle with five seats and a hatch back. It can provide a decent range of up to 175km on a full charge, which is more than five times the circumference of the island. Moreover, the model is available for sales in New Zealand.

3.1.2 Conventional Vehicle Toyota Corolla

For the conventional vehicle selection, it needs to have a similar size in comparison to the EV Nissan Leaf. Moreover, it is preferable to use a model that is currently available on

Rarotonga as it allows the comparison of whether EV is more feasible than the existing vehicle on the island.

The model selected for the conventional vehicle is Toyota Corolla Ascent Hatch, also a medium size vehicle with five seats and a hatchback. The model is available in one of the car rental companies AVIS on Rarotonga (AVIS Cook Island, 2013). The corolla model is also the bestselling car in New Zealand (N. Kloeten, 2015) and Australia in 2014 (M. Campbell, 2015). The popularity is mainly due to the fuel economy and reliability of the vehicle with a long life span. Hence it can be concluded that the two vehicles selected for comparison are similar in terms of size, popularity and most importantly its feasibility.

Figure 3.2: Nissan Leaf (Lotus Cars, 2015)

Figure 3.3: Toyota Corolla (Toyota, 2015)

3.1.3 Feasibility Study

A feasibility study would then be carried out to compare the lifecycle costs between the EV Nissan Leaf and Toyota Corolla. The net present value (NPV) is used to determine how profitable a project will be, or in this scenario how profitable it is to use the vehicle transport options (Finance Formulas, n.d.),

$$\mathrm{NPV} = \sum_{\mathrm{n=1}}^{\mathrm{life\ time}} \mathrm{cash\ flow} - \mathrm{investment\ cost}$$

The investment cost in the formula refers to the capital cost required to purchase the vehicle. The cash flow refers to the annual operation and maintenance (O&M) costs of using the vehicle, which include the maintenance cost and fuel cost. The replacement cost of the battery also needs to be considered for the EV as the battery has a limited lifespan.

The sigma notation in the formula refers to summing up all the annual expenditures on O&M (or cash flow) throughout the lifetime of the vehicle. However, it is noted that the money spent on O&M in the future is worth less than the same amount today. Firstly, this is because the money available today can be saved in the bank to generate interests. Secondly, monetary inflation causes the value of today's money to be less in the future. And lastly, there is an uncertainty or risk associated with receiving future cash flows. For example, the main reason of using EV as a transport option is due to a lower O&M cost in comparison to conventional vehicle, although it has a higher capital cost. If the EV is damaged in a road accident then it can no longer generate savings to offset the initial capital cost. Hence, the value of money in the future would worth less in today's value. As a result, discounting will be used to adjust all future cash flows ($\mathrm{F_n}$) to reflect the factors above using a discount rate (r) to a present day value (PV) using the formula below (Nyu, n.d.),

$$\mathrm{PV} = \mathrm{F_n} \times \frac{1}{(1+\mathrm{r})^{\mathrm{n}}}$$

The present worth factor (PWF) is used to represent the discounting process where,

$$\mathrm{PWF} = \frac{1}{(1+\mathrm{r})^{\mathrm{n}}}$$

Hence the NPV formula can be re-written as,

$$\mathrm{NPV} = \sum_{\mathrm{n=1}}^{\mathrm{life\ time}} \mathrm{F_n} \times \mathrm{PWF} - \mathrm{investment\ cost}$$

In 2009, AECOM in Australia performed a feasibility study for the comparison of using EVs instead of conventional vehicles used a discount rate of 7% (AECOM, 2009), thus the same discount rate will be assumed for this study.

3.1.4 Data collection

The scope of the data would prefer the most recent data available and forecasts over the lifetime of the vehicles such as the outlook of petrol price on Rarotonga. The data would be obtained from car sales companies, government websites etc. to ensure the reliability of the data. All the data will be converted to New Zealand dollar using the exchange rate in Appendix 1.1: Exchange Rates as it is the currency used on Rarotonga.

3.1.4.1 Capital Cost

The capital cost of the EV is obtained from Nissan car sales, with a cost of NZ$39,990 (NISSAN, 2015). It is assumed that a home charging station will be used for charging the EV in the analysis as there is currently no EV charging networks on Rarotonga and it allows charging to the baster. The installation cost is depended on the distance of the required electrical connection and the cost is estimated to be AU$600/NZ$652 by the Australian company Charge Point (chargepoint, n.d.).

The capital cost for the Toyota Corolla Ascent Hatch is obtained from Toyota car sales with a price of NZ$28198 (TOYOTA, 2015).

3.1.4.2 Maintenance Cost

The quotation for the maintenance cost of the EV Nissan Leaf is shown in Appendix 1.2: Nissan Leaf Maintenance Data Sheet. It is obtained from M. MacDonald, a sales consultant at Nissan Auckland Giltrap branch on 18 April 2015. The maintenance cost varies between NZ$94.8 and NZ$343.57 throughout the service life.

The scheduled maintenance for the Toyota Corolla Ascent Hatch is annually and the cost varies between NZ$300 and NZ$400, relatively higher than the EV model. The quotation is obtained from K. Chow, vehicle sales consultant at Toyota Auckland Albany branch on 18 April 2015.

3.1.4.3 Fuel Cost

In the June quarter of 2015, the petrol price on Cook Islands is at a record low of NZ$2.26/L (MFEM, 2015). Appendix 1.3: Petrol Price Outlook shows that the petrol price is constantly increasing at a rate of 4% per annum on average from 2010 to 2012. In addition the forecast of crude oil prices from both the IMF and World Bank shows an average increase of around 5% per annum respectively in the next 5 to 10 years. This is because the rapid growth of oil production in U.S. is expected to decline (World Bank, 2015). As a result, the study assumes the petrol price will increase at a constant rate of 4% per annum over the lifespan of the vehicles. Nevertheless, the future always has many uncertainties and the sensitivity analysis in section 4.1.5 will discuss about how to consider the scenarios where the actual petrol price is above or below the predicted price.

The electricity tariff on Rarotonga is shown in Table 2.3 in section 2.2.3. In terms of the prediction of future electricity price on Rarotonga, it is very uncertain due to the 100% Renewable Energy Target by 2020. Section 2.2.5 discussed the need of large scale storage facilities to integrate a high percentage of renewable energy into the grid, and it shows that the cost of a solar system with battery storage and diesel backup is more expensive than the cost of diesel generation. This suggests an increase in future electricity price. However, the current diesel fuel price is at a historical low point and it is extremely volatile to a rise in international fuel price, while there will be no impact to the cost of renewable generation. This suggests a decrease in future electricity prices. Due to the many uncertainties discussed above, the study would assume a constant electricity price over the lifespan of the vehicles.

3.1.4.4 Battery Cost

The replacement cost for the lithium ion battery is AU$5500 (NZ$5978), announced by Nissan on June 2014 (Green Car Reports, 2014). The warranty of the battery is 8 years and the battery life is projected to be at least 10 years, with around 60% to 70% of capacity left (hybridCARS, 2014). Appendix 1.4: Estimation of Nissan Leaf Battery Replacement Cost from 2015 to 2030 estimates that the battery cost in 2025 is approximately half the price in 2014, NZ$2989.

3.1.4.5 Average Daily Vehicle Kilometer Travelled (VKT)

The average daily vehicle kilometre travelled is the same as how many kilometres did the user drive per day on average? However, as these statistics are not available from Cook

Islands' government website. The circumference of Rarotonga is used as a reference instead, and it is unlikely for a local resident to travel more than a full circle around the island on average per day. The base scenario for the comparison of vehicle transports assumes an average VKT of 30km/day.

3.1.4.6 Average Vehicle Lifespan

The vehicle lifetime refers to how many kilometres the vehicle can travel over its life. It will be assumed based on the suggestion from Nissan and Toyota sales consultants. R. Young, at Toyota Auckland Albany branch, said in the email on 2 May 2015, that the Corolla Hatch with 200,000km is still a low maintenance and reliable form of transport.

In terms of the Nissan Leaf, vehicle consultant P. Hearne from Nissan Auckland, said that a distance of 100,000km is guaranteed for the Leaf and it is expected to travel a much longer distance. In addition, the EV is better suited for the island environment than conventional vehicles as they do not require the intake of air for engine combustion. It causes a problem for conventional vehicles as the air in an island environment is salty and it can reduce damage the inner component of the vehicle, thus reducing its average lifetime. As a result, this study would assume an average lifespan of 200,000km for both vehicles. For a VKT of 30km/day, the lifespan is equivalent to 18 years.

3.1.4.7 Data Summary

Table 3.1: The specifications of Nissan Leaf and Toyota Corolla

Model	Nissan Leaf	Toyota Corolla Ascent Hatch
Type of engine	Electric	Petrol
Seats	5	5
Torque/ motor power	280Nm/80kW	173Nm /103kW
Capital cost	NZ$39990	NZ$28198
Fuel cost	NZ$0.84/kWh	NZ$2.26/L
Fuel consumption	0.173kWh/km	0.061 L/km
Fuel cost per km	NZ$0.1453/km	NZ$0.1379/km
Average lifespan of vehicle	Assume 200000 (18 years)	Assume 200000 (18 years)

3.2 Comparison of Electric Bike with Motor Scooter

3.2.1 Electric Bike Easy Motion

In 2013, 40 million electric bike (E-Bikes) were sold worldwide and 85% of the sales were made in China, which suggests its dominance in the global market. China is also the largest manufacturers of E-Bikes and 83.2% of all imported E-Bikes to European are originated from China (INSG, 2014). However, although their E-Bikes from are very cheap and competitive, it is very difficult to find a model with a similar capability in comparison to the motor bike. As a result, the more expensive E-Bikes with higher qualities are being investigated from the U.S. market. The selection criteria is based a relatively high load capacities, long lifespan of the bike as well as high maximum speed and long bike range.

The model selected for the E-Bike is the Easy Motion 2016 Evo Nitro City. The E-Bike has two seats and a relatively high maximum load capacity of 300lb (136kg) in comparison to 100kg for the other E-Bikes. The bike frame also has a longer warranty of 5 years in comparison to about 2 and 3 years with other models. The motor power is 500W with a maximum speed of 45km/hour and the maximum distance the E-Bike can travel is 80km before recharging the battery. These specifications are sufficient as the speed limit in Rarotonga is 50km/hour and the circumference is only 32km (Cook Islands Travel Guide, 2015).

3.2.2 Motor Scooter Yamaha Cygnus

In order to achieve a fairer comparison with the E-Bike, a motor scooter would be selected instead of a motorcycle as the specifications are closer, for example a lower capital cost. The scooter model YAMAHA NXC125 CYGNUS as it is an available model from the Polynesia Rental Cars on Rarotonga (Polynesian Rental Cars, 2015).

Figure 3.4 Easy Motion 2016 Evo Nitro City
(Greenpath Electric Bikes, 2015)

Figure 3.5 Yamaha Cygnus
(Polynesian Rental Cars, 2015)

3.2.3 Feasibility Study

$$\text{NPV} = \sum_{n=1}^{\text{life time}} \text{cash flow} - \text{investment cost}$$

Similarly, the NPV formula is also used to determine the feasibility of E-Bike Easy Motion and the Yamaha Scooter, where the capital cost required to purchase the bike and the cash flow refers to the annual operation and maintenance (O&M) costs of using the bike transports.

3.2.4 Data Collection

3.2.4.1 Capital Cost

The capital cost of the Easy Motion E-Bike is NZ$6284/US$4399 (Greenpath Electric Bikes, 2015). However, it was unable to obtain the data for the scooter from the Yahama branches as it is an old model and only second hand prices are available. Nevertheless, an online car sales website shows that a brand new Yamaha Cygnus 125 has a cost of NZ$4345/AU$3999 (RedBook, 2015).

3.2.4.2 Maintenance Cost

Ephraem, E-bike sales consultant at Leitner eBikes in Australia, said in the email on 29 September 2015 that the maintenance for the E-Bike is the same as a regular bike, which include changing tyres, lubricate chains and adjusting brakes and gears. The electric parts do not require any maintenance and bike shops charge about AU$60 for a bicycle service. In addition, an online article from the Forbes states that the average maintenance cost of a bike is about US$100/NZ$143 per year (J.D. Roth, 2011).

On the other hand, the maintenance data for the Yamaha scooter is also unable to be obtained from the sales consultants. As a result, a more generalised maintenance cost for the scooter with the same engine size of 125cc as the selected Yamaha model would be used from other sources. A scooter sales website listed the major maintenance costs as below, changing new tyres every 10000km for NZ$109/AU$100, replacing drive belts every 15000km for NZ$196/AU$180 and brake pads every 12000km for NZ$109/AU$100. In addition, the scooter requires changing the oil every 4000km for NZ$54/AU$50 (ScooterSales, 2013).

3.2.4.3 Fuel Cost

The battery capacity of the E-Bike is 480Wh with a range up to 80km (50miles), thus the fuel consumption is calculated to be 0.006kWh/km. The fuel tank capacity of the yamaha Scooter is 7.1L with a fuel consumption of 3L/100km (The Scooter Review, 2008). It has a range of 236km. The assumption of future petrol prices and electricity prices used would be same as those in the vehicle comparison.

3.2.4.4 Battery Cost

D. Victor, sales consultant at Green Path Electric Bicycle in New York, said in the email on 20 October 2015, that the average lifetime for the E-bike Samsung Lithium Battery is approximately 5 years, with a cost of NZ$929/US$650.

3.2.4.5 Average Daily Vehicle Kilometer Travelled (VKT)

The study assumed that the average daily VKT is assumed to be 20km/day, which is lower than the value used in the EV scenario.

3.2.4.6 Average Bike Life

Brett, sales consultant from 99 Bikes Bondi Junction Sydney said in the email on 19 October, that it is hard to estimate the life of a bicycle as it is depended on the quality of the bike. Some good quality ones last 20 years, but some others fall apart in 2-3 years. The drive train of the selected model Easy Motion Evo Nitro City is manufactured by a reputable brand Shimano and the bike frame has a warranty of 5 years. Thus is can ensure its high quality standards and achieving a longer lifespan for the bike.

Murray, sales consultant at Yamaha Sydney, said that the lifetime of the scooter depends on how it has been maintained. An abused and not serviced scooter could be worn out at 10,000km and a regular serviced scooter can extend its life to about 100,000km. In addition, pass experience of the motorcyclist shows that a 125cc 4stroke YAMAHA engine has a lifespan of approximately 50,000 miles/80,000km without major problems (Motorized Bicycle Forum). The conservative value of 80,000 km will be used in the study because the scooter would have a similar problem in an island environment, where the intake of salt air can damage the inner components of the bike. The study assumes that the E-Bike also have an average lifespan of 80,000, which is equivalent to a lifespan of 11 years.

3.2.4.7 Data Summary

Table 3.2: The specifications of Easy Motion and Yamaha Cygnus

Model	Easy Motion 2016 Evo Nitro City	Yamaha Cygnus 125
Type of motor	Electric	Petrol
Seats	2	2
Maximum Speed	48km/h	90km/h
Range	80km	236km
Capital cost	NZ$6284	NZ$4347
Fuel cost	NZ$0.84/kWh	NZ$2.26/L [4]
Fuel consumption	0.006kWh/km	0.03 L/km
Fuel cost per km	NZ$0.005/km	NZ$0.07/km
Assumed lifespan	80000km (11 years)	80000km (11 years)

3.3 Design of Solar System

The section above has discussed the high electricity price on Rarotonga. As a result, a rooftop household solar system will be included in the model for charging the EV or the E-Bike. A feasibility study would be performed to identify whether the solar system is beneficial.

