

# Making New Zealand's Energy System Renewable

Master of Sustainable Cities - 3rd Semester 2014

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**Synopsis**

New Zealand is highly dependent on fossil fuels for its transport sector, and in recent years the vulnerability of the New Zealand economy and society to its dependence on fossil fuels has been exposed.

This report investigates three options for New Zealand to partly shift away from fossil fuels, towards renewable energy in the electricity system, and light vehicle fleet by 2040.

The study focuses on making the electricity system 100% renewable and switching 50% of the light vehicle fuel consumption to renewable energy by 2040. The alternative energy supply options for light vehicles that were assessed were: electric vehicles; ethanol/biodiesel; and methanol/DME.

Each scenario assessed in this study was done in EnergyPLAN.

It was determined in this study that a 100% renewable electricity system in New Zealand is technically possible. Each scenario would consist of increased wind and geothermal electricity capacity, and instead of fossil fuel condensing power plants, a 1200 MW biomass condensing power plant would be required in order to meet peaking demands. The electric vehicle scenario would require a pumped hydro power plant to store some electricity for the electric vehicles. The ethanol/biodiesel scenario would not require an addition of pumped hydro but wind and geothermal would be increased to achieve a 100% renewable system. The methanol/DME scenario would require electrolyzers for producing hydrogen required for making methanol/DME. This would require the largest increase in wind capacity out of all the scenarios.

The aim of this study was to demonstrate that renewable alternatives are technically possible. Further research should be carried out into these scenarios in terms of further refinements and feasibility studies.

## Preface

This report was written for the internship semester of the Master Programme of Sustainable Cities at Aalborg University Copenhagen between 1st September 2013 and the 8th January 2014. It was carried out in the context of the semester theme which was focused on:

*“Applying theoretical insight and the methodological knowledge obtained during semester 1 and 2 in a real-life situation in a non-Danish setting.”*

This project was carried out for Generation Zero but I was located at the Department of Development and Planning, Aalborg University Copenhagen. The results from this project will be communicated with Generation Zero, and it is expected that my Master Thesis will build upon this research and this research will also be presented to Generation Zero.

This project was carried out with supervision from David Connolly whom is affiliated with the Department of Development and Planning, Aalborg University Copenhagen. A big thanks goes to David for the support he gave me during this project.

This project relied heavily on data collected from the New Zealand Government and a big thanks goes to the people involved in producing the data. Also a big thanks goes to Nicky McLean who helped me source the data from New Zealand and to understand it.

## Abstract

New Zealand is highly dependent on fossil fuels for its transport sector, and in recent years the vulnerability of the New Zealand economy and society to its dependence on fossil fuels has been exposed. For example after the 2008 Global Financial Crisis, when the price of petrol and diesel rose sharply. Not only are there economic implications from this dependence, but the environmental impact from fossil fuel consumption is becoming increasingly apparent, as can be seen with anthropogenic climate change. If New Zealand is to avoid increased economic and social risk in the next few decades, the country should shift from fossil fuels to renewable energy sources.

This report investigates three options for New Zealand to partly shift away from fossil fuels, towards renewable energy in the electricity system, and light vehicle fleet by 2040. The study focuses on making the electricity system 100% renewable and switching 50% of the light vehicle fuel consumption to renewable energy by 2040. The alternative energy supply options for light vehicles that were assessed were: electric vehicles; ethanol/biodiesel; and methanol/DME.

This study uses Choice Awareness Theory as a basis for the methodology. It is theorised that the organisations and the institutional framework surrounding the current regime will influence the awareness of choice for future energy systems. When society aims to change its objectives, which implies that a radical technological change may occur, the existing organisations will try to make it seem that there is no option to choose a radical change, and the only option is to choose an option presented by the current organisations, or nothing at all. When such a situation arises it is important to understand that this is occurring and that alternative choices are possible, and that the awareness of them needs to be raised at various levels.

This study theorises that the options presented for the future energy system of New Zealand by the New Zealand Government do not represent the only choices.

Each scenario assessed in this study was done in EnergyPLAN. EnergyPLAN is a tool that was developed in parallel with the Choice Awareness Theory. The first strategy in the theory is about designing concrete technical alternatives, and EnergyPLAN allows the user to do this. It is a comprehensive tool that provides the possibility to model many different energy system configurations. The tool can be used to present state-of-the-art energy system analyses for 100% renewable energy systems, and it allows the user to determine the technical viability of the proposed energy system.

It was determined in this study that a 100% renewable electricity system in New Zealand is technically possible. Each scenario would consist of increased wind and geothermal electricity capacity, and instead of fossil fuel condensing power plants, a 1200 MW biomass condensing power plant would be required in order to meet peaking demands. The electric vehicle scenario would require a pumped hydro power plant to store some electricity for the electric vehicles. The ethanol/biodiesel scenario would not require an addition of pumped hydro but wind and geothermal would be increased to achieve a 100% renewable system. It is also possible to supply enough biomass for the biofuels in this scenario in New Zealand. The methanol/DME scenario would require electrolyzers for producing hydrogen required for making methanol/DME. This would require the largest increase in wind capacity out of all the scenarios. This scenario is similar to the ethanol/biodiesel scenario but it relies more on electricity to produce the biofuel and less biomass. This means that this scenario could be implemented quicker since less biomass is required to grow over the coming years.

It was not possible to select an ideal scenario for New Zealand's energy future in this study, which was not the aim. The aim was to demonstrate that renewable alternatives are technically possible. Further research should be carried out into these scenarios in terms of further refinements and feasibility studies.

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## 1 The New Zealand Energy Situation

Today the New Zealand population exists within a modern society. With a maturing market-based economy New Zealand is considered prosperous and developed. Gross Domestic Product (Purchasing Power Parity) per capita is around \$30,000 USD as of 2013 (International Monetary Fund, 2013). The economy consists of mainly two export sectors being tourism and agriculture. One of the critical elements underpinning these sectors, and the society, is a well-functioning and efficient energy system. Access to energy is absolutely necessary to enable these sectors to perform as they do today. Furthermore, access by the citizens to energy is vital in order to maintain the lifestyles that they have. Like any other modern society New Zealand's energy system consists of four main energy forms, namely: electrical energy; liquefied energy (mostly fossil fuels); gaseous energy; and heat energy. Each form of energy is utilised to support a particular aspect of the society.

A key element of the energy system is to serve a well-functioning transport system. Over the past few decades as the economy of New Zealand has developed, a dependence on liquid energy, or liquefied fossil fuels, has also developed. This is shown below in Figure 1-1 in the red part from 1990 to 2011. The dependence of the society on all other forms of energy in New Zealand is also shown in Figure 1-1, for example electricity is shown in blue.

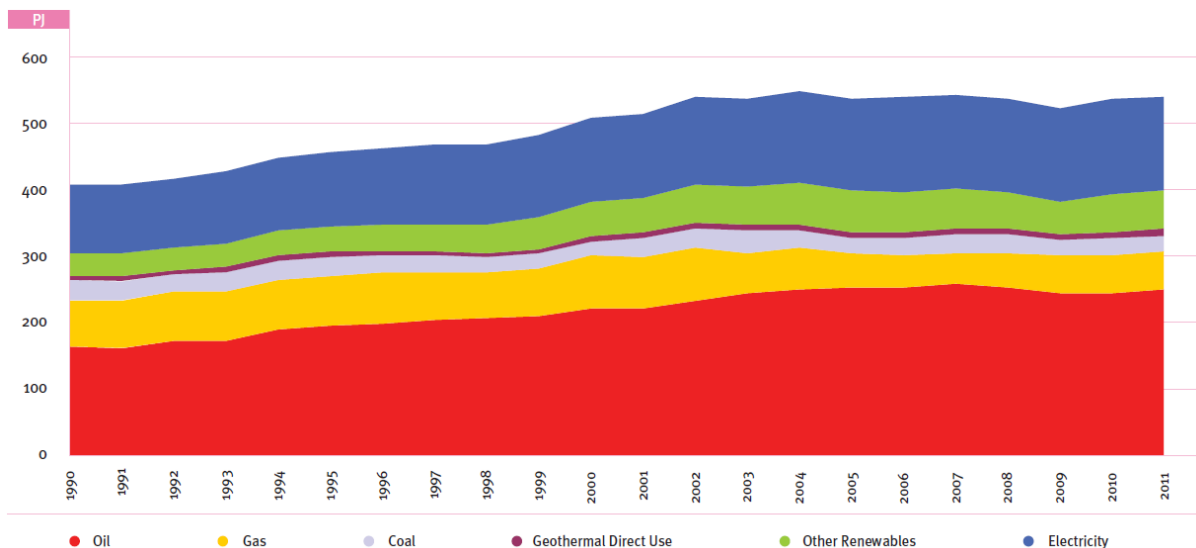


Figure 1-1: New Zealand total consumer energy by fuel for 1990 – 2011 (Ministry of Economic Development, 2012)