3.3.1 Optimum Tilt Angle

Rarotonga is located in the southern hemisphere, with a longitude and latitude of 160°W and 21.5°S (Maps of World, n.a). In order to maximise the solar radiation gain on the solar panels, they should be orientated north to the direction of the equator so that the sun will not go behind the panels during the day. In addition, the solar radiation gain is depended on the tilt angles of the solar panels as shown in figure 3.6 below.

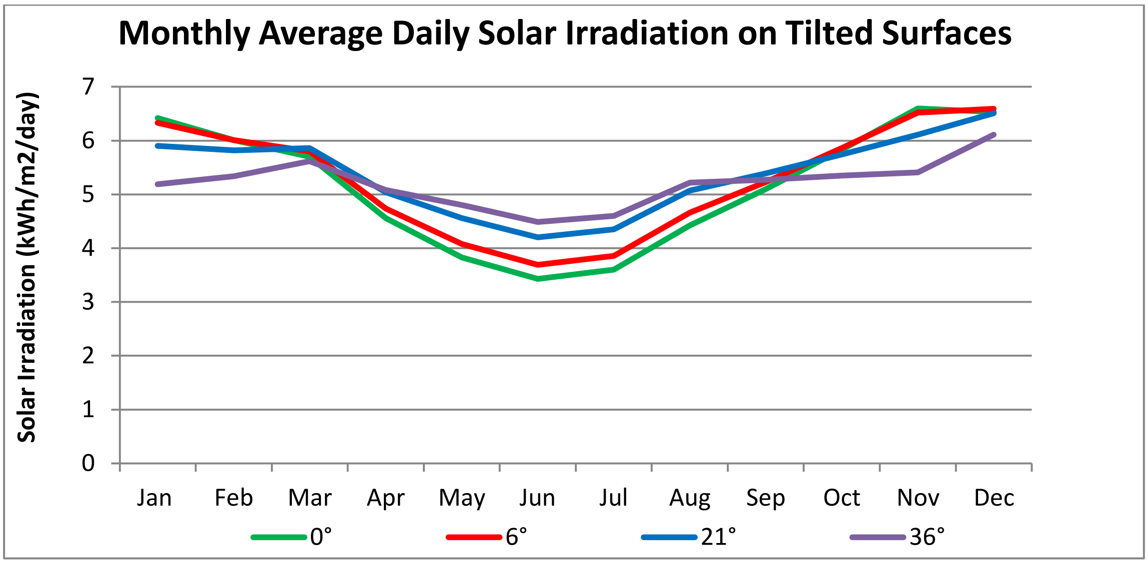


Figure 3.6: Monthly Average Daily Solar Irradiation on Rarotonga (NASA, 2015).

The maximum solar radiation gain occurs when the solar panels are perpendicular to the Sun's solar array. During winter months from April to September, the Sun is lower in the sky. As a result, a higher tilt angle is required to gain the maximum solar radiation on the panels. On the other hand, the Sun is higher in the sky during summer months from October to March and a lower tilt angle would gain more solar radiation.

The optimum tilt angle is determined based on the objective of the solar system. In section 2.2.6, it has been mentioned that TAU's Net-Metering Policy allow customers to export up to 2kW solar energy into the grid and the energy credits received will be accumulated for a period of up to 12 months. As a result, the main objective of the solar system is to achieve maximum energy generation throughout the year instead of optimising for winter or summer generation. It is assumed that a fixed tilt angle will be used for this study.

Since the latitude of Rarotonga is below $25°$, the optimum fixed tilt angle can be calculated using the following equation (Landau, 2014),

$$\text{Optimum angle} = \text{latitude} \times 0.87$$

The optimum angle is calculated to be $21.8°$. However, due to the availability of data the tilt angle of $21°$ will be used instead, with an annual average daily solar irradiation of 5.38kWh/m^2/day (NASA, 2015).

3.3.2 System Size and Module Selection

The size of the rooftop household solar system should be rated at a maximum of 2kW, which is the limit of TAU's Net Metering Policy. Otherwise battery storage will be required to store the extra energy generated. This would increase the system cost as the current battery technology is still expensive. In addition, it is assumed the system is designed for an average family size of 4, where the monthly load is calculated to be 798.4kWh in Appendix 2.1.

The type of solar panel selected for the system would be the 250W Polycrystalline module from Yingli Solar. This is because Yingli is one of the largest solar panel manufacturers around the world. Yingli panels have been rated highly for performance, quality and durability by PHOTON and TUV Rhineland (YINGLI SOLAR, 2015).

3.3.3 Inverter Selection

The selection of the inverter is recommended to be undersized to 80% of the system size. As a result, the inverter can be rated at around 1.6kW. The inverter also needs to comply with the grid connection requirement on Rarotonga with AC outputs ranged from 220V to 240V (Government of the Cook Islands, 2012). The SMA inverter Sunny Boy 1600TL will be selected as it has a maximum DC input power of 1.7kW and a nominal AC output of 220V to 240V (SMA, 2015).

3.3.4 Array Design

Due to the maximum and minimum temperature in Rarotonga, the operational voltage of the selected module will be ranged from 25.3V to 31.4V, while the maximum open circuit voltage is 39.7V (See Appendix 3.5). These values would be used to identify the number of modules that can be connected in a string to the inverter by considering the inverter voltage window. The calculation shows that a configuration of 8 modules connected in series with no parallel strings are suitable for the SMA inverter.

3.3.5 Data Collection for Solar System

3.3.5.1 Capital Cost

The cost of the Yingli module is AU$262/NZ$285 with an expected lifetime of 25 years (GoGreenSolar, 2015), while the SMA inverter has a capital cost of AU$1250/NZ$1359 (eBay, 2015) with an estimated lifespan of approximately 10 years (MASTERVOLT, n.d.).

Table 3.3 below summarise the capital cost for the major components of the PV system, with a total cost of $12061.

Table 3.3: Capital costs for major components of the 2kW solar system

Major Components	Brand	Model	Life Expectancy	Quantity	Price	Total
Module	Yingli	YL250P-29b	25 years	8	NZ$285	NZ$2278
Grid Inverter	SMA	Sunny Boy 1600TL	10 years	1	NZ$1359	NZ$1359
Total Capital Cost						NZ$3637

3.3.5.2 Maintenance Cost

The annual maintenance includes an inspection of the PV system to ensure they are operating efficiently and safely, as well as cleaning of the panels. The average annual maintenance cost of a 2kW system is approximately NZ$330 (Craig B., 2013).

3.3.5.3 Fuel Savings

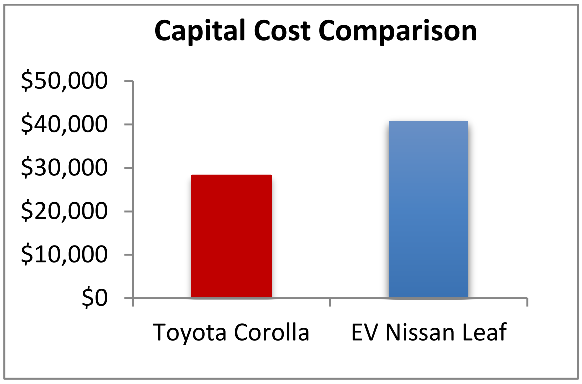
The calculation in Appendix 3.3 shows that the annual average system yield of the 2kW system with 8 Yingli panels is 2986kWh. From Appendix 2.1, the annual energy use for an average household of four is 9581kWh on Rarotonga, which is much higher than the energy production from the 2kW solar system. This ensures that all the energy produced would be used to offset the electricity cost from the grid. In addition, the electric tariff used to calculate the solar savings is $84c/kWh.

4 Results and Discussions

4.1 Feasibility Study of Vehicle Transports

4.1.1 EV Nissan Leaf VS Toyota Corolla

The main components of the NPV for the vehicle transport options is the capital cost and the annual O&M costs shown in the figures below. The annual O&M costs throughout the lifetime of the vehicle is converted to a presented day value and it is shown as an annual average figure (See Appendix 5.1: NPV Calculation for Toyota Corolla and Appendix 5.2: NPV Calculation for EV Nissan Leaf).



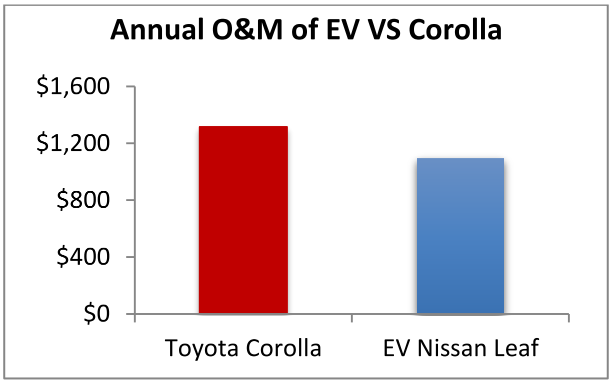


Figure 4.1: Capital Cost of Leaf VS Corolla Figure 4.2: Capital Cost of Leaf VS Corolla

The Leaf has a higher capital cost in comparison to the Corolla due to the high battery cost in the vehicle. On the other hand, the annual O&M costs are lower due to savings in maintenance and lower operating fuel costs. This is because the electrical components of an EV require less maintenance and the scenario assumed a constant increase of electricity price at 4% per annum throughout the lifetime of the vehicle.

Nevertheless, Appendix 5.2: NPV Calculation for EV Nissan Leaf shows that the Leaf has an NPV of -$60333 and Corolla for −$51861 in Appendix 5.1: NPV Calculation for Toyota Corolla. A negative NPV corresponds to the lifecycle costs of the transport options in today's value. As a result, the Leaf is not feasible in comparison to the Corolla as it has a more negative NPV. This is mainly due to the current high electricity tariff at $84c/kWh on Rarotonga, which meant a high fuel cost for charging the EV using electricity from the grid. In addition, the petrol price is at a historical low of $2.26/L and it favours the use of conventional vehicles. Although the scenario predicts that the petrol price will increase, the annual savings from the O&M of the Leaf is not enough to offset its higher capital cost.

4.1.2 EV Nissan Leaf with 2kW Solar VS Toyota Corolla

In this scenario, a 2kW solar system will be used to generate electricity for charging the EV to avoid the high electricity cost. The capital cost in figure 4.3 is similar to the previous scenario apart from the additional capital cost of the solar system at $3637 (Appendix 5.3: NPV Calculation for EV Nissan Leaf and a 2kW Solar System) being added to the EV option. However, figure 4.4 shows that the 2kW solar system is extremely cost effective as it covers all the operating fuel costs for the EV. Moreover, additional energy is generated from the solar system to offset other loads after covering the EV load (Appendix 5.3: NPV Calculation for EV Nissan Leaf and a 2kW Solar System). The additional savings from the solar cover the costs of the EV maintenance and result in a positive annual savings for the EV scenario as a whole.

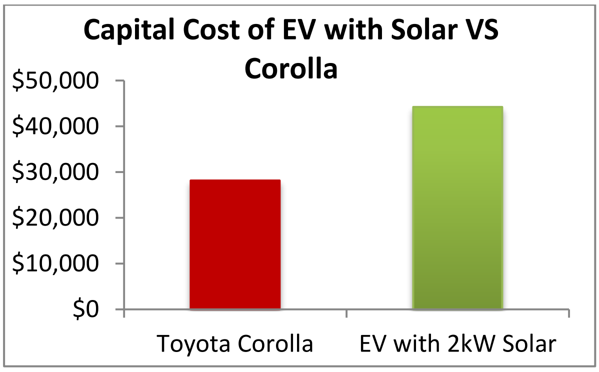


Figure 4.3: Capital cost comparison with solar

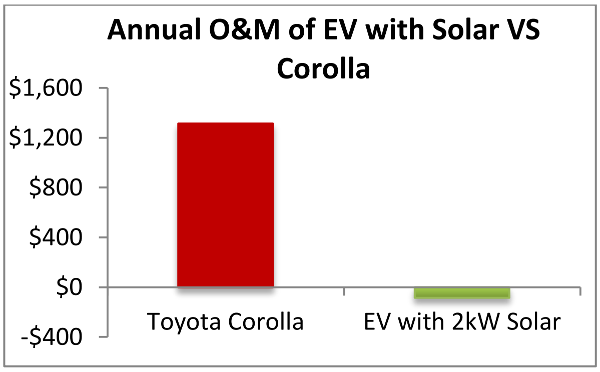


Figure 4.4: Annual cost comparison with solar

The benefit of the solar system is further supported by the results from the NPV calculation, where the Leaf with a 2kW solar system has an NPV of -$42168 and -$51861 for the Corolla. The lifecycle benefits of the solar system helps to offset the lifecycle cost of the EV, thus making it a feasible transport option in comparison of using the Corolla.

4.1.3 EV Nissan Leaf with 2kW Solar and Battery Storage VS Toyota Corolla

The 2kW solar system in the previous scenario is very cost effective mainly due to the grid incentive policy on Rarotonga, where households can use the grid as a storage for the energy produced from the 2kW solar system. The study also wants to analyse the impact when the incentive is removed by including battery storage in the system, as the EV is mainly charged during night time where solar is not available. The size of the battery is based on storing the average energy generated by the 2kW solar system on a daily basis and the cost is found to be $11233 (See Appendix 4.1: Design of Battery Storage System). This adds a significant amount of capital cost to the EV option as shown in figure 4.5, where the EV option is doubled the capital cost for the Corolla. In addition, the battery used in the system has a limited lifespan and thus the replacement cost needs to be included in the annual O&M. As a result, the net savings from the solar would be reduced in comparison to the previous scenario as shown in figure 4.6.

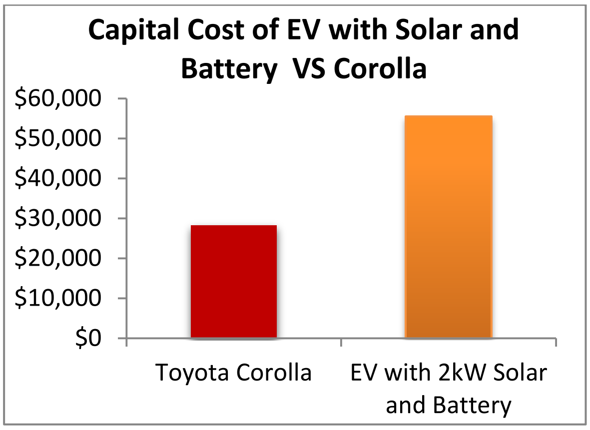


Figure 4.5: Capital cost comparison

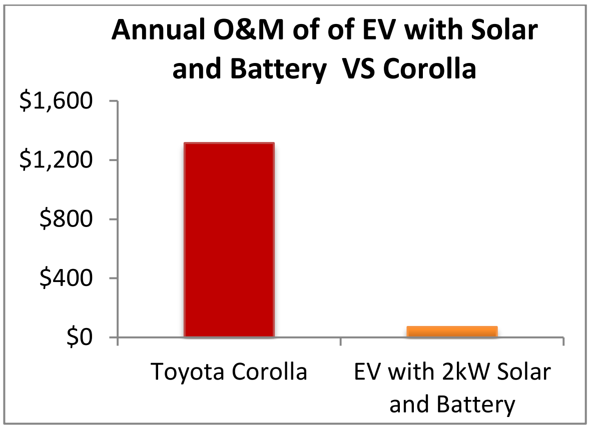


Figure 4.6: Annual cost comparison

Due to the additional capital costs of the battery in the system, the NPV for the EV with a 2kW solar system is calculated to be -$57251 in Appendix 5.4, while the NPV for Corolla is −$51861. Hence the results show that the EV is not feasible in comparison to Corolla when the grid incentive policy is removed and battery storage is needed.

4.1.4 Sensitivity Analysis

The results of NPV for the three EV scenarios are summarised in table 4.1 below and it can be seen that using the EV with a 2kW solar system is the most feasible option. As a result, a more in depth analysis would be carried out for this EV option.

Table 4.1: Feasibility of EV Scenarios Against Toyota Corolla

	Toyota Corolla	**EV Nissan Leaf**	**EV + 2kW Solar**	**EV + 2kW Solar + Battery Storage**
NPV	-$51861	-$60333	-$42168	-$57251
Difference in NPV against Corolla	-	-$8472	+$9693	-$5390
Feasible?	-	**N**	**Y**	**N**

Section 3.1.4 has discussed the data sources for the feasibility study of the EV and there are many uncertainties involved in the data. Rarotonga is a remote island and the transport of equipment such as the vehicle and solar modules to the island can inherently increases the capital costs of the system. In addition, the introduction of vehicle tax from the government can further increase the capital cost for the EV.

There are also uncertainties associated with the collected data for the annual O&M cost. Firstly, the vehicles might require a more frequent maintenance due to the use on an island environment where salt is a problem. However, this issue is more related to the Corolla as the EV does not require any intake of air for engine combustions. The salty air could cause the inner components of the Corolla to degrade faster. The maintenance cost for the solar panels could also be higher due to salt degradation which reduces the efficiency of the system. Nevertheless, a high dirt factor of 0.9 has been already considered in the solar output calculation. Moreover, the scenario assumed that all additional energy generated would be used to offset other loads in the house at a fix cost of $84c/kWh throughout the system life. Any reduction in electricity price on Rarotonga can reduce the net savings from the 2kW solar system. Finally, the scenario assumed that the petrol cost would be increasing at a constant rate of 4% per annum throughout the lifetime of the analysis. Although this is a general prediction trend by both WTO and IMF, the future always has uncertainties such as the discovery of new oil reserves, which could potentially reduce future petrol prices. As a result, a sensitivity analysis is required to model the uncertainties of the data collected which could potentially impact on the feasibility on the chosen transport option. The initial data collected and assumptions used in the scenario will be used as a base case as shown in figure 4.7, with an NPV of $9693 in comparison to using Corolla as a transport option. The sensitivity analyse would then model a deviation of 5%, 10% and 15% away from the costs and savings from the base case. The results show that a change in the system capital cost and future petrol cost has the most impact on the feasibility of the EV option. This is followed by a change in net solar savings and the system maintenance cost has the least impact. The worst case scenario is where the capital cost increases by 15% and future petrol prices reduces by 15%, where the NPV is reduced to about $7000. Nevertheless, all scenarios showed a positive NPV for the EV with 2kW Solar in comparison to the Corolla, thus the chosen transport option is feasible within the range of the sensitivity analysis.

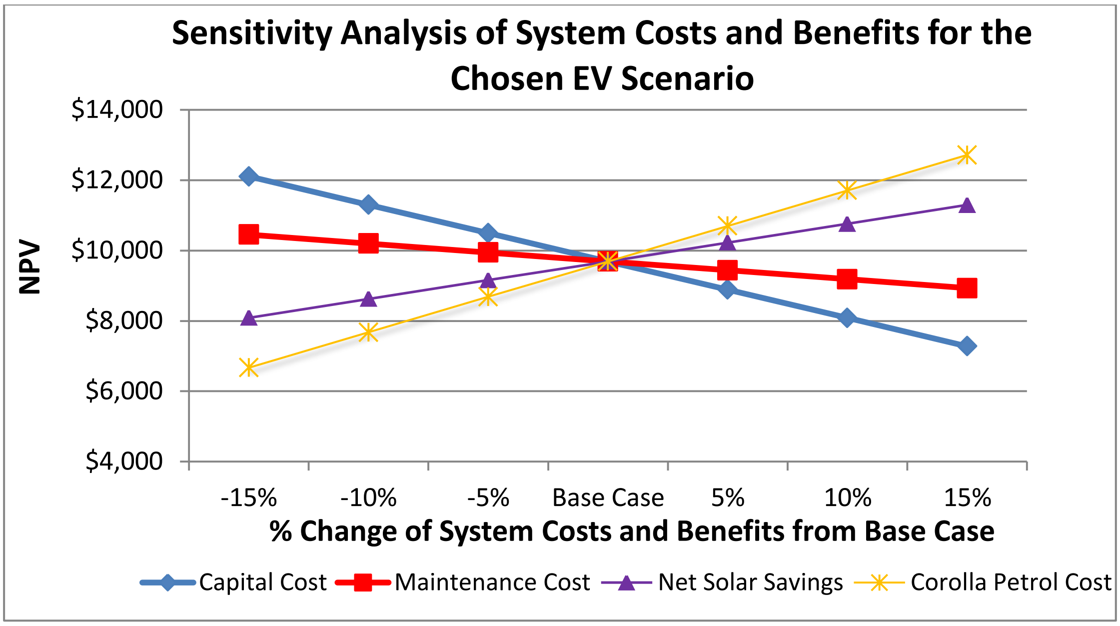


Figure 4.7: Sensitivity Analysis for the chosen EV Scenario

Apart from above factors, the assumed lifespan of the vehicle and the average distance travelled per day and also impact the lifecycle costs and benefits of the chosen option. Figure x shows that the option is more feasible when the daily usage of the vehicle is reduced to 20km. This is because the base case assumed a vehicle lifespan of 200,000 km, equivalent to 18 years of lifespan. A lower usage level at 20km/day corresponds to a vehicle lifespan of 27 years. Since the current petrol price is low on Rarotonga, a longer vehicle lifespan meant that it can take advantages of the fuel savings from a higher petrol price in a longer term, assuming that the petrol price would continue to increase in the future.

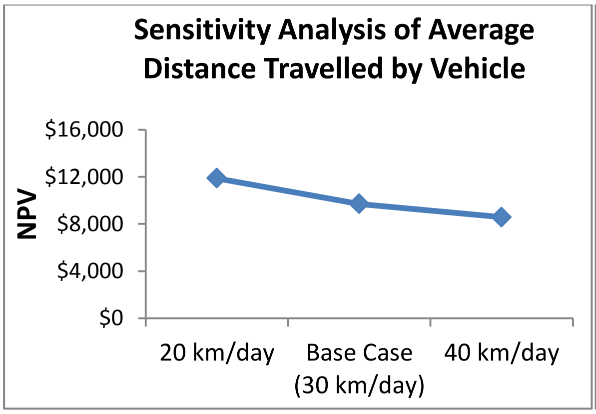


Figure 4.8: Sensitivity analysis of daily VKT

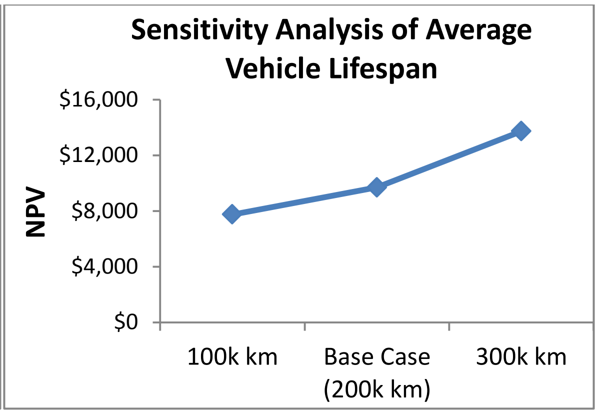


Figure 4.9: Sensitivity analysis of vehicle life

Similarly, figure 4.9 shows the sensitivity analysis on the average lifespan of the vehicle. Although the car sales consultants suggest a lifespan of 200,000 km, the actual lifetime of the vehicles could be higher so that the EV can generate more savings throughout its life to offset the initial cost and make the option more feasible. Conversely, the lifespan could be lower due to the impact of salt on an island environment. The figures above show a positive NPV for the different scenarios, which suggest the chosen EV option is still feasible.

4.2 Feasibility Study of Bike Transports

4.2.1 E-Bike Easy Motion VS Yamaha Cygnus

The bike transport options would be investigated in a similar way like the vehicle transport options. Figure 4.1 below show that the capital cost for the E-Bike is a little higher than the Yamaha Scooter, however its annual O&M cost (see figure 4.11) is about three times lower. This is mainly because the electrical component of the E-Bike is maintenance free and its maintenance is like a regular push bike which is simple and inexpensive. On the other hand, many components of the Yamaha scooter like the tyre, drive belts, brake pads and oil need to be changed regularly and they are a lot more expensive. Moreover, the fuel consumption for the E-Bike is only 0.006kWh/km which is very small. Hence the operating fuel cost is low despite the high electricity price at $84c/kWh.

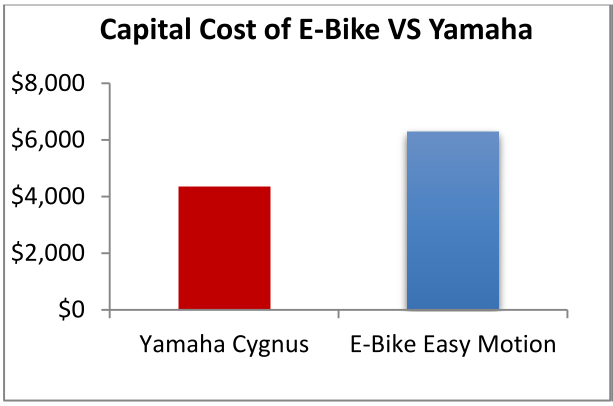


Figure 4.10: Sensitivity analysis of capital cost

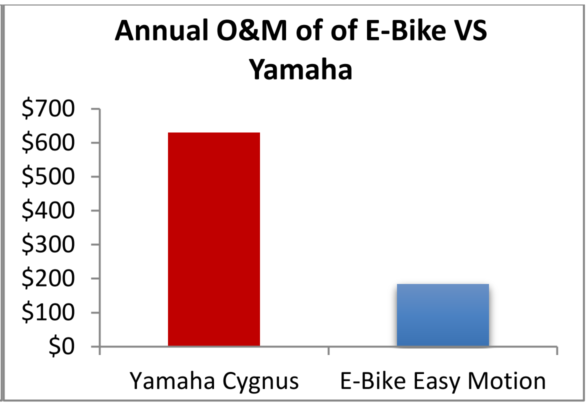


Figure 4.11: Sensitivity analysis of annual cost

Due to the factors above, the NPV of the E-Bike is calculated to be -$8293 and -$11271 for the Yamaha Scooter (See Appendix 5.5 NPV Calculation for Yamaha CygnusAppendix 5.6 NPV Calculation for E-Bike Easy Motion). A negative NPV represent the lifecycle costs of the two transport options and the E-Bike has a lower lifecycle cost. The difference of the NPV is found to be $2978. This meant that the use of the E-Bike Easy Motion in comparison to the Yamaha Cygnus scooter has a net value gain of $2978, thus it is a more feasible bike transport option.

4.2.2 E-Bike Easy Motion with 2kW Solar VS Yamaha Cygnus

It has been proven that E-Bike is feasible in comparison to scooter as a transport option. However, it is also useful to know whether the use a 2kW Solar system would make it a more attractive option. Similar to the EV scenario, the capital cost would be increased due to the solar system but the annual O&M cost will be negative due to additional solar savings by offsetting other household loads (See Appendix 5.8 NPV of E-Bike with 2kW Solar System). The solar savings is much more significant in comparison to the EV scenario as the load of the E-Bike is small and a lot more energy can be used to offset other loads and generate savings.

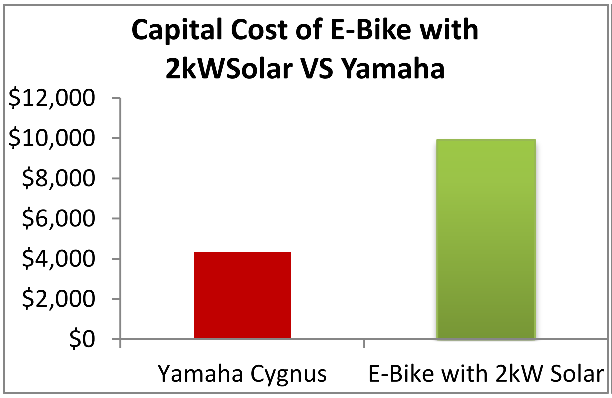


Figure 4.12: Sensitivity analysis of capital cost

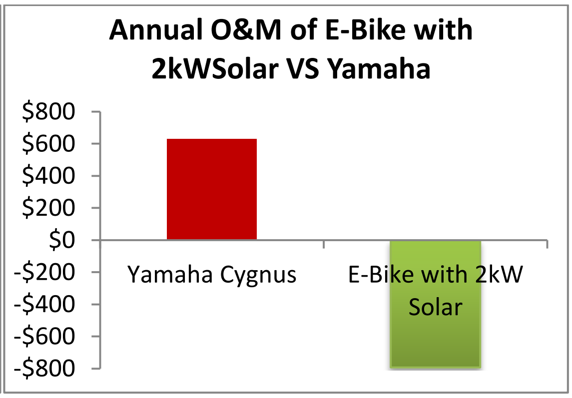


Figure 4.13: Sensitivity analysis of annual cost

The results in Appendix 5.8 NPV of E-Bike with 2kW Solar System shows that the NPV of the E-Bike with a 2kW solar system has an NPV of $9871, i.e. the lifecycle benefits of the solar system covers all lifecycle costs of the E-Bike. The NPV of the Yamaha scooter remains the same at -$11271 and the difference in NPV is found to be $21142, which suggests that the E-Bike scenario is extremely cost effective in comparison to the use of the scooter.

4.2.3 E-Bike Easy Motion with 2kW Solar and Battery Storage VS Yamaha Cygnus

Finally, the impact on the removal of the grid incentive policy will be analysed by including battery storage for the energy generated by the 2kW solar system. The capital cost and the annual O&M costs are shown in the figures below.