The dependence on fossil fuels happened partly because fossil fuels were relatively cheap and abundant. However in recent years there has been a couple of occasions where the vulnerability of the New Zealand society (and the rest of the modern world) has been exposed to the risk from its dependence on fossil fuels. For example in Figure 1-2, following the 2008 Global Financial Crisis (GFC) a spike in real prices for petrol and diesel is seen in 2008. And a general rise is seen in the real price from 1998 to 2011.

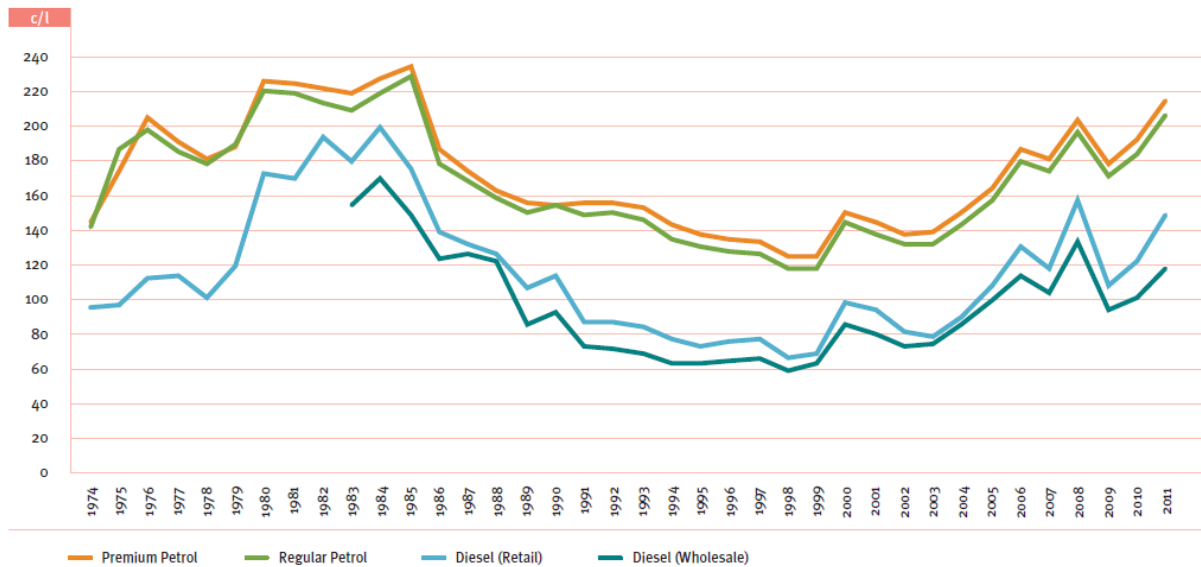


Figure 1-2: Real petrol and diesel prices from 1974 - 2011 (Ministry of Economic Development, 2012)

Furthermore, as the science around climate change improves and progressively gets closer to proving that anthropogenic climate change exists (IPCC, 2013), the likeliness of the price for carbon being implemented gets higher. This would increase the cost of carbon intense fuels, like petrol and diesel, even further and thus this is another instance where the vulnerability of being dependent on fossil fuels is exposed.

Aside from the economic vulnerabilities facing the New Zealand society from climate change, there are also the planetary implications from climate change. As a whole, New Zealand does not contribute much to the global greenhouse gas emissions from its energy sector. But based on equality and ethics, being a nation closely tied with most other modern nations across the globe and having global responsibilities and obligations, if these other countries are attempting to reduce their greenhouse gas emissions, New Zealand is politically obliged to do so as well.

## 1.1 Some alternative options

In recent years numerous renewable energy options have entered the market to replace fossil fuels for light vehicles, for example electric vehicles, ethanol, biodiesel and so on.

Electric vehicles are becoming increasingly popular as an alternative vehicle to the Combustion Engine Vehicle (CEV) with new models being released by the motor manufacturing companies each year. However, currently in New Zealand there are less than one thousand electric vehicles in the country (Ministry of Transport, 2013), compared with around 3,000,000 fossil fuel powered vehicles in total.

A large amount of research was carried out in New Zealand into ethanol from woody biomass during 2007-2009 (Scion, 2007) (Scion, 2008) (Scion, 2009a) (Scion, 2009b) and this research showed that ethanol is a viable option in New Zealand for light vehicles. Ethanol is currently being used partly in a petrol blend. This is produced as a by-product from dairy processing. But the highest blends are only around 10% ethanol and this blend is not widespread yet.

Biodiesel has been found to be a good replacement for diesel and can be produced from purpose grown crops such as rapeseed. In Sweden biodiesel is the most common biofuel but in New Zealand biodiesel is not very common.

In the Danish research project called the Coherent Energy and Environmental System Analysis (CEESA) it was concluded that methanol is a suitable option for biofuel as opposed to ethanol because it requires a simpler procedure to produce and it uses less biomass than ethanol per fuel output (Aalborg University, 2013). It achieves this by using more electricity in the production process, than ethanol for example. Dimethyl Ether (DME) can also be easily converted from methanol, and is a replacement for diesel.

## 1.2 Focus of this report

This report has been prepared for Semester 3 of the Master Program. The report aims to investigate some options New Zealand has to shift its energy sector away from the economic volatility of fossil fuels, towards less economically volatile renewable energy sources, such as biofuels.

This study does not investigate all elements of the energy sector. It focuses on the electricity system as a whole (a large part of the sector), and the light vehicle fleet. Previous research has investigated turning the New Zealand electricity sector into 100% renewable (Mason, Page, & Williamson, 2010) (Mason, Page, & Williamson, 2013). However these studies did not consider the transport sector in the energy system. The light vehicle fleet in New Zealand is an abnormally major component of the energy sector in New Zealand, consuming around 22% of the energy, and this study will incorporate this sector along with the electricity sector.

Heavy transport and air travel is excluded in this study. It is expected that the transition, if it occurs, would be a long process and there is plenty of time for the research to investigate these other parts of the energy sector as well. Also, it is expected that different components of the energy sector will shift away from fossil fuels at different stages and beginning with the light transport fleet appears to be a suitable starting point. It is assumed that smaller vehicles make it easier to change to alternative energy types compared with larger vehicles that consume more energy such as trucks and aeroplanes.

The research question asked in this study is, "How would the New Zealand energy system be technically designed, when it is composed of 100% renewable electricity and 50% of the light vehicles (reference year 2011) are replaced with either electric vehicles, ethanol/biodiesel, or methanol/DME?"

And.

"What would be some of the implications from this design, in terms of electricity and primary energy demand, carbon dioxide equivalent emissions, and costs?"

These questions have not been investigated in New Zealand before and they are the kind of questions that need to be answered if New Zealand is to shift away from fossil fuels. Not only are the questions important for understanding the technical requirements, but the answers are also important for creating awareness about the opportunities that exist and that can be achieved in New Zealand. Creating the awareness is the first step required before these changes can be demanded and initiated.