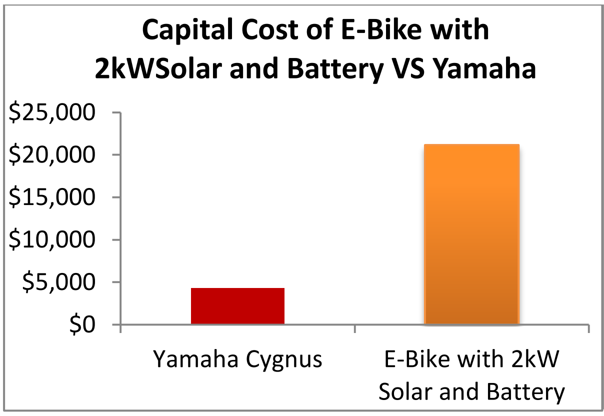


Figure 4.14: Sensitivity analysis of capital cost

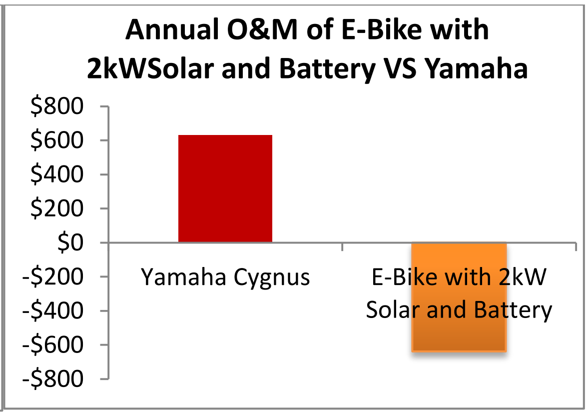


Figure 4.15: Sensitivity analysis of annual cost

Despite the high capital cost of the battery storage, the energy savings from the solar system have offset a large portion of the system capital cost. Appendix 5.9 NPV of E-Bike with 2kW Solar System and Battery Storageshows that the NPV of the E-Bike with 2kW solar and battery storage is -$5212, while the NPV is -$11271 for the scooter. This result in a difference of NPV of $6059 and thus the E-bike with a solar system is feasible without the grid incentive policy.

4.2.4 Sensitivity Analysis

The results of NPV for the three E-Bike scenarios are summarised in table 4.2 below and it can be seen that using the E-Bike with a 2kW solar system is the most feasible option. Hence a sensitivity analysis would be carried out for this E-Bike scenario to explore the option in more detail.

Table 4.2: Feasibility of E-Bike Scenarios Against Yamaha Cygnus

	Yamaha Cygnus	**E-Bike Easy Motion**	**E-Bike + 2kW Solar**	**E-Bike + 2kW Solar + Battery Storage**
NPV	-$11271	-$8293	$9871	-$5212
Difference in NPV against the scooter	-	$2978	$21142	$6059
Feasible?	-	**Y**	**Y**	**Y**

The purpose of the sensitivity analysis is similar to the EV scenario in section x above, where the data collected for the E-Bike such as the capital costs, maintenance costs etc. has many uncertainties and assumptions involved. The result of the sensitivity analysis is shown in figure 4.16.

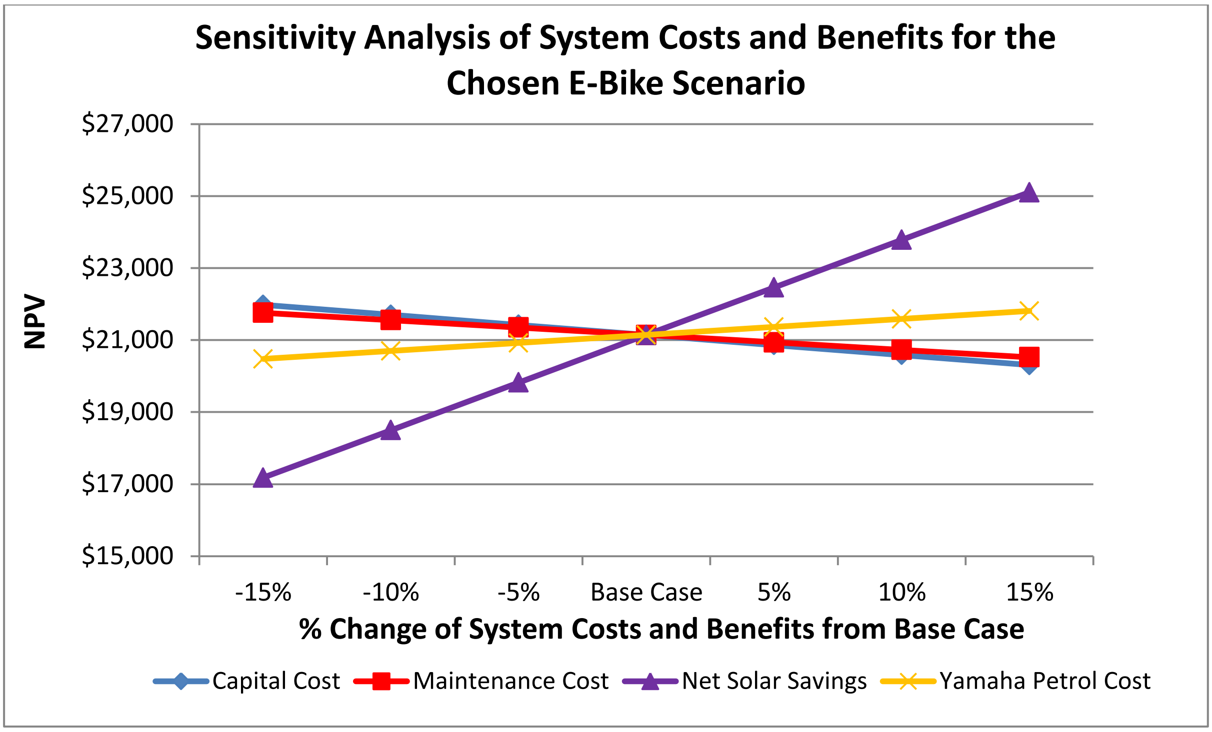


Figure 4.16: Sensitivity Analysis for Chosen E-Bike Scenario

Unlike the sensitivity analysis for the EV scenario, the petrol cost has a small impact on the overall feasibility as the fuel consumption for the Yamaha scooter is only 0.03L/km, which is less than half the fuel consumption for the Corolla. A lower fuel consumption meant that a change in petrol prices will have minimal impact on the fuel savings. In addition, the E-Bike scenario assumed that the scooter have an average lifespan of 80,000km, which is also lower than the Corolla. The other assumption used is a constant increase of electricity price of 4% per annum. Thus a lower lifespan meant that it can not take advantage of the high petrol price in the future so any changes in fuel prices would have a less impact on the NPV.

The change in capital cost in this E-Bike Scenario is also equally important to the change in fuel costs. One of the main advantages of using an E-Bike in comparison to a scooter is the fuel savings in the long term to offset the higher capital cost of the E-Bike. When the lifespan of the vehicle is low, the initial capital cost would be more important factor. For example, a lower capital cost meant a shorter lifespan is needed to offset the initial capital cost.

The change in maintenance cost impact the least on the NPV as it's the smallest component in the annual O&M cost. On the other hand, solar savings contribute to a large amount of annual savings. The main reason is that the load requirement for the E-Bike is a lot smaller than the load requirement of the EV. Thus a higher amount of excess energy can be used to offset other loads in the house at a price of $84c/kWh and generate savings. Thus a change in the electricity is most sensitive to the NPV of the E-Bike scenario. Nevertheless, all the cases in figure 4.16 show a positive NPV, which meant that it is a feasible transport option within the range of the sensitivity analysis.

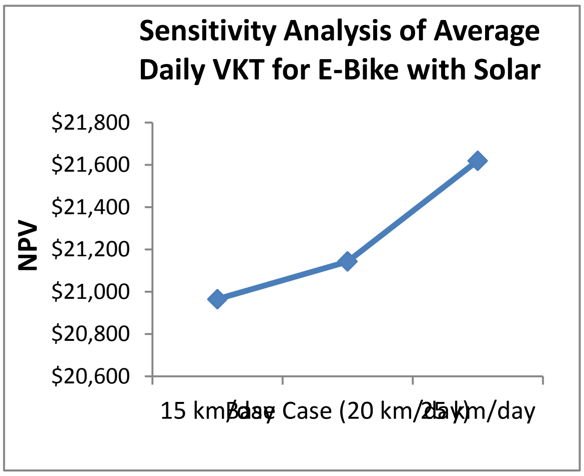


Figure 4.17: Sensitivity Analysis for VKT

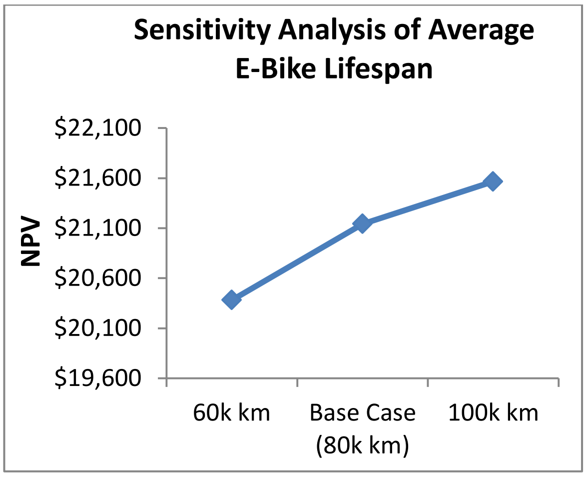


Figure 4.18: Sensitivity Analysis for Lifespan

In addition, the assumed lifespan of the bike and the average distance travelled per day and also impact the lifecycle costs and benefits of the chosen option. Figure 4.17 shows that the option is more feasible when the daily usage of the vehicle is higher, which is opposite to the result from the EV scenario. Although a lower usage of the E-Bike can extend its life to take advantage of future fuel savings from high petrol prices. As discussed in section 3.1.3, future cash flows have risks and uncertainties, and thus they worth less in comparison to today's value. i.e. Fuel savings generated today worth more than those in the future. Moreover, the current operating fuel cost for the E-Bike is $0.005/km, which is a significantly lower than the scooter at $0.07/km (Table 3.2). On the other hand, the operating fuel cost for the EV is $0.15/km and $0.14/km for the Corolla (Table 3.1). Hence the feasibility of the EV scenario is much more depended on the increase of operating fuel cost for the Corolla in order to generate more fuel savings.

On the other hand, the sensitivity analysis for the assumed lifespan of the bike is the same as the EV scenario, where an increase of the assumed lifespan would make the E-Bike a more feasible option. This is because electric transport options have a higher capital cost, and the longer lifespan allow generating more fuel savings to offset their initial capital cost.

4.3 Public Transport Options on Rarotonga

4.3.1 Lifecycle Cost and Capital Cost

The section above discusses about the feasibility between electrical and conventional transport options. It is also interested to know whether vehicle transports are more cost effective in comparison to bike transports. The figure below shows the lifecycle costs of the different transport options converted to a per km basis, based on the assumed lifespan used in the above analysis.

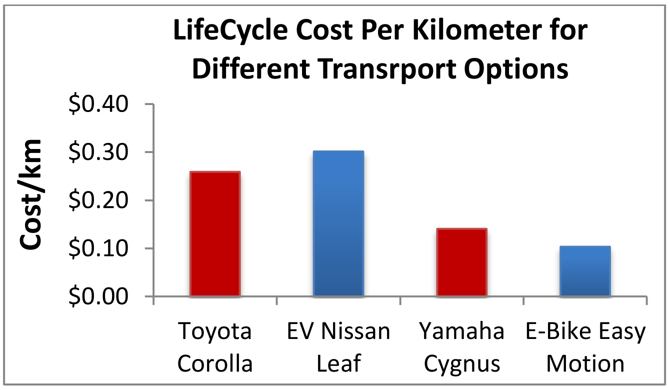


Figure 4.19: Lifecycle cost per kilometre of vehicle and bike transport options

It can be seen that the E-Bike Easy Motion is still the most cost effective transport options after considering the respective average lifespan. Figure 4.20 below also shows that the E-Bike has a relatively low capital cost which made it more affordable to the general public. The high capital cost of the Nissan Leaf could be one of the major barriers which prevent a massive deployment of using the EV Nissan Leaf on Rarotonga. Unless the government of Cook Islands introduce tax incentive programs for the uptake of EV like in the US to favour the use of EV.

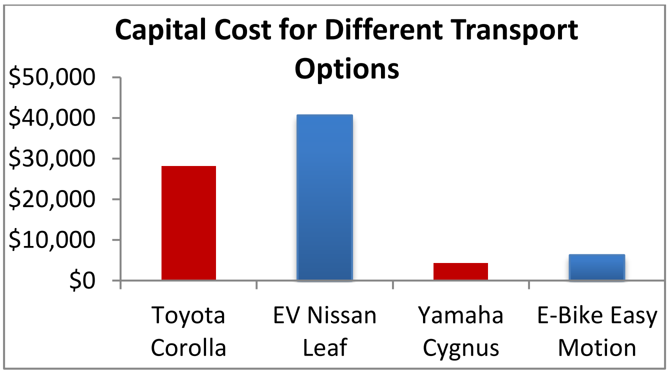


Figure 4.20: Capital cost comparison of vehicle and bike transport options

Finally the capital cost of the solar system will be discussed. From section 4.1.2, it can be seen that the EV Nissan Leaf is only feasible with the use of a 2kW system. However, the electricity company on Rarotonga TAU announced in 2014 that even with all the upgrades on the grid network, current studies suggest the maximum RE penetration level into the grid is limited to be 3.3MW (TAU, 2014). As a result, when the limit is reached there is a potential where the grid incentive policy to encourage the uptake of a 2kW solar system would be removed. Thus a large amount of capital cost of battery storage needs to be considered for the EV option. On the other hand, since the E-Bike is still feasible without the use of a 2kW solar system (See section 4.2.1). Hence the E-Bike option avoids the need of a solar system with battery storage when the grid incentive policy is removed.

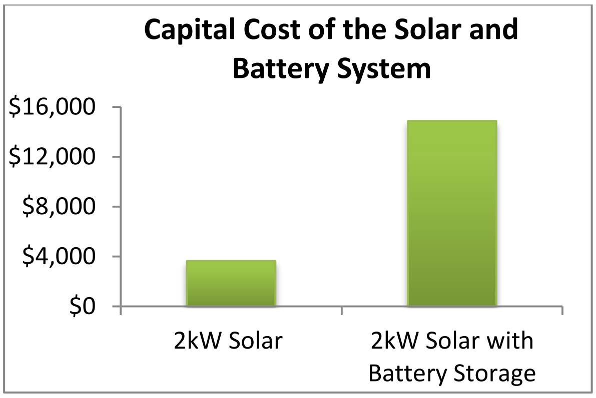


Figure 4.20: Capital cost of solar and battery system

4.3.2 Impact on Grid

Apart from the consideration of the capital cost and lifecycle cost of the transport options. The study also analyse the impact of the two electric transport options on the grid network on Rarotonga.

4.3.2.1 EV

As there is currently no EV charging infrastructure on Rarotonga, the EV is most likely to be charged at home during night time. In section 2.2.6, it has been discussed that the majority of the renewable energy generation on Rarotonga is solar energy, which generate during the day and it cause a mismatch between the load of EV and the supply of solar energy. As a result, without energy storage facilities such as large scale battery storage or pump hydro, the deployment of EV on Rarotonga would increase the use on diesel generation, which violate the main objective of the study which is to reduce the reliance on import fuels.

This is further supported by looking into the minimum operating level of the large diesel plants on Rarotonga. In general, the large thermal plants would vary the power output to match a change in the demand of electricity. However, due to the constraints of the plant the output cannot reduce below a minimum operating level. In addition, large thermal plants do not shut down during periods of low demand at night because there are extra costs associated with the start up and shut down of a plant. As a result, it would be desirable to have loads during the night time that is greater than the minimum operating level so the large thermal plants can stay on the grid. Table 2.2 of the section 2.2.1, the large diesel plants on Rarotonga has an available capacity of 9.5MW in 2012 and the minimum operating level for diesel plant is about 10%. (I. McGill, pers. comm., 18 Oct. 2015). which is equivalent to 0.95MW. Figure 4.21 below shows the average demand on Rarotonga during the weekday at night time is approximately 2.6MW. Thus the current load has exceeded the minimum operating level and any additional load like EV charging would result in higher diesel use.

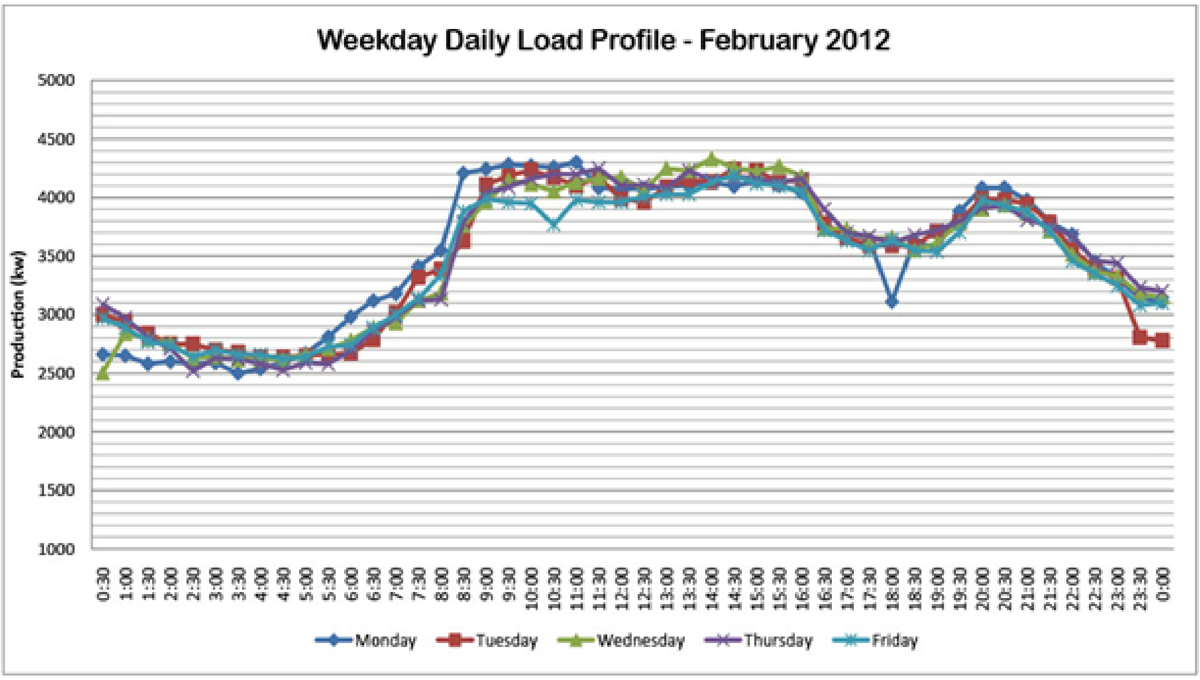


Figure 4.21: Weekday load profiles in Rarotonga, Feb 2012 (PEEP2, 2015)

4.3.2.2 E-Bike.

On the other hand, the charging of the E-Bike is much more flexible as the battery is removable and it can use any standard outlets for charging. This provides an opportunity for the E-Bike users to charge their battery during the day, where the energy source could potentially come from solar generations and eliminate the need of storage facilities in comparison to charging the EV. In addition, the battery size of the E-Bike is 0.48kWh while the EV battery capacity is 24kWh. Even if the E-Bike user needs to charge the battery during night time, the impact of as an additional load is significantly smaller in comparison to the EV battery.

4.3.3 Carbon Reduction

This section would analyse the amount of carbon emission reduction by replacing the Toyota Corolla and the Yamaha scooter with renewable energy powered electric transports on Rarotonga. The fuel consumption for the Toyota Corolla is 0.061L/km. and for the assumed VKT in the study of 30km/day, the annual fuel consumption of petrol is 668L (See Appendix 6.1: Calculation for Carbon Emission Reduction) A conversion factor is then used to convert the fuel consumption to the amount of carbon emissions and the result is shown in figure 4.22 below. Similarly, the fuel Consumption of Yamaha Cygnus is 0.03L/km and the assumed VKT for the scooter of 20km/day requires an annual fuel consumption of $219L$ of petrol. Figure x shows that the potential of emission reduction for a vehicle is about three times higher in comparison to the scooter.

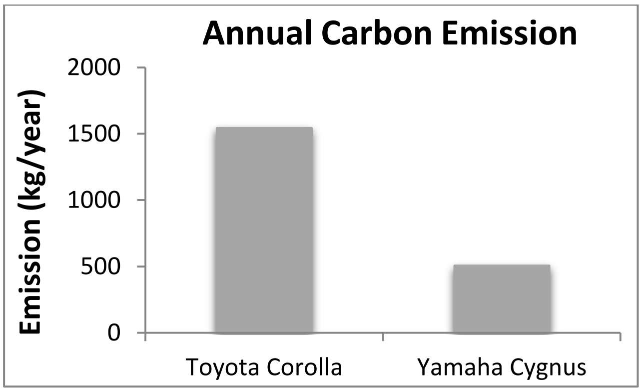


Figure 4.22: Potential Carbon Offset from Corolla and the Scooter

4.3.4 A Cost Effective Electric Bike Model

In the previous section where the E-Bike Easy Motion is selected for the comparison in the feasibility study, the criteria is based on a high quality E-Bike which is more expensive. The aim is to allow a fairer comparison against the motor scooter. However, it might not be the most suitable model to be implemented on Rarotonga. Another E-Bike model to be considered is the Cycleman LEB03 model. It has a much lower capital cost of US$405/NZ$579, quoted by J. Woo, E-bike sales consultant at CYCLEMAN China office. This is about ten times cheaper than the high quality Easy Motion E-Bike. Apart from a low capital cost, it has a smart system where the user’s mobile phone can be connected to the bike by Bluetooth to display information such as bike speed, battery level and the current location. The electrical components of the E-Bike are connected with water proof plugs, which meant they are easily removable for maintenance. In addition, unlike most of other E-bikes with multiple gears, the selected model has a single gear which further reduces the maintenance cost. Finally, the type of battery used is lithium ion and it has an addition function which is to allow users to charge their mobile phones (CYCLEMAN, 2015). These advance features with the integration of a smart system are really attractive for tourists on Rarotonga, as well as the local residents. The bike components are manufactured in Austria with a two year warranty on the battery and the bike frame and assembled in China. Finally, the replacement cost of the battery is low at NZ$157, once again about 6 times lower than the cost of the other battery. The smaller battery range of 28km is the main reason for the cheap battery but it would be enough for the use on Rarotonga as it only has a circumference of 32km and users can still pedal the bike in the event where the battery has ran out. Thus the model b

Figure 4.23: CYCLEMAN E-Bike (CYCLEMAN, 2015)

5 Limitations and Future Work

One of the major limitations in the report is the accuracy and uncertainty for the data such as the capital cost and maintenance cost of vehicles and bikes that are used in the feasibility study. There are also many assumptions used in the different scenarios such as the vehicle lifespan and average daily usage of the vehicle. Nevertheless, the sensitivity analysis in section 4.1.4 and 4.2.4 has attempted to analysis the impact the change in the value for the collected data on the overall feasibility of the transport option.

The potential tasks that could improve the accuracy of the data are listed below:

1. For the cost of the solar system, obtain a 2solar quotation from the local solar company ANDERSONS, provided that a household address on Rarotonga is available. Enquire them about the average maintenance cost.
2. For the capital cost, maintenance cost and lifespan data of the transport options, enquire the local car or bike rental shops about relevant information in regards to their models currently in use, such as the additional shipping costs required to import equipment to Rarotonga.
3. It is also useful to talk to the first electric transport company on Rarotonga called E-tuktuk to discuss any issue with maintenance with the use of electric transport options on an island environment due to the humidity and salt. Another option is to perform further case studies in cities like California in the US, where the vehicle is also affected by salt degradation.
4. Perform household travel surveys on Rarotonga about the average vehicle kilometre travelled for their vehicle or bikes per day. The survey can also include asking local residents about their knowledge in electric bikes and what features do they like the most. For example, rank the criteria such as the cost, maximum speed and load capacity of the E-Bike. This can help to choose a model that suits the interest of the local people for the feasibility study. Finally, the study did not include any vehicle insurance as Rarotonga is a small island and a safe place. It is noted that EV has a higher insurance than the Corolla while E-Bike does not require any insurance so it would be useful to know.
5. Investigate the annual electricity bills from individual households, which can help to improve the accuracy for the calculation of solar savings from using a 2kW solar system.
6. Contact local weather stations to check whether ground solar data are available instead of using satellite data which is less accurate.

Future Work

1. A more sophisticated modelling and forecast system to predict the future petrol prices on Rarotonga. This helps to improve the result from the fuel savings of using electric transport options.
2. Analyse the use of smart charge points for EV, where the rate of charging can be reduced in periods of high demand.
3. Investigate the possibility of TAU providing payments for individual household for the use of a battery system as it helps to stabilise the grid. In return, it helps to make the EV option with solar and battery more feasible.
4. Investigate the feasibility of an electric bike sharing system on Rarotonga as it promotes a large scale deployment of electric transport on Rarotonga. It has proven to be cost effective in many cities of US which help to lower the transport cost for the local residents and tourists. In addition, the electricity company TAU on Rarotonga could potential join the bike sharing system in terms on operating the spare battery of the bike sharing system and use them as aggregators in terms of providing grid stability from the high penetration of renewable energy.

6 Conclusion

The feasibility analyse shows that network incentive policy on Rarotonga have made household solar systems (less than 2kW) extremely affordable. Since the electric transport technologies use electricity as the main fuel source, they are also attractive by using in compliment with the household solar system. Nevertheless, the use of electric vehicle on Rarotonga can be seen as an additional load to the grid during night time, causing an increase in petrol use. As a result, the deployment of electric vehicle on Rarotonga is only suitable when large scale storage facilities like pumped hydro plants are available.

On the other hand, the use of electric bike have a minimum impact on the grid as the battery is removable and can be charged in a standard wall socket during the day, thus taking advantage of the solar energy generated without the need of large scale storage. In addition, the electric bike is feasible in regardless of whether the grid incentive policy is available. Its lower capital cost made it much more affordable to the general public and thus it can be concluded that the electric bike has the greatest potential in terms of using it as the main form of transport on Rarotonga. Electric bikes can play an important role in reducing the fuel supply risk as well as the level of carbon emissions on Rarotonga, thus making it a better place for the future generations on the island.

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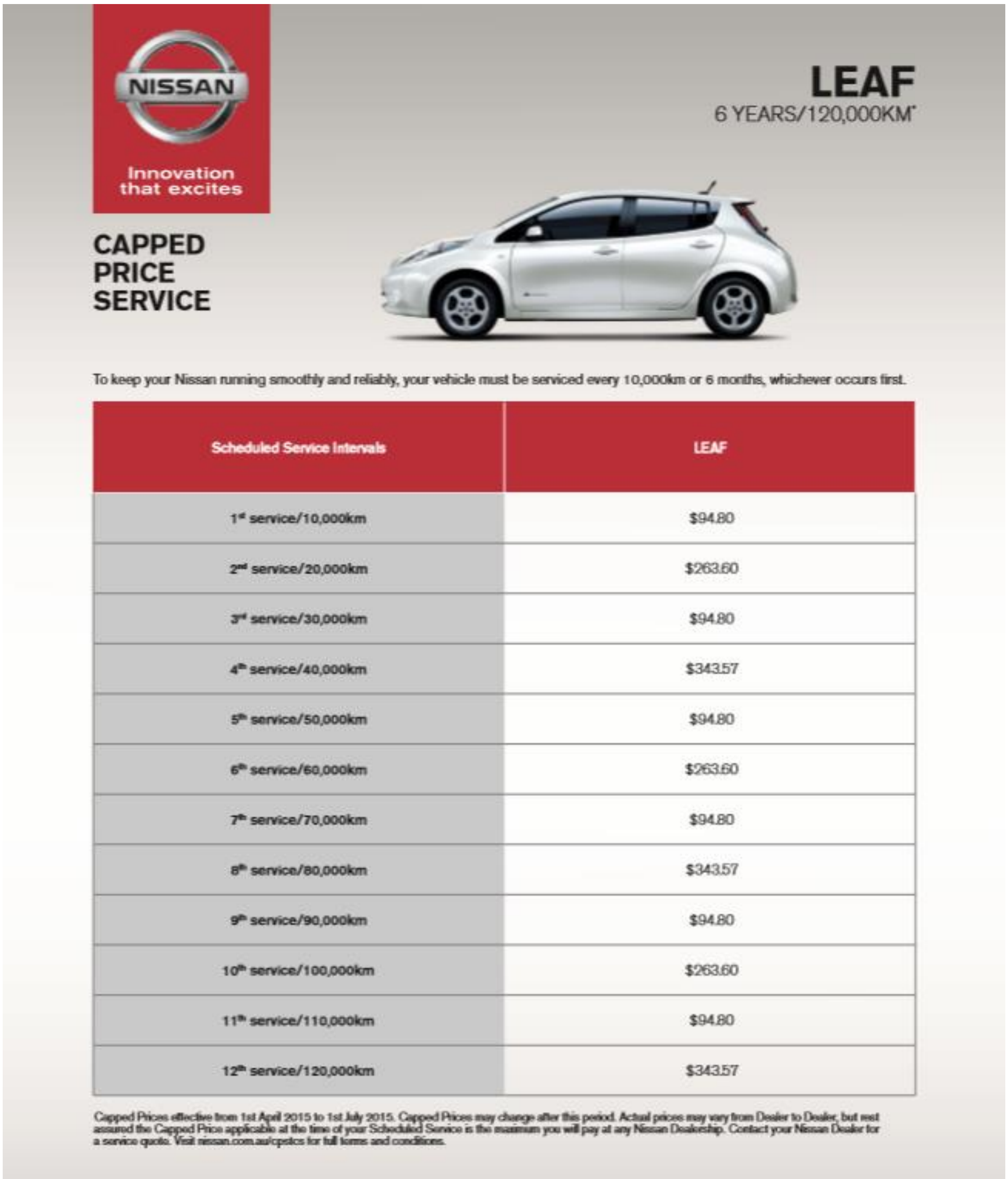
[Accessed: 14/03/15]

Appendix 1

Appendix 1.1: Exchange Rates

NZ$1 = AU$0.92, NZ$1 = US$0.7, NZ$1= EUR$0.62

Appendix 1.2: Nissan Leaf Maintenance Data Sheet



NISSAN
Innovation that excites

LEAF
6 YEARS/120,000KM*

CAPPED PRICE SERVICE

To keep your Nissan running smoothly and reliably, your vehicle must be serviced every 10,000km or 6 months, whichever occurs first.

Scheduled Service Intervals	LEAF
1st service/10,000km	$94.80
2nd service/20,000km	$263.60
3rd service/30,000km	$94.80
4th service/40,000km	$343.57
5th service/50,000km	$94.80
6th service/60,000km	$263.60
7th service/70,000km	$94.80
8th service/80,000km	$343.57
9th service/90,000km	$94.80
10th service/100,000km	$263.60
11th service/110,000km	$94.80
12th service/120,000km	$343.57

Capped Prices effective from 1st April 2015 to 1st July 2015. Capped Prices may change after this period. Actual prices may vary from Dealer to Dealer, but rest assured the Capped Price applicable at the time of your Scheduled Service is the maximum you will pay at any Nissan Dealership. Contact your Nissan Dealer for a service quote. Visit nissan.com.au/cpstcs for full terms and conditions.