## 1.3 Generation Zero

This report has been prepared for Semester 3 of the Master Program, but it has also been prepared, and will be presented, to the organisation called Generation Zero from New Zealand, since this was my internship organisation. Generation Zero is a group of young New Zealanders who work on creating political action on climate change in order to create a zero carbon New Zealand (Generation Zero, 2013a). The organisation is heavily involved in creating awareness around climate change and is engaged in providing alternative solutions to lead New Zealand in a direction away from an intense carbon economy.

The organisation has initiated a project called 100% Possible and the main aim of this project is in line with the aims of this present study. 100% Possible is a collaborative campaign between Generation Zero, 350 Aotearoa

and WWF aimed to help move New Zealand beyond fossil fuels. The ambition of the campaign is to promote the idea about powering New Zealand homes, businesses and industries with 100% renewable energy. The project goes further by promoting and publicising options for smart transport networks also powered by renewable energy. The project also looks at how the New Zealand economy can be strong and benefit when it does not depend on fossil fuels (Generation Zero, 2013b)

Ultimately the aim of 100% Possible would be to promote how New Zealand could have a 100% renewable society. This study fits in with the aim of this campaign as it investigates the current state of the energy system in New Zealand and investigates possible pathways towards a society driven by more renewable energy over the next decades.

#### **1.4 Structure of the report**

This report is a scientific study and therefore it is structured this way. The first section below describes the theory underpinning the methodology applied in this study which is Choice Awareness Theory. This theory was chosen since it is focused on creating awareness of choices in the energy system, and it provides strategies for achieving this. This is relevant for this study since the aim is demonstrate more choices for New Zealand's energy future. Following the theory description, the methodology to determine how New Zealand could shift from fossil fuels to renewable energy is described. One of the strategies from the theory is that of designing concrete technical alternatives to the current system. The analytical framework of this study is focused on creating these alternatives using EnergyPLAN, which is an energy system analysis tool designed with the purpose of creating technical energy system alternatives. EnergyPLAN provides the appropriate results for communication to the wider public and experts in the energy field. Results relate to the technical validity of the alternative energy systems, as well as economic, and energy and environmental implications. The main findings from the assessment of the alternatives will be presented and discussed in the report in terms of their strengths and weaknesses, and the next steps will be described in the concluding section.

Since this topic is a big issue which will take a long time and a lot of effort to solve, it is expected that this research will only be one piece of the puzzle, and it will form the preliminary work for the fourth semester Master Thesis that will go further into detail.

## 2 Theory: What choice does New Zealand have?

The purpose of this study is to assess some possible future energy scenarios for New Zealand for future decades. Therefore the research carried out for the New Zealand energy system in this study investigates the future until 2040. It is assumed that a transition to a more sustainable energy system would take a number of years therefore a long time horizon is deemed appropriate.

The New Zealand Government has already released what it predicts for the energy system in the future to 2029. Being the political institution in New Zealand with the authority to implement new policies and generally steer the direction of New Zealand's society and energy system, the New Zealand Government is a good proxy for understanding where the New Zealand energy system is going, and this helps for predicting the future energy trends. Through the Ministry of Economic Development the government analyses and forecasts future energy trends in New Zealand and implements the appropriate energy policy. The New Zealand Government released a document called "Energy Outlook 2011" which describes the predicted future energy system to 2029. This document is one of the main energy related documents given publicity in New Zealand and is seen as the main document for understanding where New Zealand's energy system is heading. Figure 2-1 below is presented to illustrate the future electricity generation mix predicted for the future by the Government.

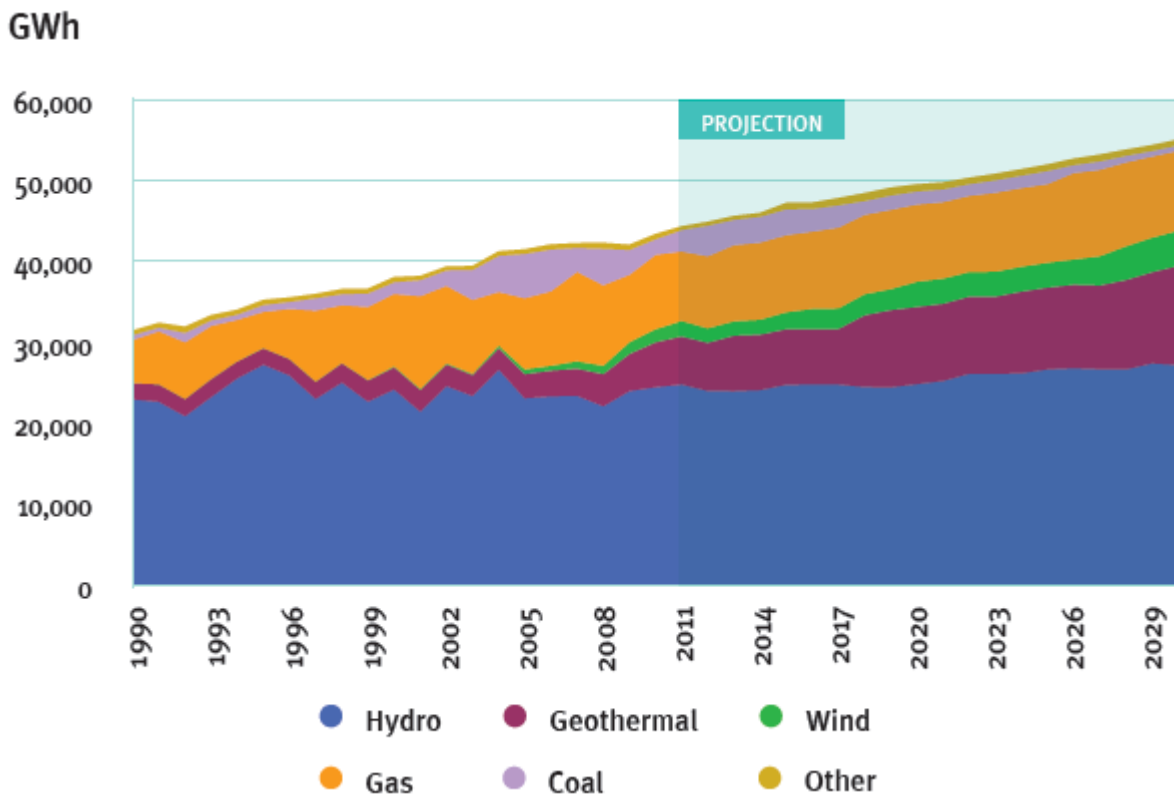


Figure 2-1: Electricity generation by fuel type projection from 1990 - 2029. (Ministry of Economic Development, 2011)

Figure 2-1 shows that the electricity consumption is predicted to grow continuously into the future following the same growth rate as previous years. There seems to be no indication of conservation measures leading to decreased electricity consumption. This figure also shows that the projection for electricity production in the next decades is still expected to be dominated by hydro power with increasing geothermal and wind penetration. However the figure also shows a continued reliance on natural gas and small amounts of coal and other (biomass) sources. But coal will be phased out over time.

The Government has also released a projection for road transport liquid fuel demand for future decades which is shown in Figure 2-2. This figure is a good indicator of the political thinking and action that will occur around liquid fuels in the future. For example it is a good indicator about the kind of policies that will be introduced for fossil fuels and other alternative renewable fuels.

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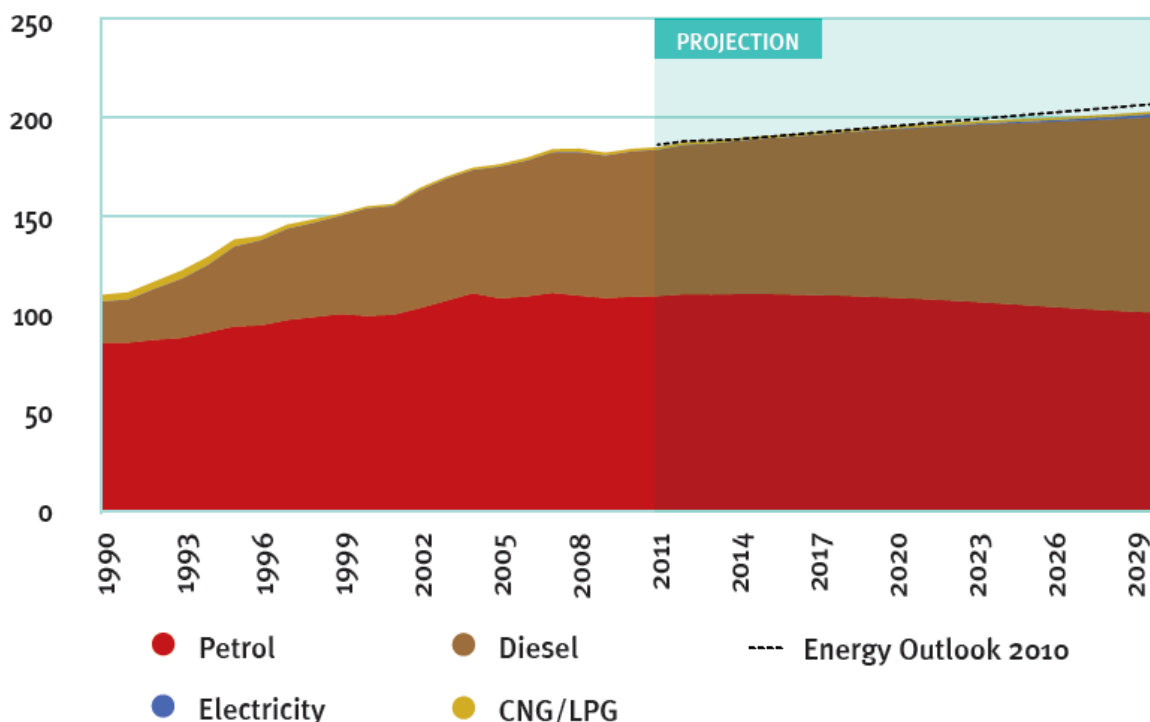


Figure 2-2: Road transport demand projection by fuel type from 1990- 2029. (Ministry of Economic Development, 2011)

Figure 2-2 shows clearly that dependence on oil will remain high in the next decades and overall fossil fuel use will increase in the coming decades. It is predicted that it will increase in the form of diesel but decrease in the form of petrol. The trend to shift to diesel has already started in the last few years, caused by the price rises in petrol. The prediction from the “Energy Outlook 2010” is shown in the figure (black dotted line) which shows that the prediction from 2011 is a slight decrease from the prediction from 2010, but this is very small.

The figures above are seen as the most reliable predictions for the future energy system in New Zealand. But the Government has also produced another document that investigates different scenarios to 2040 for the transport energy system in a report called “New Zealand’s Energy Outlook 2009/2010: Changing Gear”. In this report, alternative fuels such as ethanol and electric cars were investigated in the scenarios. The purpose of the document was to show the outcomes from different approaches to transition the transport sector from fossil fuels to renewable fuels.

The report predicted a best-case scenario for New Zealand to shift away from fossil fuels, and it showed that New Zealand can have less demand for oil in the future which results from vehicle efficiency improvements, uptake of electric vehicles and development of a local biofuels industry. Biomass would make up more than 25% of the country’s total primary energy supply by 2040 (Ministry of Economic Development, 2010). Up to 60% of this would be used for biofuels and the remainder for heat production and cogeneration. This was the maximum level of biomass predicted by 2040.

Despite this optimistic prediction, this prediction is only a prediction, and it is concluded for this report that this document has no political backing or support and lacks much credibility. This report is not a policy or strategy document and it is not evident anywhere that these predictions have any support, i.e. there have been no public announcements or policy implementation to support the scenario outcomes. Therefore it is concluded that the predictions in this report are unreliable and the figures presented above from the "Energy Outlook 2011" are more realistic indicators of New Zealand's energy future at this stage.

These two documents produced by the New Zealand Government for predicting the energy future highlights a big problem for changing the energy system in the future. On one hand the government prepares a scenario document (New Zealand's Energy Outlook 2009/2010: Changing Gear) that introduces a number of renewable energy options that could lead New Zealand to having less dependence on fossil fuels. But on the other hand the Government publicises the "Energy Outlook 2011" document which does not involve any of the scenario findings. It appears that the Government does not present any of the renewable energy options from the scenarios as choices for the "Energy Outlook 2011" and the choices are simply hidden within the "New Zealand's Energy Outlook 2009/2010: Changing Gear" document. The "Energy Outlook 2011" provides a very limited scope of choice for the future. The main change is that petrol is switched to diesel in the future. This lack of choice provided by the Government is the basis for the theory chosen for this study which is called Choice Awareness Theory, and this is described in the following section.

## 2.1 Choice Awareness Theory

As shown in the example above the New Zealand Government does not provide the choices for the future of the energy system in a reliable way. The public does not have much say in the future predictions. Therefore this study takes point of departure from Choice Awareness Theory which focuses on this issue and provides a strategy to counteract it.

Choice Awareness Theory evolved by analysing different energy systems, mainly in Denmark, over the past 25 years (Lund, 2010) therefore it is relevant for this study since this study is assessing the energy system for New Zealand. Choice Awareness Theory theorises that the organisations and institutional framework surrounding the current regime will influence the awareness of choice. For example as described above in the scenario analysis from the Government, it is possible that these alternative renewable energy options are not presented in order to support the current status quo and to avoid radical technological change. Essentially, through the perception of reality and the interests of the organisations currently involved, the awareness of choice is influenced and limited (Lund, 2010). Those in power do not want to lose their power and influence.

This study theorises that the options presented for the future by the Government do not represent the only choices for the energy system for New Zealand. When faced with long term predictions from the Government it seems that this *is* what will happen since it comes from the main governing body of the country, but in reality there are always other choices and this study takes its departure from this theory. This study theorises that the options are not the only way forward and significantly different alternatives may be possible. Even the most optimistic scenarios (as presented in the "New Zealand's Energy Outlook 2009/2010: Changing Gear" document) presented by the Government could be significantly more different.

In New Zealand, over the past century the energy system has developed into its current state today. The organisation as a whole consists of particular institutions and organisations, including the citizenry, that seek to benefit from the system. One example in New Zealand is the Maui Gas Field off the coast of Taranaki which has been providing natural gas since the 1970s, of which a proportion of this gas is sent directly to the Huntly power station (New Zealand's largest power station) to generate electricity. It is expected that gas supply from the Taranaki Basin will last for the next couple of decades with new fields being commissioned in the last few years (TAG Oil, 2013). TAG Oil is a majority owner of the Maui Gas Field and this is one example of an organisation being involved in the energy system and it being interested in maintaining its position in the network. The natural

gas arrangement is supported by particular institutions, organisation and the Government. In Figure 2-1 the reason why natural gas remains a major part of the electricity mix probably is attributed to this arrangement.

Aside from the natural gas part of the system, New Zealand has always been reliant on hydro power which accounts for over 50% of the electricity generation. And having this large proportion of renewable electricity makes it easier to increase other parts of the electricity system so that the whole electricity system is 100% renewable. However the natural gas component is a big barrier for converting the electricity grid to 100% renewable electricity.

This study is also focused on the light vehicle transport sector and this sector is an even bigger challenge in New Zealand since it depends more than 95% on fossil fuels and the shift away from this would involve radical technological change. Furthermore the switch away from fossil fuels will probably mean that electricity would need to be integrated much more into the transport system meaning further technological change.

The concept of radical technological change is a key component of Choice Awareness Theory and it is explained further below.