Figure 1: Maintenance Cost for Nissan Leaf on April 2015.

Appendix 1.3: Petrol Price Outlook

Table 1: Petrol Price in Cook Islands from 2010 to 2014 (MFEM, 2015)

Year	2010	2011	2012	2013	2014	Jun 2015
Petrol Price ($/L)	2.45	2.59	2.65	2.64	2.6	2.26
Percentage Change	-	5.7%	2.3%	-0.4%	-1.5%	-13.1%

$(5.7 + 2.3) \div 2 = 4\%$

Hence a 4% increase in petrol price on average from 2010 to 2012.

Table 2: Medium Term Commodity Prices Baseline (In U.S. Dollars) (International Monetary Fund, 2015)

Commodities	Units	2015A1	2016A1	2017A1	2018A1	2019A1	2020A1
Spot Crude 1/	$/bbl	58.14	65.6525	69.2	71.76	73.1	74.03
Percentage change			12.9%	5.4%	3.7%	1.9%	1.3%
Average percentage change per annum							5.0%

$\text{Percentage change} = (\text{current year's oil price} - \text{previous year's oil price}) \div \text{previous year's oil price}$

Table 3: World Bank Commodities Price Forecast (in real 2010 US dollars) (World Bank, 2015)

	Units	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Crude Oil Price	$/bbl	50.3	52.9	55.6	58.4	61.4	64.6	67.9	71.4	75	78.9	82.9
Percentage change			5.2%	5.1%	5.0%	5.1%	5.2%	5.1%	5.2%	5.0%	5.2%	5.1%
Average percentage change per annum												5.1%

Appendix 1.4: Estimation of Nissan Leaf Battery Replacement Cost from 2015 to 2030

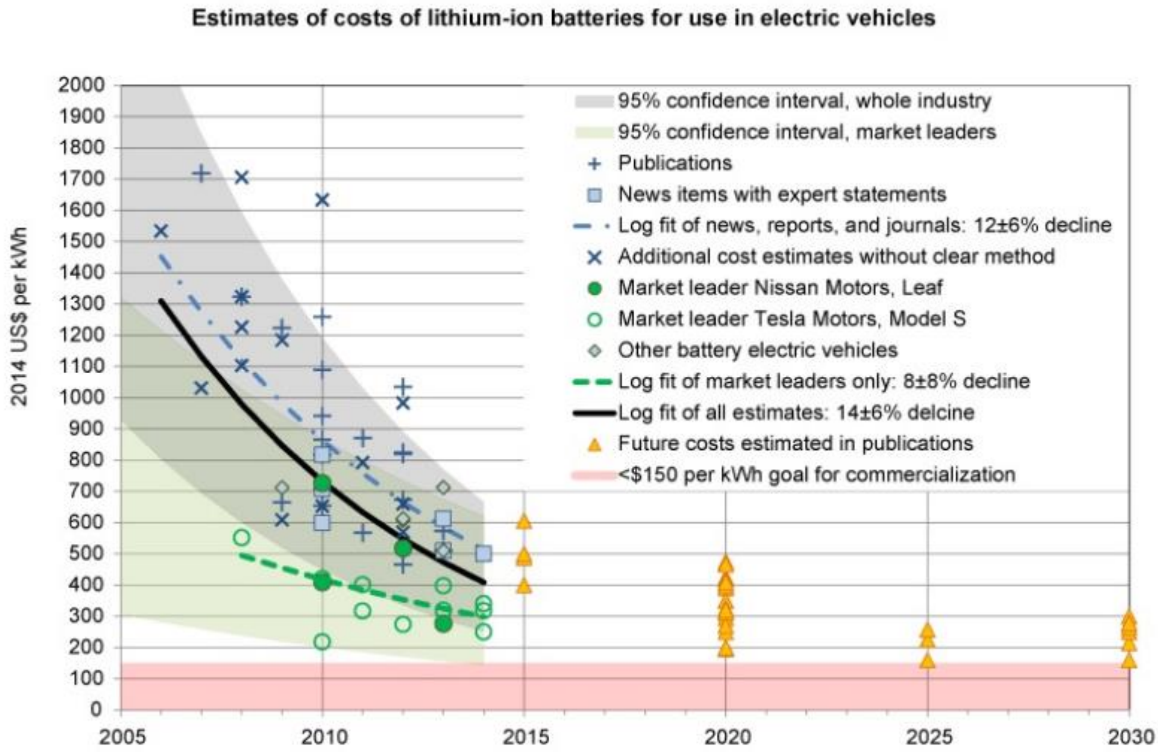


Figure 2: Estimated costs of lithium-ion batteries by 2030 (rtcc, 2015).

The figure shows that the battery cost per kWh is about 150 in 2050 and it is 300 in 2014 from Nissan. $150 \div 300 = 50\%$.

Appendix 2

Appendix 2.1: Household Load Calculation

The study assume that the EV and the 2kW solar system is designed for an average household with an annual load of 9581kWh, this is equivalent to 798.4kWh per month on average.

Table 4: Island Electrification (Government of the Cook Islands, 2012)

Island Electrification									
Island	Maximum Demand kW	Total Households	Indicative Population	Population/ Household	kWh	kW / Person	kW / Household	kWh/person	kWh/House hold
Rakahanga	18	50	77	1.54	76000	0.23	0.36	987	1520
Pukapuka	35	97	453	4.67	33649	0.08	0.36	74	347
Nassau	10	32	73	2.28	39420	0.14	0.31	540	1232
Manihiki	30	97	243	2.51	300000	0.12	0.31	1235	3093
Palmerston	8	18	60	3.33	28733	0.13	0.44	479	1596
Penrhyn	50	66	203	3.08	124000	0.25	0.76	611	1879
Mitiaro	39	145	189	1.30	120000	0.21	0.27	635	828
Atiu	100	158	481	3.04	332000	0.21	0.63	690	2101
Mauke	90	106	307	2.90	220000	0.29	0.85	717	2075
Mangaia	120	177	573	3.24	441000	0.21	0.68	770	2492
Aititaki	620	535	2035	3.80	3291000	0.30	1.16	1617	6151
Rarotonga	5000	3009	13097	4.35	28828000	0.38	1.66	2201	9581

Table 5: TAU Electricity Tariff in 2011 (PEEP2, 2015)

Domestic	Rate	Commercial	Rate	Demand	Rate per	Dual Tariff	Rate
First 60 kWh/Month	@ 57c	All	@ 81c	kWh used	@ 72c	First 60 kWh/Month	@ 57c
61 to 300 kWh/Month	@ 80c			Peak/kW	$30.00	61 to 240 kWh/Month	@ 80c
Balance	@ 84c			Shoulder /kW	$26.00	Balance	@ 84c
		Service charge	$5.00	Service charge	$20.00	Service charge	$10.00

Since the average monthly load is higher than 300kWh, any additional such as EV charging would result in an electricity tariff of $84c/kWh.

In addition, the monthly load above 300kWh is 498.4kWh,

$$798.4 - 300 = 498.4kWh$$

Hence any solar generation under 498.4kWh would use the tariff $84c/kWh to calculate the solar savings in offsetting the load.

Appendix 3

Appendix 3.1: YINGLI Module Data Sheet

ELECTRICAL PERFORMANCE

Electrical parameters at Standard Test Conditions (STC)							
Module type			YLxxxP-29b (xxx=P_{max})				
Power output	P_{max}	W	260	255	250	245	240
Power output tolerances	ΔP_{max}	W	0 / + 5				
Module efficiency	η_m	%	16.0	15.7	15.4	15.1	14.8
Voltage at P_{max}	V_{mpp}	V	30.3	30.0	29.8	29.6	29.3
Current at P_{max}	I_{mpp}	A	8.59	8.49	8.39	8.28	8.18
Open-circuit voltage	V_{oc}	V	37.7	37.7	37.6	37.5	37.5
Short-circuit current	I_{sc}	A	9.09	9.01	8.92	8.83	8.75

THERMAL CHARACTERISTICS

Nominal operating cell temperature	NOCT	°C	46 +/- 2
Temperature coefficient of P_{max}	γ	%/°C	-0.42
Temperature coefficient of V_{oc}	β_{Voc}	%/°C	-0.32
Temperature coefficient of I_{sc}	α_{Isc}	%/°C	0.05
Temperature coefficient of V_{mpp}	β_{Vmpp}	%/°C	-0.42

Figure 3: Yingli Module Data Sheet

Appendix 3.2: SMA Inverter Data Sheet

Technical data	Sunny Boy 1600TL
Input (DC)	
Max. DC power (@ cos φ = 1)	1700 W
Max. DC voltage	600 V
MPP voltage range	155 V - 480 V
DC nominal voltage	400 V
Min. DC voltage / start voltage	125 V / 150 V
Max. input current / per string	11 A / 11 A
Number of MPP trackers / strings per MPP tracker	1 / 1
Output (AC)	
AC nominal power (@ 230 V, 50 Hz)	1600 W
Max. AC apparent power	1600 VA
Nominal AC voltage; range	220, 230, 240 V; 180 V - 260 V
AC grid frequency; range	50 Hz; -4.5 Hz, +2.5 Hz
Max. output current	11 A
Power factor (cos φ)	1
Phase conductors / connection phases	1 / 1
Efficiency	
Max. efficiency / Euro-eta	96.0 % / 95.0 %
Protection devices	
DC reverse-polarity protection	●
ESS switch-disconnector	○
AC short circuit protection	●
Ground fault monitoring	●
Grid monitoring (SMA Grid Guard)	●
Galvanically isolated / all-pole sensitive fault current monitoring unit	–/●
Protection class / overvoltage category	I / III
General data	
Dimensions (W / H / D) in mm	440 / 339 / 214
Weight	16 kg
Operating temperature range	-25 °C ... +60 °C
Noise emission (typical)	≤ 33 dB(A)
Internal consumption (night)	< 0.1 W
Topology	transformerless
Cooling concept	Convection
Electronics protection rating / connection area (as per IEC 60529)	IP65 / IP65
Climatic category (per IEC 60721-3-4)	4K4H
Features	
DC connection: SUNCLIX	●
AC connection: screw terminal / plug connector / spring-type terminal	–/●/–
Display: text line / graphic	●/–
Interfaces: RS485 / *Bluetooth®*	○/○
Warranty: 5 / 10 / 15 / 20 / 25 years	●/○/○/○/○
Certificates and permits (more available on request)	CE, VDE 0126-1-1, EN 50438*, C10/C11, PPDS, UTE C15-712-1, AS4777
* Does not apply to all national deviations of EN 50438	
● Standard features ○ Optional features – not available	
Data at nominal conditions	
Type designation	SB 1600TL-10

Figure 4: SMA Data Sheet

Appendix 3.3: Annual Energy Output of 2kW Solar

$P_{array\_stc} = 2\text{kW}$ (system size)

$H_{tilt} = 5.38\text{PSH}$ (average solar irradiation)

Average temperature = 24.2°C (NASA, 2015)

$f_{temp} = 1 - \gamma_v(T_{cell} - T_{stc}) = 1 - 0.0042(24.2 + 25 - 25) = 0.8984$

$f_{man} = 1$ (Manufacture tolerance of 0% to +5%)

$f_{dirt} = 0.9$ (Assume a higher factor due to salt degradation on Rarotonga)

$\eta_{inv} = 0.95$ (Assume 5% inverter loss)

$\eta_{pv\_inv} = 0.99$ (Assume 1% cable loss)

$\text{System loss factor} = f_{temp} \times f_{man} \times f_{dirt} \times \eta_{inv} \times \eta_{pv_{inv}}$

$= 0.9286 \times 1 \times 0.9 \times 6.55 \times 0.95 \times 0.9603 = 0.7604$

$E_{sys} = P_{array\_stc} \times H_{tilt} \times \text{System loss factor} \times 365$

$= 2 \times 5.38 \times 0.7604 \times 365$

$= 2986\text{kWh/year}$

Appendix 3.4: Climate Data

The temperature of the Cook Islands is also important for the system design as the maximum and minimum temperature can impact on the operational voltage of the PV panels. Figure 5 below shows the data of the site over the past 15 years.

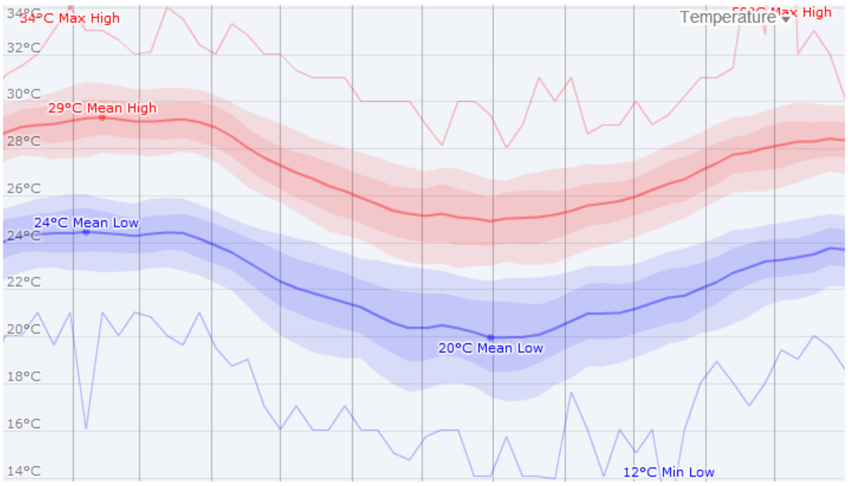


Figure 5: Average Monthly Temperature on Cook Islands (WeatherSpark, 2015)

Appendix 3.5: System Array Design

Yingli Module: MPP Voltage Calculations

$P_{module\_stc} = 250W$

$V_{mp\_stc} = 29.8V$, $V_{oc\_stc} = 37.6V$, $\gamma = -0.0042/°C$

$T_{a\_max} = 34°C$, $T_{a\_min} = 12°C$

Assume the module is well ventilated: $T_{cell\_max} = T_{a\_max} + 25°$

$$V_{mp\_mod\_min} = V_{mp\_stc} - V_{mp\_stc} \times \gamma \times \left(T_{cell\_max} - T_{stc}\right)$$

$$V_{mp\_mod\_min} = 29.8 - 29.8 \times 0.0042 \times (34 + 25 - 25)$$

$$V_{mp\_mod\_min} = 25.54V$$

Assume less than 1% of voltage drop from DC cables for the rooftop solar system

$$V_{mp\_mod\_min\_vdrop} = 25.54 \times 0.99 = 25.29V$$

Module does not have any heat gain from the Sun in the morning, $T_{cell\_min} = T_{a\_min}$

$$V_{mp\_mod\_max} = V_{mp\_stc} - V_{mp\_stc} \times \gamma \times \left(T_{cell\_min} - T_{stc}\right)$$

$$V_{mp\_mod\_max} = 29.8 - 29.8 \times 0.0042 \times (12 - 25)$$

$$V_{mp\_mod\_max} = 31.43V$$

$$V_{oc\_mod\_max} = V_{oc\_stc} - V_{mp\_stc} \times \gamma \times \left(T_{cell\_min} - T_{stc}\right)$$

$$V_{oc\_mod\_max} = 37.6 - 37.6 \times 0.0042 \times (12 - 25)$$

$$V_{oc\_mod\_max} = 39.65V$$

The minimum and maximum MPP voltages would be used to identify the restriction of the number of modules that can be connected in a string to the inverter in the section below.