### ***2.1.1 Fearing the need for Radical Technological Change***

Choice Awareness Theory was developed through analysing energy systems from numerous countries and how they could be changed to be based on more renewable sources. A central component to the theory concerns the definition of technology and its role in this change, since technology is what is actually being changed in the system. It is not only the physical part of technology that is changed however. Technology actually consists of four elements (Müller, Remmen, & Christensen, 1984). These elements are product, knowledge, technique and organisation. Usually when one element changes then the others adapt to this change. This happens all the time, for example, when a computer is upgraded to a later model the product changes, but the technique, knowledge and organisation around this technology remains the same. Thus this is not a radical technological change. Choice Awareness Theory focuses on the radical technological change which is when two or more of the elements of technology change. When the theory is applied to energy systems the focus is mostly on the organisation element of technology since this is what usually is disrupted for renewable energy systems. In New Zealand it is likely that when shifting towards a 100% renewable electricity system a radical technological change is required, for example when shifting away from natural gas to a renewable fuel the product and organisations involved will change. And a radical technological change is almost certainly required when shifting away from fossil fuels to renewable energy in the light vehicle sector.

The Choice Awareness Theory has been tested numerous times over the past 25 years when assessing energy systems from different countries, largely in Denmark, and consequently it has been refined and partly validated during this period. The theory is very relevant for this study since this study aims to try to do the same as has been done over the past 25 years using the theory. Also, this is the first time this theory is being tested in New Zealand.

In summary the theory poses two theses that arise from the fear of radical technological change.

Thesis 1 (Lund, 2010)

When society aims to change its objectives, such as having a 100% renewable energy system, which implies that a radical technological change may occur – for example shifting away from fossil fuels – the existing organisations will try to make it seem that there is no option to choose a radical change and the only option is to choose an option presented by the current organisations or nothing at all. When these organisations are faced with a threat of change that could lessen their power and influence, they will create a perception that society has no other choice but to accept a choice that further prolongs the organisations own agenda (Lund, 2009). One example is that organisations will use risk assessment when assessing change, rather than alternative assessment (O'Brian,



2000). The use of alternative assessment is mightily opposed by the current regime. Whereas the use of risk assessment is much more manageable since through this type of assessment the risks involved with the “desired” choice can be assessed in detail, even if the choice is not the most suitable. Whereas with alternative assessment, a number of different choices must be assessed.

Thesis 2 (Lund, 2010)

The first thesis is that choices are being hidden. And the second thesis is that it is possible to create awareness that these alternative choices do exist and that society can make a choice. When such a situation arises it is important to understand that this is occurring and that society should understand that alternative choices are possible and the awareness of them needs to be raised at various levels. It is recommended by the theory that Choice Awareness Theory should be followed in order to raise these choices. The theory can be used as a tool to counteract this first element. Four key strategies are proposed by the theory to raise awareness and implement new energy systems (and for other transitions too) (Lund, 2010) Figure 2-3.

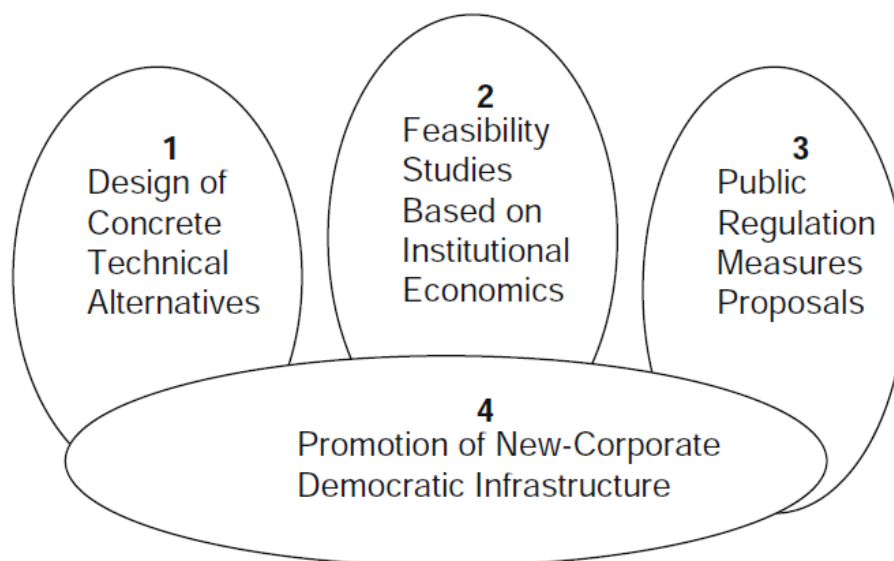


Figure 2-3: Choice Awareness strategies (Lund, 2010)

The first strategy is concerned with the technical validity of alternative choices. It is not possible to simply suggest an alternative if it has not been technically assessed to see if it possible. The technical assessment involves a thorough analysis of the system being proposed so that it is robust and can withstand critique. The second strategy takes the technical alternative a step further and determines the feasibility of the alternative in terms of economic viability. This is based on institutional economics or the real economic system that the energy system exists in. Institutional economics is concerned with how humans have created institutions that shape how the economy works. For example the natural gas example given above has been institutionalised into the energy system of New Zealand and thus economic activity is shaped around this organisational institution. The feasibility studies assess how the changes in the energy system would fit into these current institutional economic structures. The third strategy is concerned with the public regulation measures that should be implemented in order to shift towards the alternative choices. New regulations are necessary to supplant the old system with the new system. However the main barrier to this is that the policy of Government is also controlled by the current system, because of the institutionalised economics. For example if the extraction of natural gas provides economic growth and jobs and can be used for political power, then this old technology will be supported over new technologies. Therefore, coupled with the third strategy the last strategy is added which stretches across all the other strategies and it involves the promotion of a new-corporate democratic infrastructure. This means that there needs to be a change in how democratic decisions are made. If the old

corporate organisations have easy access to Government it makes it easier for them to manipulate political decisions and to maintain their position. This often excludes society from having a choice or any opinion. This was seen in 2013 when the New Zealand Government made proposals to make it law that all new oil exploration licences are granted without the requirement for public notification or hearings (The National Business Review, 2013). This exclusion of the public from making any choice is an example of old corporate democracy.

### 3 Methodology: The approach of this study

In this study it is theorised that the first element of Choice Awareness Theory is evident in New Zealand, where alternative choices are being hidden and that the awareness of choices in New Zealand for future energy systems is being limited by the interests of the current stakeholders involved. This is understandable since the current stakeholders have the most to lose if there is radical technological change and they are not involved in the new arrangement. But it is not the aim of this study to prove this first thesis. It is simply an assumption at this stage, which is justifiable since it is still possible to carry out the second thesis without testing thesis one.

The strategies in thesis two address very difficult problems, such as changing the democratic decision making process, but these problems must be addressed if any significant change is to occur, or if society wants to have any democratic power in the future. Currently, the power is being shifted from the public to private enterprise. Despite the importance of addressing these problems, this study only addresses the first strategy - to define concrete technical alternatives to help raise awareness about what is possible. Only this first strategy is carried out due to time constraints. These strategies address problems that will be solved over a number of years and this study can only provide one piece of the puzzle. It is expected that a follow-up Master Thesis will be carried out to build upon the findings of this study.

Since this study focuses on the design of concrete technical alternatives to the current energy system, in the next section, the current energy system that is assessed and altered in this study is described.

#### 3.1 Energy system elements assessed in this study

The energy system in New Zealand consists of a number of different elements that demand energy, such as residential heating, industry, transport, and so on. However in this study only two elements of the energy system are modified and assessed:

1. The electricity generation system; and
2. The light vehicle fleet.

The electricity generation system is a major component of the energy system in New Zealand therefore by including this in the scenario analysis it is a major step forward. The light vehicle fleet in New Zealand is a major consumer of energy and fossil fuels and is also a major problem to be solved therefore this has also been chosen for this study. Other elements of the energy system such as the heating system, industry and other transport types are not modified and analysed in this study but these may be included in subsequent assessments. As explained above, the process of shifting to an alternative system based on renewable energy will take time and further assessments should be carried out over time.

#### 3.2 Demonstrating the possibilities in EnergyPLAN

As explained above, in this study, concrete technical alternatives will be designed for the electricity system and the light vehicle fleet, and in order to design these concrete technical alternative the tool EnergyPLAN is utilised.