SMA Inverter

The voltage window of the SMA inverter is 155V to 480V, with a maximum allowable voltage of 600V. A 5% safety factor is used for the maximum voltages and 10% for minimum voltages.

$$155 \times 1.1 = 170.5\text{V}$$

$$480 \times 0.95 = 456\text{V}$$

$$600 \times 0.95 = 570\text{V}$$

The voltage window of the inverter becomes 170.5V to 456V, with a maximum allowable voltage of 570V.

$N_{s\_min} = 170.5 \div 25.29 = 6.7 = 7$

$N_{s\_max} = 456 \div 31.43 = 14.5 = 14$

Maximum voltage window check, $570 \div 39.65 = 14.3 = 14$

$I_{sc\_stc} = 8.92\text{A}$

The maximum input current for the inverter is 11A.

$N_{P\_max} = 11 \div 8.92 = 1.23 = 1$

In order to have a 2kW solar system, 8 Yingli modules are required,

$2000 \div 250 = 8$

As a result, the configuration of the system is 8 modules connected in series with no parallel strings.

Appendix 4

Appendix 4.1: Design of Battery Storage System

The main objective of the battery storage is to store energy generated during the day and offset loads during night time. As a result, the battery will be sized based on the average daily energy generation.

Appendix 3.3 shows the annual solar output is 2986kWh, this is equivalent to 8.18kWh per day. As the storage load is greater than 4kWh, a 48V battery system is used.

$\text{Daily Ah} = 8.18 \times 1000 \div 48 = 170\text{Ah}$

$\text{f}_{\text{temp}} = 0.98\ (\text{T}_{\text{min}} = 18°)$

$\text{Assume max DOD} = 0.7$

$\text{Actual Battery Capacity} = 170 \div (0.98 \times 0.7) = 248.4\text{Ah}$

The selected battery for the system is the Sonnenschein A602/370 with a capacity of 272Ah at C_{10}, 2V

$\text{N}_{\text{p}} = 272 \div 248.4 \approx 1$

$\text{N}_{\text{S}} = 48 \div 2 = 24$

$\text{N}_{\text{T}} = 1 \times 24 = 24$

Cost of battery = $468 each

$\text{Cost of battery system} = 468 \times 24 = \$11232$

Appendix 5

Appendix 5.1: NPV Calculation for Toyota Corolla

$$\text{NPV} = \sum_{\text{n=1}}^{\text{life time}} \text{cash flow} - \text{investment cost}$$

The section below uses the data collected in section 3.1.4 in the report.

Investment Cost

The vehicle cost of the Toyota Corolla is NZ$28198. This is the only investment cost.

Annual O&M Cost (F_n)

1. Maintenance Cost

The maintenance cost of Toyota Corolla varies between NZ$300 and NZ$400 every year throughout its service life.

2. Fuel Cost

The petrol fuel consumption of the Corolla is 0.061L/km and the petrol cost of the EV is NZ$2.26/L. It is assumed that the vehicle travel 30km/day on average.

$$\text{Annual Corolla Fuel Cost in Year 1} = 0.061 \times 30 \times 2.26 \times 365 = \text{NZ\$1509.57}$$

It is also assumed that the petrol price increases at a constant rate of 4% per annum over the lifespan of the vehicle.

$$\text{Annual Corolla Fuel Cost in Year n} = 1509.57 \times 1.04^{\text{n}}$$

The annual O&M is a cost and thus the future cash flow will be negative,

$$\text{Annual O}\&M \ = -(Maintennace\ Cost + Fuel\ Cost)$$

Table 6 below shows the results of the feasibility study on the purchase of the Toyota Corolla, where the future cash flow ($\mathrm{F_n}$) is converted to a present day value (PV) throughout the lifetime of the vehicle. By summing up the PV in every year, the NPV is found to be $-\mathrm{NZ\$51861}$.

Table 6: NPV calculation for Toyota Corolla

Year	Corolla Capital	Corolla Maintenance	Corolla Fuel	Annual O&M (F_n)	PWF	Present Value (PV)
0	$ 28,198	$ -	$ -	-$ 28,198	1.00	-$ 28,198
1	$ -	$ 300	$ 1,510	-$ 1,810	0.93	-$ 1,691
2	$ -	$ 400	$ 1,570	-$ 1,970	0.87	-$ 1,721
3	$ -	$ 300	$ 1,633	-$ 1,933	0.82	-$ 1,578
4	$ -	$ 400	$ 1,698	-$ 2,098	0.76	-$ 1,601
5	$ -	$ 300	$ 1,766	-$ 2,066	0.71	-$ 1,473
6	$ -	$ 400	$ 1,837	-$ 2,237	0.67	-$ 1,490
7	$ -	$ 300	$ 1,910	-$ 2,210	0.62	-$ 1,376
8	$ -	$ 400	$ 1,986	-$ 2,386	0.58	-$ 1,389
9	$ -	$ 300	$ 2,066	-$ 2,366	0.54	-$ 1,287
10	$ -	$ 400	$ 2,149	-$ 2,549	0.51	-$ 1,296
11	$ -	$ 300	$ 2,235	-$ 2,535	0.48	-$ 1,204
12	$ -	$ 400	$ 2,324	-$ 2,724	0.44	-$ 1,209
13	$ -	$ 300	$ 2,417	-$ 2,717	0.41	-$ 1,127
14	$ -	$ 400	$ 2,514	-$ 2,914	0.39	-$ 1,130
15	$ -	$ 300	$ 2,614	-$ 2,914	0.36	-$ 1,056
16	$ -	$ 400	$ 2,719	-$ 3,119	0.34	-$ 1,056
17	$ -	$ 300	$ 2,827	-$ 3,127	0.32	-$ 990
18	$ -	$ 400	$ 2,940	-$ 3,340	0.30	-$ 988
					NPV	-$ 51,861

Average Cost per km Travelled

The lifecycle cost of the Toyota Corolla is the same as the NPV in table 6, NZ$51861. Since the lifespan of the vehicle is assumed to be 200,000km. The average cost per kilometre travelled is calculated to be $NZ\$0.2593/km$,

$$51861 \div 200000 = NZ\$0.2593/km$$

Average Annual O&M Cost

The average annual O&M cost in today's value refers to the average of the PV column in table 6 from year 1 to year 18. The annual O&M is calculated to be NZ$1315.

Appendix 5.2: NPV Calculation for EV Nissan Leaf

$$\mathrm{NPV} = \sum_{\mathrm{n=1}}^{\mathrm{life\ time}} \mathrm{cash\ flow} - \mathrm{investment\ cost}$$

Investment Cost

The vehicle cost of the EV Nissan Leaf is NZ$39990 and the installation cost of the home charging station is NZ$652.

$$\text{Investment cost} = 39990 + 652 = \text{NZ\$}40642$$

Annual O&M Cost ($\mathrm{F_n}$)

1. Maintenance Cost

The maintenance cost of Nissan Leaf varies between NZ$94.8 and NZ$343.57 throughout its service life. The full scheduled data sheet is in appendix.

2. Fuel Cost

The fuel consumption of the EV is 0.173kWh/km and the electricity cost of charging the EV is NZ$0.84/kWh. It is assumed that the vehicle travel 30km/day on average.

$$\text{Annual EV Fuel Cost in Year 1} \ = 0.173 \times 0.84 \times 30 \times 365 = \text{NZ\$}1591$$

The study also assumed that the electricity cost remain constant over the lifespan of the vehicle.

3. Battery Replacement Cost

In figure 2 of the Nissan Leaf data sheet in appendix 1.4, the green trend line represents market leaders (Nissan Leaf) in lithium ion battery productions. The cost per kWh is US$300 in 2015 and it is predicted to reduce to US$150 by 2025. This is equivalent to a 50% reduction in battery cost.

The study assumes the battery will be replaced once over the 18 years of lifespan for the EV as the battery is expected to last for 10 years. The current battery cost is NZ$5978, thus the battery replacement cost is calculated to be NZ$2989,

$$5978 \times 50\% = \text{NZ\$}2989$$

$$\text{Annual O\&}M \ = -(Maintennace\ Cost + Fuel\ Cost + Replacement\ Cost)$$

It is noted that the battery replacement cost is only added in the 8^{th} year of the study.

Table 7 below shows the results of the feasibility study on the purchase of the EV Nissan Leaf, where the NPV is found to be $-\text{NZ\$}60332$.

Table 7: NPV Calculation of the EV Nissan Leaf

Year	EV Capital/ Replacement	EV Maintenance	EV Fuel	Annual O&M (F_n)	PWF	Present Value (PV)
0	$ 40,642	$ -	$ -	-$ 40,642	1.00	-$ 40,642
1	$ -	$ 95	$ 1,591	-$ 1,686	0.93	-$ 1,576
2	$ -	$ 264	$ 1,591	-$ 1,855	0.87	-$ 1,620
3	$ -	$ 95	$ 1,591	-$ 1,686	0.82	-$ 1,376
4	$ -	$ 344	$ 1,591	-$ 1,935	0.76	-$ 1,476
5	$ -	$ 95	$ 1,591	-$ 1,686	0.71	-$ 1,202
6	$ -	$ 264	$ 1,591	-$ 1,855	0.67	-$ 1,236
7	$ -	$ 95	$ 1,591	-$ 1,686	0.62	-$ 1,050
8	$ 2,989	$ 344	$ 1,591	-$ 4,924	0.58	-$ 2,866
9	$ -	$ 95	$ 1,591	-$ 1,686	0.54	-$ 917
10	$ -	$ 264	$ 1,591	-$ 1,855	0.51	-$ 943
11	$ -	$ 95	$ 1,591	-$ 1,686	0.48	-$ 801
12	$ -	$ 344	$ 1,591	-$ 1,935	0.44	-$ 859
13	$ -	$ 95	$ 1,591	-$ 1,686	0.41	-$ 700
14	$ -	$ 264	$ 1,591	-$ 1,855	0.39	-$ 719
15	$ -	$ 95	$ 1,591	-$ 1,686	0.36	-$ 611
16	$ -	$ 344	$ 1,591	-$ 1,935	0.34	-$ 655
17	$ -	$ 95	$ 1,591	-$ 1,686	0.32	-$ 534
18	$ -	$ 264	$ 1,591	-$ 1,855	0.30	-$ 549
					NPV	-$ 60,332

Average Cost per km Travelled

The lifecycle cost of the EV Nissan Leaf is the same as the NPV in table 7, NZ$60333. Since the lifespan of the vehicle is assumed to be 200,000km. The average cost per kilometre travelled is calculated to be $NZ\$0.3017/km$,

$$60333 \div 200000 = NZ\$0.3017/km$$

Average Annual O&M Cost

The average annual O&M cost in today's value refers to the average of the PV column in table 7 from year 1 to year 18. The annual O&M is calculated to be NZ$1094.

Appendix 5.3: NPV Calculation for EV Nissan Leaf and a 2kW Solar System

In this scenario, a 2kW solar system will be used to power the EV instead of using electricity from the grid. Thus the variables in the NPV formula need to be reconsidered.

$$\text{NPV} = \sum_{\text{n}=1}^{\text{life time}} \text{cash flow} - \text{investment cost}$$

The investment cost refers to the capital cost required to purchase the EV, as well as the 2kW solar system. The cash flow refers to the annual maintenance cost, fuel cost and replacement cost of the battery from using the EV. Similarly, maintenance cost is also associated with the 2kW solar system. The inverter is assumed to have a lifetime of 10 years, and hence the replacement cost for the inverter needs to be considered.

Table 8: Net Solar Savings in the EV Scenario

Year	Total Solar Generation (kWh)	EV Load (kWh)	Net Generation (kWh)	Net Solar Savings
1	2887	1,894	992	$ 833
2	2867	1,894	973	$ 817
3	2848	1,894	954	$ 801
4	2829	1,894	935	$ 785
5	2810	1,894	916	$ 769
6	2791	1,894	897	$ 753
7	2772	1,894	878	$ 738
8	2754	1,894	860	$ 722
9	2735	1,894	841	$ 706
10	2717	1,894	823	$ 691
11	2699	1,894	805	$ 676
12	2681	1,894	786	$ 661
13	2663	1,894	768	$ 646
14	2645	1,894	751	$ 631
15	2627	1,894	733	$ 616
16	2610	1,894	715	$ 601
17	2592	1,894	698	$ 586
18	2575	1,894	680	$ 572
19	2558	-	2,558	$ 2,148
20	2540	-	2,540	$ 2,134
21	2523	-	2,523	$ 2,120
22	2506	-	2,506	$ 2,105
23	2490	-	2,490	$ 2,091
24	2473	-	2,473	$ 2,077
25	2456	-	2,456	$ 2,063

Investment Cost

The cost of the solar panel for the 2kW system is NZ$2278 with an inverter cost of NZ$1359.

$$\text{Investment cost} = 12444 + 2278 + 1359 = \text{NZ\$}16081$$

Solar System Operating Cost

The lifetime of the inverter is assumed to be 10 years.

Corolla Fuel Cost

The fuel consumption of the Corolla is 0.061L/km and the petrol cost of the EV is NZ$2.26/L. It is assumed that the vehicle travel 30km/day on average.

$$\text{Annual Corolla Fuel Cost in Year 1} = 0.061 \times 30 \times 2.26 \times 365 = \text{NZ\$}1509.57$$

It is also assumed that the petrol price increases at a constant rate of 4% per annum over the lifespan of the vehicle. For example,

$$\text{Annual Corolla Fuel Cost in Year 2} = 1509.57 \times 1.04 = \text{NZ\$}1569.95$$

Table 9: Feasibility of EV with 2kW Solar Against Toyota Corolla

Year	Capital/ Replacement	Solar Maintenance	Net Solar Savings	EV Maintenance	Net Annual O&M (F_n)	PWF	Present Value (PV)
0	$ 44,279	$ -	$ -	$ -	-$ 44,279	1.00	-$ 44,279
1	$ -	$ 330	$ 833	$ 95	$ 409	0.93	$ 382
2	$ -	$ 330	$ 817	$ 264	$ 224	0.87	$ 195
3	$ -	$ 330	$ 801	$ 95	$ 376	0.82	$ 307
4	$ -	$ 330	$ 785	$ 344	$ 111	0.76	$ 85
5	$ -	$ 330	$ 769	$ 95	$ 344	0.71	$ 245
6	$ -	$ 330	$ 753	$ 264	$ 160	0.67	$ 106
7	$ -	$ 330	$ 738	$ 95	$ 313	0.62	$ 195
8	$ 2,989	$ 330	$ 722	$ 344	-$ 2,941	0.58	-$ 1,712
9	$ -	$ 330	$ 706	$ 95	$ 282	0.54	$ 153
10	$ 1,359	$ 330	$ 691	$ 264	-$ 1,261	0.51	-$ 641
11	$ -	$ 330	$ 676	$ 95	$ 251	0.48	$ 119
12	$ -	$ 330	$ 661	$ 344	-$ 13	0.44	-$ 6
13	$ -	$ 330	$ 646	$ 95	$ 221	0.41	$ 92
14	$ -	$ 330	$ 631	$ 264	$ 37	0.39	$ 14
15	$ -	$ 330	$ 616	$ 95	$ 191	0.36	$ 69
16	$ -	$ 330	$ 601	$ 344	-$ 73	0.34	-$ 25
17	$ -	$ 330	$ 586	$ 95	$ 161	0.32	$ 51
18	$ -	$ 330	$ 572	$ 264	-$ 22	0.30	-$ 7
19	$ -	$ 330	$ 2,148	$ -	$ 1,818	0.28	$ 503
20	$ 1,359	$ 330	$ 2,134	$ -	$ 445	0.26	$ 115
21	$ -	$ 330	$ 2,120	$ -	$ 1,790	0.24	$ 432
22	$ -	$ 330	$ 2,105	$ -	$ 1,775	0.23	$ 401
23	$ -	$ 330	$ 2,091	$ -	$ 1,761	0.21	$ 372
24	$ -	$ 330	$ 2,077	$ -	$ 1,747	0.20	$ 344
25	$ -	$ 330	$ 2,063	$ -	$ 1,733	0.18	$ 319
						NPV	-$ 42,168

Average Annual O&M Cost

The average net annual O&M cost in today's value refers to the average of the present value column from year 1 to 25 in table 9. It is calculated to be –NZ$84 (A positive present value refers to annual savings or a negative annual cost).