EnergyPLAN is a tool that was developed in parallel with the Choice Awareness Theory. Since the first strategy in the theory is about designing concrete technical alternatives, it was necessary to have a tool to achieve this. Therefore EnergyPLAN was developed. It is a comprehensive tool that has been in development since 1999.

It provides the possibility to model many different energy system configurations, for example for national or regional systems. The tool can be used to present state-of-the-art energy system analyses for 100% renewable energy systems, and allows the user to determine the technical viability of the proposed energy system. In all, the user can test different electricity grid mixes, transport options, individual heating options, individual technologies, socio-economic costs, and more. The EnergyPLAN tool even includes energy regulation strategies

based on common strategies demonstrated around the world. Since EnergyPLAN is focused on raising awareness of alternative options, it is continually updated with the most recent energy technologies so that they can be included in an assessment and presented to society.

Figure 3-1 provides an illustration of all the components that may be modelled in EnergyPLAN.

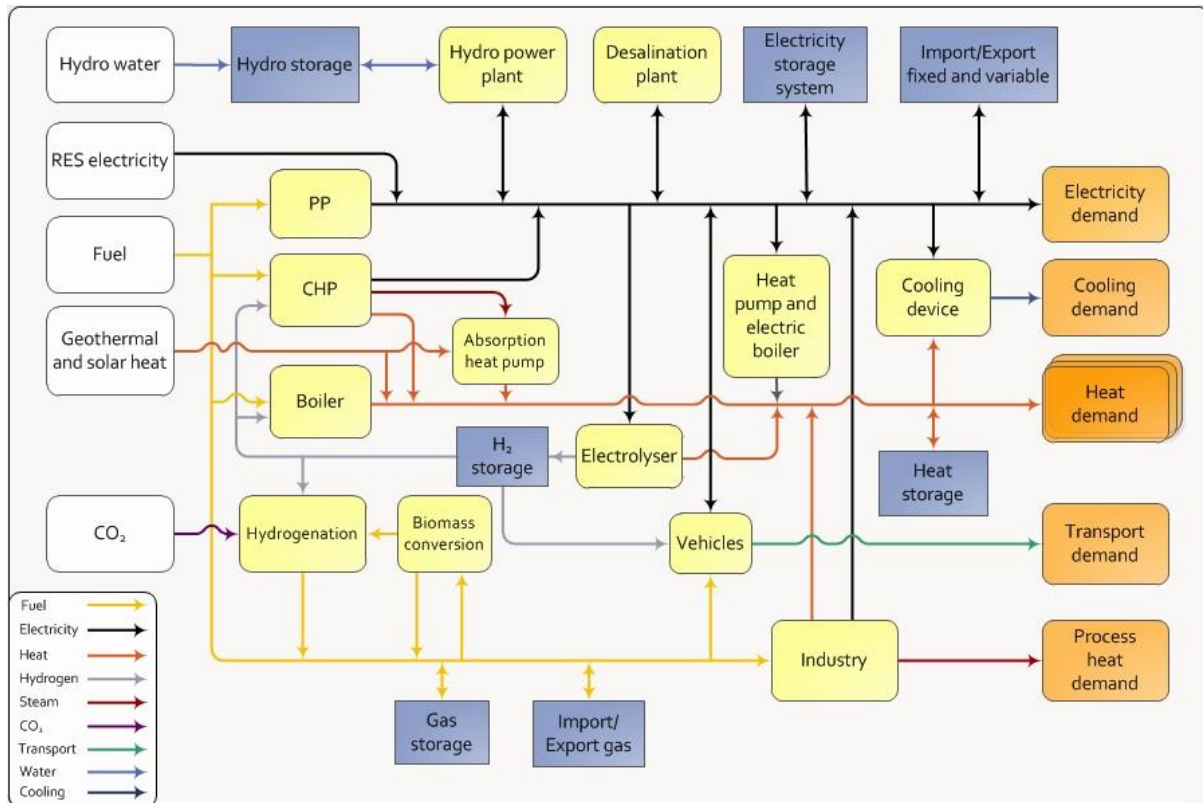


Figure 3-1: Energy system parameters available in EnergyPLAN for scenario testing (Lund, 2010)

More details about EnergyPLAN can be found at <http://www.energyplan.eu/>.

The difference between this tool and other energy tools is that it has been designed with the Choice Awareness Theory in mind. Meaning that it enables the user to assess radically different energy systems that can be communicated in a technically viable way. The tool is not designed to include only the current technologies in which it would simply further the emplacement of these technologies. It aims to promote a shift away from these old technologies by technically assessing the introduction of newer technologies in different ways. For example, by linking the electricity sector with the transport sector for the production of biofuels such as methanol.

EnergyPLAN contains a number of specific formulas to calculate whether the distribution profiles for the demand side, and the generation side, like wind, are able to be in sync throughout the entire year so that the system is technically valid. This becomes even more important when the transport sector is incorporated more fully with the electricity sector, for example if a large proportion of light vehicles become dependent on electricity; thus creating high variation in the electricity system. EnergyPLAN is able to quantify the technical validity of this and to deliver specific answers.

EnergyPLAN delivers results for the different energy systems in terms of electricity grid stability, electricity generation/consumption, total primary energy demand (fossil or biomass), carbon dioxide equivalent emissions, total annual costs, and more.

The results generated from EnergyPLAN can be presented to a wider audience to raise awareness about different choices, which is the aim of this study.

There are four main requirements to design concrete technical alternatives and to model them in EnergyPLAN (Lund, 2010):

- Step 1: Defining reference energy demands
- Step 2: Defining a reference energy supply system
- Step 3: Defining the regulation of the energy supply system
- Step 4: Defining alternatives

This study carried out all four of these steps, and each step is described in the following section. The detailed data collected for this study can be extracted from the EnergyPLAN models and from the associated files created for the study. The web link to the files can be found in Appendix A.

In this study, all elements of the energy system that consumed energy are included. Even those elements that are not included in the scenario analyses; for example heating and industry energy demand. The aim is to assess the entire energy system, and all these elements were kept constant in the scenario analysis. Only the electricity sector and light vehicle energy consumption was modified in the scenarios and the aim is to determine the influence these changes have on the entire energy system. Only the data that was modified in the scenarios is described in the sections below.

### 3.2.1 Defining reference energy demands

In order to understand where to progress the energy system, the researcher must first understand where they currently are. Therefore it is vitally important to include the reference energy system of a particular year in EnergyPLAN.

The reference year chosen for this study was 2011, and the total electricity demand and consumption in New Zealand in 2011 was 43.1 TWh. Data was collected from the New Zealand Energy Data File developed by the Ministry of Economic Development (Ministry of Economic Development, 2012). This value includes the parasitic load of the power stations and line distribution and transmission losses. The total electricity demand is required in EnergyPLAN since it provides the tool with an understanding of how much electricity is required in an entire year and that which needs to be met by the different electricity generation technologies. In New Zealand four main electricity sources supply electricity, namely: hydropower; wind; geothermal; and condensing power plants (fossil fuel and biomass).

The total demand and breakdown of supply of electricity is presented in Table 3-1 below. Further details about the electricity supply data are described in Section 3.2.2.

Table 3-1: Electricity demand and supply for New Zealand in 2011

		Unit (TWh)	Proportion of total
<b>Demand</b>	Entire country for 2011	43.1	N/A
<b>Supply</b>	Hydro power	24.8	57.5%
	Natural gas	8.0	18.6%
	Geothermal	5.8	13.5%
	Coal	2.0	4.6%
	Wind	1.9	4.4%
	Biomass	0.5	1.2%
	Oil	0.1	0.2%

In addition to the total electricity demand, the distribution of this demand per hour throughout the year is also required. It is critical that the distribution of electricity demand and supply is entered correctly in EnergyPLAN. This allows the tool to determine whether the alternative scenarios that are modelled are technically valid at all points during the year. I.e. whether enough electricity is produced at a certain point in time or if there is a shortfall. A sample of the electricity distribution from the first week of 2011 is presented in Figure 3-2 below. This distribution is entered in EnergyPLAN for the entire year which consists of hourly data points or 8784 points (24 X 366 days for the leap year). The entire distribution can be found in a .text file in the web link in Appendix A.

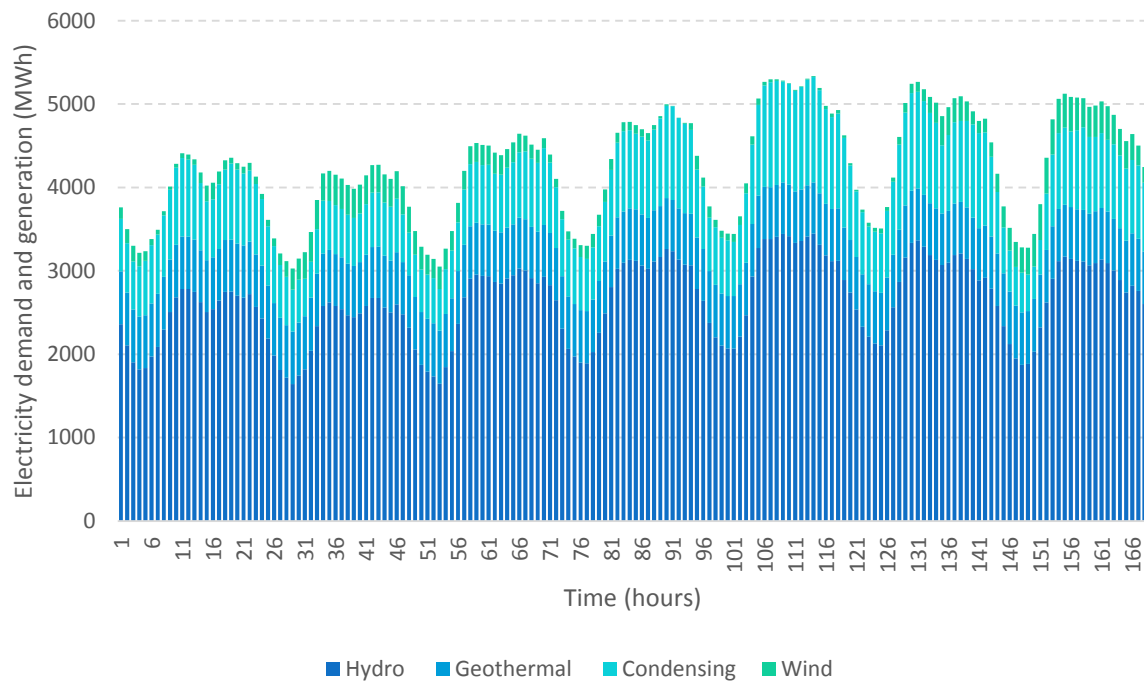


Figure 3-2: First week (168 hours) of 2011 electricity demand and generation by type

As shown in Figure 3-2, the electricity demand in the first week peaks at around 5200 MWh (hour 114). Over this week hydro accounts for the majority of the electricity produced, followed by geothermal and the condensing power plants. Wind accounts for less electricity and is more variable than the other electricity types. In an alternative energy system this breakdown of electricity production would be different.

### 3.2.2 Defining a reference energy supply system

Once the reference electricity demand is entered in EnergyPLAN, the reference energy supply system is then required for EnergyPLAN. This is essentially the sources of electricity that contribute to balancing the electricity demand. Part of this is shown in Figure 3-2 above. In New Zealand four main electricity sources supply electricity, namely: hydropower; wind; geothermal; and the condensing power plants (fossil fuel and biomass). The total production capacity in New Zealand in 2011 was 9708 MW.

Each of these electricity production systems are described in more detail below.

#### 3.2.2.1 Hydro

In New Zealand 58% of the electricity was produced by hydro power in 2011. The generative capacity was 5266 MW and the total electricity generated was 24.83 TWh of electricity. Data was collected from the New Zealand

Energy Data File developed by the Ministry of Economic Development (Ministry of Economic Development, 2012).

An important piece of data required for EnergyPLAN is the total storage capacity of hydropower in New Zealand, and the hourly distribution of water supply into the storage. In 2011 the total potential storage level of hydropower was 4541 GWh. Together these data, along with the total electricity generated by hydropower in the year, allow EnergyPLAN to calculate the distribution of power production throughout the year, and the distributed storage level throughout the year. The distributed storage level is critical since it allows EnergyPLAN to understand how much potential electricity is available at any given hour in the year. This allows the tool to calculate how much electricity can be generated using hydropower, or that needs to be produced from other sources at any hour in the year. Although EnergyPLAN calculates the distributed storage level based on the inputted data, in this study the actual distributed storage level was also sourced for New Zealand (the data was collected from the New Zealand Electricity Authority System Operators Centralised Dataset (CDS) (Electricity Authority, 2013)) and it was discovered that the distributed storage level calculated in EnergyPLAN and in real life was different. The reasons why this occurred and the implications of this are discussed in Section 5.2 (Discussion: Hydro power influence on Import and CEEP).

The hourly distribution profile for water deposited into the storage can be found in the web link in a .text file in Appendix A.

### 3.2.2.2 Geothermal

In New Zealand 13.5% of the electricity was produced by geothermal power in 2011. The total operating capacity was 780 MW producing 5.77 TWh of electricity. This electricity data was collected from the New Zealand Energy Data File developed by the Ministry of Economic Development (Ministry of Economic Development, 2012).

An hourly distribution profile for the geothermal electricity production was required for EnergyPLAN and this can be found in the web in a .text file in Appendix A. The hourly distribution profile data can be downloaded from the CDS part of the New Zealand Electricity Authority website (Electricity Authority, 2013).

### 3.2.2.3 Wind

In New Zealand 4.4% of the electricity was produced by wind power in 2011. The total operating capacity was 539 MW producing 1.93 TWh of electricity. This electricity data was collected from the New Zealand Energy Data File developed by the Ministry of Economic Development (Ministry of Economic Development, 2012).

An hourly distribution profile for the wind electricity production was required for EnergyPLAN and this can be found in the web link in a .text file in Appendix A. The hourly distribution profile data can be downloaded from the CDS part of the New Zealand Electricity Authority website (Electricity Authority, 2013).

### 3.2.2.4 Condensing power plants

In New Zealand 25% of the electricity was produced by condensing power plants in 2011. The total operating capacity was 3042 MW producing 10.66 TWh of electricity. This electricity data was collected from the New Zealand Energy Data File developed by the Ministry of Economic Development (Ministry of Economic Development, 2012).

In 2011 there was 571 MW of cogeneration power plant capacity producing 2.51 TWh, and a small amount of this electricity was produced from industrial cogeneration plants which are fuelled mostly by biomass. The major part was produced by natural gas cogeneration where the main purpose is to produce electricity. The small amount of industrial electricity should be included in the industry section of EnergyPLAN (modifications of the industrial energy use was not included in this study). But in this study the electricity produced from this

cogeneration was included in the total condensing plant electricity production (in the electricity system) because this was a small amount of electricity and it makes the analysis more straightforward and has minimal impact. However this should be investigated further in future research.

The proportion of electricity generated via different fuel types in the condensing plants, including cogeneration, were as follows:

- 75% natural gas
- 19% coal
- 1% oil
- 5% biomass

### 3.2.2.5 Light vehicle transport demand

In this study only the light vehicle transport energy demand is assessed. However in EnergyPLAN all the transport data for the country is entered, which includes heavy transport, air travel, light vehicle travel and so on. The results will indicate how much impact a shift of 50% of the light vehicle travel to renewable energy, will make to the entire transport system and energy system.

In 2011 the total transport fuel consumption in New Zealand was 56 TWh (Ministry of Business, Innovation & Employment, 2013). The split between different end uses is shown in Figure 3-3 and the light vehicle component is shown as well.