Appendix 5.4: NPV Calculation for EV with 2kW Solar and Battery Storage

Investment Cost

The vehicle cost of the EV Nissan Leaf is NZ$39990 and the installation cost of the home charging station is NZ$652.

$$\text{Investment cost} = 39990 + 652 = \text{NZ\$}40642$$

Annual O&M Cost (F_n)

1. Maintenance Cost

The maintenance cost of Nissan Leaf varies between NZ$94.8 and NZ$343.57 throughout its service life. The full scheduled data sheet is in appendix 1.2.

2. Fuel Cost

The fuel consumption of the EV is 0.173kWh/km and the electricity cost of charging the EV is NZ$0.84/kWh. It is assumed that the vehicle travel 30km/day on average.

$$\text{Annual EV Fuel Cost in Year 1} = 0.173 \times 0.84 \times 30 \times 365 = \text{NZ\$}1591$$

The study also assumed that the electricity cost remain constant over the lifespan of the vehicle.

Table 10: Feasibility of EV with 2kW Solar Against Toyota Corolla

Year	Capital/ Replacement	Solar Maintenance	Net Solar Savings	EV Maintenance	Net Annual O&M (F_n)	PWF	Present Value (PV)
0	$ 55,512	$ -	$ -	$ -	-$ 55,512	1.00	-$ 55,512
1	$ -	$ 330	$ 833	$ 95	$ 409	0.93	$ 382
2	$ -	$ 330	$ 817	$ 264	$ 224	0.87	$ 195
3	$ -	$ 330	$ 801	$ 95	$ 376	0.82	$ 307
4	$ -	$ 330	$ 785	$ 344	$ 111	0.76	$ 85
5	$ -	$ 330	$ 769	$ 95	$ 344	0.71	$ 245
6	$ -	$ 330	$ 753	$ 264	$ 160	0.67	$ 106
7	$ -	$ 330	$ 738	$ 95	$ 313	0.62	$ 195
8	$ 2,989	$ 330	$ 722	$ 344	-$ 2,941	0.58	-$ 1,712
9	$ -	$ 330	$ 706	$ 95	$ 282	0.54	$ 153
10	$ 1,359	$ 330	$ 691	$ 264	-$ 1,261	0.51	-$ 641
11	$ -	$ 330	$ 676	$ 95	$ 251	0.48	$ 119
12	$ 8,672	$ 330	$ 661	$ 344	-$ 8,685	0.44	-$ 3,856
13	$ -	$ 330	$ 646	$ 95	$ 221	0.41	$ 92
14	$ -	$ 330	$ 631	$ 264	$ 37	0.39	$ 14
15	$ -	$ 330	$ 616	$ 95	$ 191	0.36	$ 69
16	$ -	$ 330	$ 601	$ 344	-$ 73	0.34	-$ 25
17	$ -	$ 330	$ 586	$ 95	$ 161	0.32	$ 51
18	$ -	$ 330	$ 572	$ 264	-$ 22	0.30	-$ 7
19	$ -	$ 330	$ 2,148	$ -	$ 1,818	0.28	$ 503
20	$ 1,359	$ 330	$ 2,134	$ -	$ 445	0.26	$ 115
21	$ -	$ 330	$ 2,120	$ -	$ 1,790	0.24	$ 432
22	$ -	$ 330	$ 2,105	$ -	$ 1,775	0.23	$ 401
23	$ -	$ 330	$ 2,091	$ -	$ 1,761	0.21	$ 372
24	$ -	$ 330	$ 2,077	$ -	$ 1,747	0.20	$ 344
25	$ -	$ 330	$ 2,063	$ -	$ 1,733	0.18	$ 319
						NPV	-$ 57,251

Average Annual O&M Cost

The average net annual O&M cost is calculated to be NZ$70.

Appendix 4.5 to Appendix 4.7 uses the same methods to calculate the NPV as the EV scenario and only the results are recorded below

Appendix 5.5 NPV Calculation for Yamaha Cygnus

Table 11: NPV Calculation for Yamaha Cygnus

Year	Yamaha Capital	Yamaha Maintenance	Yamaha Fuel	Annual O&M (F_n)	PWF	Present Value (PV)
0	$ 4,347	$ -	$ -	-$ 4,347	1.00	-$ 4,347
1	$ -	$ 108	$ 495	-$ 603	0.93	-$ 563
2	$ -	$ 522	$ 515	-$ 1,037	0.87	-$ 906
3	$ -	$ 326	$ 535	-$ 861	0.82	-$ 703
4	$ -	$ 304	$ 557	-$ 861	0.76	-$ 657
5	$ -	$ 326	$ 579	-$ 905	0.71	-$ 645
6	$ -	$ 522	$ 602	-$ 1,124	0.67	-$ 749
7	$ -	$ 108	$ 626	-$ 734	0.62	-$ 457
8	$ -	$ 522	$ 651	-$ 1,173	0.58	-$ 683
9	$ -	$ 326	$ 677	-$ 1,003	0.54	-$ 546
10	$ -	$ 304	$ 704	-$ 1,008	0.51	-$ 513
11	$ -	$ 326	$ 733	-$ 1,059	0.48	-$ 503
					NPV	-$ 11271

Appendix 5.6 NPV Calculation for E-Bike Easy Motion

Table 12: NPV Calculation for E-Bike

Year	E-Bike Capital/ Replacement	E-Bike Maintenance	E-Bike Fuel	Annual O&M (F_n)	PWF	Present Value (PV)
0	$ 6,284	$ -	$ -	-$ 6,284	1.00	-$ 6,284
1	$ -	$ 143	$ 37	-$ 180	0.93	-$ 168
2	$ -	$ 143	$ 37	-$ 180	0.87	-$ 157
3	$ -	$ 143	$ 37	-$ 180	0.82	-$ 147
4	$ -	$ 143	$ 37	-$ 180	0.76	-$ 137
5	$ 929	$ 143	$ 37	-$ 1,108	0.71	-$ 790
6	$ -	$ 143	$ 37	-$ 180	0.67	-$ 120
7	$ -	$ 143	$ 37	-$ 180	0.62	-$ 112
8	$ -	$ 143	$ 37	-$ 180	0.58	-$ 105
9	$ -	$ 143	$ 37	-$ 180	0.54	-$ 98
10	$ -	$ 143	$ 37	-$ 180	0.51	-$ 91
11	$ -	$ 143	$ 37	-$ 180	0.48	-$ 85
					NPV	-$ 8,293

Appendix 5.7 Net Solar Savings with the E-Bike Scenario

Table 13: Net Solar Savings with E-Bike

Year	Total Solar Generation (kWh)	EV Load (kWh)	Net Generation (kWh)	Net Solar Savings
1	2887	43.8	2,843	$ 2,388
2	2867	43.8	2,823	$ 2,372
3	2848	43.8	2,804	$ 2,356
4	2829	43.8	2,785	$ 2,339
5	2810	43.8	2,766	$ 2,324
6	2791	43.8	2,747	$ 2,308
7	2772	43.8	2,729	$ 2,292
8	2754	43.8	2,710	$ 2,276
9	2735	43.8	2,692	$ 2,261
10	2717	43.8	2,673	$ 2,246
11	2699	43.8	2,655	$ 2,230
12	2681	-	2,681	$ 2,252
13	2663	-	2,663	$ 2,237
14	2645	-	2,645	$ 2,222
15	2627	-	2,627	$ 2,207
16	2610	-	2,610	$ 2,192
17	2592	-	2,592	$ 2,177
18	2575	-	2,575	$ 2,163
19	2558	-	2,558	$ 2,148
20	2540	-	2,540	$ 2,134
21	2523	-	2,523	$ 2,120
22	2506	-	2,506	$ 2,105
23	2490	-	2,490	$ 2,091
24	2473	-	2,473	$ 2,077
25	2456	-	2,456	$ 2,063

Appendix 5.8 NPV of E-Bike with 2kW Solar System

Table 14: NPV of E-Bike with 2kW Solar System

Year	System Capital/ Replacement	Solar Maintenance	Net Solar Savings	E-Bike Maintenance	Annual O&M (F_n)	PWF	Present Value (PV)
0	$ 9,921	$ -	$ -	$ -	-$ 9,921	1.00	-$ 9,921
1	$ -	$ 330	$ 2,388	$ 143	$ 1,915	0.93	$ 1,790
2	$ -	$ 330	$ 2,372	$ 143	$ 1,899	0.87	$ 1,658
3	$ -	$ 330	$ 2,356	$ 143	$ 1,883	0.82	$ 1,537
4	$ -	$ 330	$ 2,339	$ 143	$ 1,867	0.76	$ 1,424
5	$ 929	$ 330	$ 2,324	$ 143	$ 922	0.71	$ 657
6	$ -	$ 330	$ 2,308	$ 143	$ 1,835	0.67	$ 1,223
7	$ -	$ 330	$ 2,292	$ 143	$ 1,819	0.62	$ 1,133
8	$ -	$ 330	$ 2,276	$ 143	$ 1,804	0.58	$ 1,050
9	$ -	$ 330	$ 2,261	$ 143	$ 1,788	0.54	$ 973
10	$ 1,359	$ 330	$ 2,246	$ 143	$ 414	0.51	$ 210
11	$ -	$ 330	$ 2,230	$ 143	$ 1,757	0.48	$ 835
12	$ -	$ 330	$ 2,252	$ -	$ 1,922	0.44	$ 853
13	$ -	$ 330	$ 2,237	$ -	$ 1,907	0.41	$ 791
14	$ -	$ 330	$ 2,222	$ -	$ 1,892	0.39	$ 734
15	$ -	$ 330	$ 2,207	$ -	$ 1,877	0.36	$ 680
16	$ -	$ 330	$ 2,192	$ -	$ 1,862	0.34	$ 631
17	$ -	$ 330	$ 2,177	$ -	$ 1,847	0.32	$ 585
18	$ -	$ 330	$ 2,163	$ -	$ 1,833	0.30	$ 542
19	$ -	$ 330	$ 2,148	$ -	$ 1,818	0.28	$ 503
20	$ 1,359	$ 330	$ 2,134	$ -	$ 445	0.26	$ 115
21	$ -	$ 330	$ 2,120	$ -	$ 1,790	0.24	$ 432
22	$ -	$ 330	$ 2,105	$ -	$ 1,775	0.23	$ 401
23	$ -	$ 330	$ 2,091	$ -	$ 1,761	0.21	$ 372
24	$ -	$ 330	$ 2,077	$ -	$ 1,747	0.20	$ 344
25	$ -	$ 330	$ 2,063	$ -	$ 1,733	0.18	$ 319
						NPV	$ 9,871

Appendix 5.9 NPV of E-Bike with 2kW Solar System and Battery Storage

Table 15: NPV of E-Bike with 2kW Solar System and Battery Storage

Year	System Capital/ Replacement	Solar Maintenance	Net Solar Savings	E-Bike Maintenance	FV	PWF	Present Value (PV)
0	$ 21,154	$ -	$ -	$ -	-$ 21,154	1.00	-$ 21,154
1	$ -	$ 330	$ 2,388	$ 143	$ 1,915	0.93	$ 1,790
2	$ -	$ 330	$ 2,372	$ 143	$ 1,899	0.87	$ 1,658
3	$ -	$ 330	$ 2,356	$ 143	$ 1,883	0.82	$ 1,537
4	$ -	$ 330	$ 2,339	$ 143	$ 1,867	0.76	$ 1,424
5	$ 929	$ 330	$ 2,324	$ 143	$ 922	0.71	$ 657
6	$ -	$ 330	$ 2,308	$ 143	$ 1,835	0.67	$ 1,223
7	$ -	$ 330	$ 2,292	$ 143	$ 1,819	0.62	$ 1,133
8	$ -	$ 330	$ 2,276	$ 143	$ 1,804	0.58	$ 1,050
9	$ -	$ 330	$ 2,261	$ 143	$ 1,788	0.54	$ 973
10	$ 1,359	$ 330	$ 2,246	$ 143	$ 414	0.51	$ 210
11	$ -	$ 330	$ 2,230	$ 143	$ 1,757	0.48	$ 835
12	$ 8,672	$ 330	$ 2,252	$ -	-$ 6,750	0.44	-$ 2,997
13	$ -	$ 330	$ 2,237	$ -	$ 1,907	0.41	$ 791
14	$ -	$ 330	$ 2,222	$ -	$ 1,892	0.39	$ 734
15	$ -	$ 330	$ 2,207	$ -	$ 1,877	0.36	$ 680
16	$ -	$ 330	$ 2,192	$ -	$ 1,862	0.34	$ 631
17	$ -	$ 330	$ 2,177	$ -	$ 1,847	0.32	$ 585
18	$ -	$ 330	$ 2,163	$ -	$ 1,833	0.30	$ 542
19	$ -	$ 330	$ 2,148	$ -	$ 1,818	0.28	$ 503
20	$ 1,359	$ 330	$ 2,134	$ -	$ 445	0.26	$ 115
21	$ -	$ 330	$ 2,120	$ -	$ 1,790	0.24	$ 432
22	$ -	$ 330	$ 2,105	$ -	$ 1,775	0.23	$ 401
23	$ -	$ 330	$ 2,091	$ -	$ 1,761	0.21	$ 372
24	$ -	$ 330	$ 2,077	$ -	$ 1,747	0.20	$ 344
25	$ -	$ 330	$ 2,063	$ -	$ 1,733	0.18	$ 319
						NPV	-$ 5,212

Appendix 6

Appendix 6.1: Calculation for Carbon Emission Reduction

The fuel consumption for the Toyota Corolla is 0.061L/km. For the assumed VKT in the study of 30km/day, the annual fuel consumption is $668L$ of petrol,

$$0.061 \times 30 \times 365 \approx 668L/year$$

1L petrol = 2.31 kg CO2-e (CARBON TRUST, 2011)

$\text{Annual Carbon Emission} = 668 \times 2.31 \approx 1543$ kg CO2-e per vehicle.

Fuel Consumption of Yamaha Cygnus is 0.03L/km. For the assumed VKT in the study of 20km/day, the annual fuel consumption is $219L$ of petrol,

$$0.03 \times 20 \times 365 = 219L/year$$

1L petrol = 2.31 kg CO2-e (CARBON TRUST, 2011)

$\text{Annual Carbon Emission} = 219 \times 2.31 \approx 506$ kg CO2-e per motorbike.