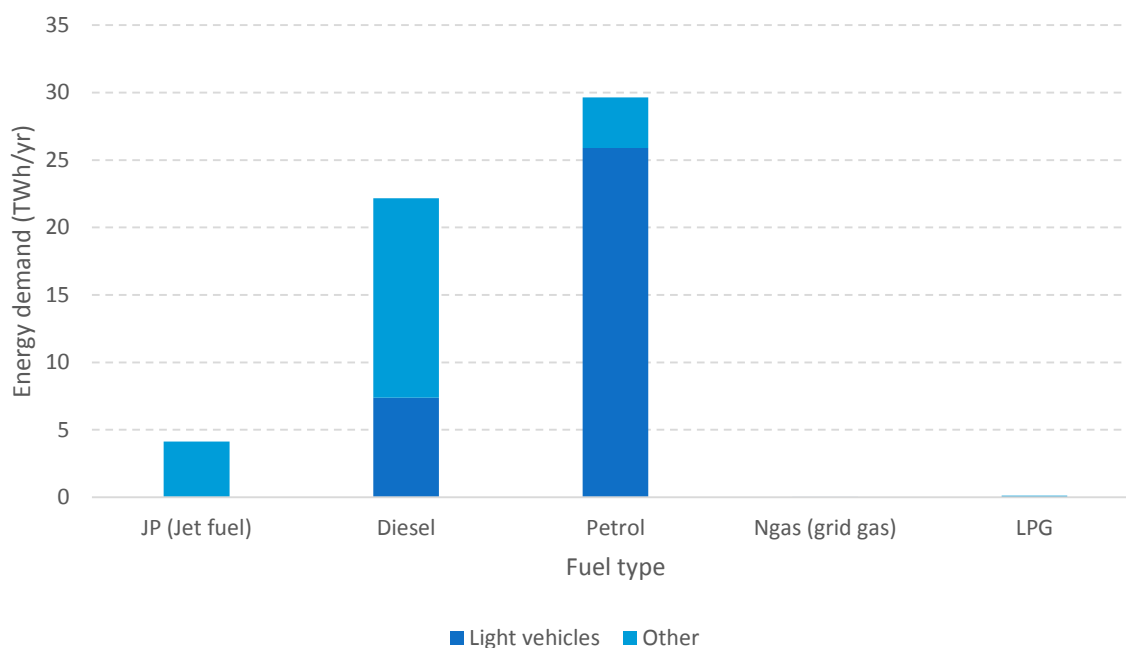


Figure 3-3: Transport energy demand for 2011 for light vehicles and all others split between fuel types (Data source: ...)

In total, light vehicles accounted for 7.38 TWh or 33% of the diesel transport consumption in New Zealand. The petrol light vehicles accounted for 25.89 TWh or 87% of the total petrol transport consumption.



In this study 50% of these values will be replaced with renewable energy. So 3.69 TWh of diesel, and 12.945 TWh of petrol are replaced. The reason why only half the amount is replaced is because this is deemed realistic. The New Zealand light vehicle fuel consumption is very high and it is assumed that to replace more than 50% of the light vehicle fuel consumption with renewable energy in the next 30 years is optimistic. In subsequent research the proportion of light vehicle transport converted to renewable energy may be increased.

### ***3.2.3 Defining the regulation of the energy supply system***

In EnergyPLAN it is possible to implement a regulation strategy for regulating the energy system. For example there can be technical or economic regulations. An example of a technical regulation is that individual heat pumps could be set to consume excess electricity generation when this occurs. Despite the availability of the regulation strategies in EnergyPLAN, in this study no regulation strategy was entered for the scenarios since the regulations require further investigation for New Zealand conditions.

### ***3.2.4 Defining alternatives***

The last step in the methodology for designing concrete technical alternatives is defining the actual alternative scenarios.

When defining the alternative system configurations there needs to be some decision criteria, since it is potentially possible to define many configurations, and the difficulty is to know which ones to progress with. Note that the new energy configurations proposed in this study are expected to reach completion in the next 30 or more years, and therefore the criteria can be ambitious. In this study the decision criteria were as follows:

- 1) The energy demand for the entire energy system (including electricity and light vehicle transport) remains at the same level from 2011 to 2040

It is uncertain whether the future energy demand will be higher or lower than today's energy consumption. Going by the trends it is likely that it will increase, but since conservation measures are the first, and one of the most important elements of changing an energy system, it could also be expected that in the future less energy is demanded. And therefore it is valid to assume that energy would remain at the same level from 2011 until 2040. An increase in energy demand over time should be investigated in future research.

- 2) All future energy system configurations are scaled up to 100% renewable electricity supply by 2040

The first step for all alternatives was to modify the electricity system to be 100% renewable. The reason for this, instead of 90% for example, is because it means New Zealand can be 100% self-sufficient, can lower its carbon dioxide equivalent emissions, and it is not exposed to the risks from scarce and expensive fossil fuels. As shown above, the New Zealand reference electricity system consists of around 75% renewable energy dominated by hydro power and to increase this to 100% is not unrealistic and should not be too difficult.

Geothermal and wind power are considered two of the main renewable energy options to use for a 100% renewable energy system in New Zealand (Mason, Page, & Williamson, 2010). Therefore these electricity sources are increased as far as possible when modelling the alternative scenarios.

- 3) 50% of the energy supplied to the light vehicle transport fleet is switched to renewable energy by 2040

The second consideration is that half of the New Zealand light vehicle transport fleet is converted to renewable energy, using the data from 2011. As explained above New Zealand has an abnormal number of light vehicles and a high fuel consumption, and the transition from non-renewable energy to renewable energy in the fleet would take a long period. Therefore it is assumed that 50% could be changed by 2040.

- 4) Three alternative renewable energy options for light vehicles are assessed, being: electric vehicles; ethanol/biodiesel; and methanol/DME,

Due to time constraints, only the most probable renewable energy options are selected for each configuration in this study. Additional options should be investigated in future research.

Based on these considerations the scenarios defined for the project were:

- A) Using data from 2011, the electricity system is 100% renewable and 50% of the light vehicles (petrol and diesel) are electric vehicles by 2040
- B) Using data from 2011, the electricity system is 100% renewable and 50% of the light vehicles (petrol and diesel) are fueled with ethanol/biodiesel by 2040
- C) Using data from 2011, the electricity system is 100% renewable and 50% of the light vehicles (petrol and diesel) are fueled with methanol/DME by 2040

The main aim of the study is to determine the technical viability of each of these alternative scenarios. However in addition, in the analysis of each alternative scenario, the total electricity demand and mix, primary energy demand, costs and carbon dioxide equivalent emissions will be compared.

For each scenario, the electricity grid is expected to be different since the electricity demand would vary. The different electricity grid mixes are described further in Section 4 (Results: Alternative Scenarios). But the light vehicle energy supply characteristics assumed for each scenario are described below.

### ***3.2.5 Details of alternative transport energy supply***

#### **3.2.5.1 Electric vehicles**

In the electric vehicles scenario, it was assumed that all light vehicles were converted to an electric vehicle with the same specifications as the 2013 Nissan Leaf (Nissan, 2013). The battery capacity of this vehicle is 24KWh and the range is 160 km.

In New Zealand there are just over 3,000,000 light vehicles (Ministry of Transport, 2013) and it was assumed that each vehicle drives the same distance and consumes the same amount of fuel. Therefore effectively 1,500,000 vehicles are replaced with electric vehicles by 2040. On average the vehicles drive 12,000 km per year (Ministry of Transport, 2013). This means that each vehicle is charged 75 times per year. In total 3 TWh per annum would be required to replace half of the light vehicle petrol and diesel consumption, based on a 90% charge efficiency from grid to electric vehicle.

A smart charge, as opposed to a dump charge, electricity system was assumed in this scenario. The smart charge system is expected to be more common in the future compared with the dump charge. The smart charge works by charging vehicles in correlation to the electricity system in order to avoid excess electricity production or shortfalls in electricity production. For the smart charge, a demand profile is required for electric vehicles during a year. The demand profile for the electric vehicles used in this study was based on the United States demand profile for light vehicle transport from 2001. A sample of this profile is shown in Figure 3-4 below for the first 100 hours of the year.

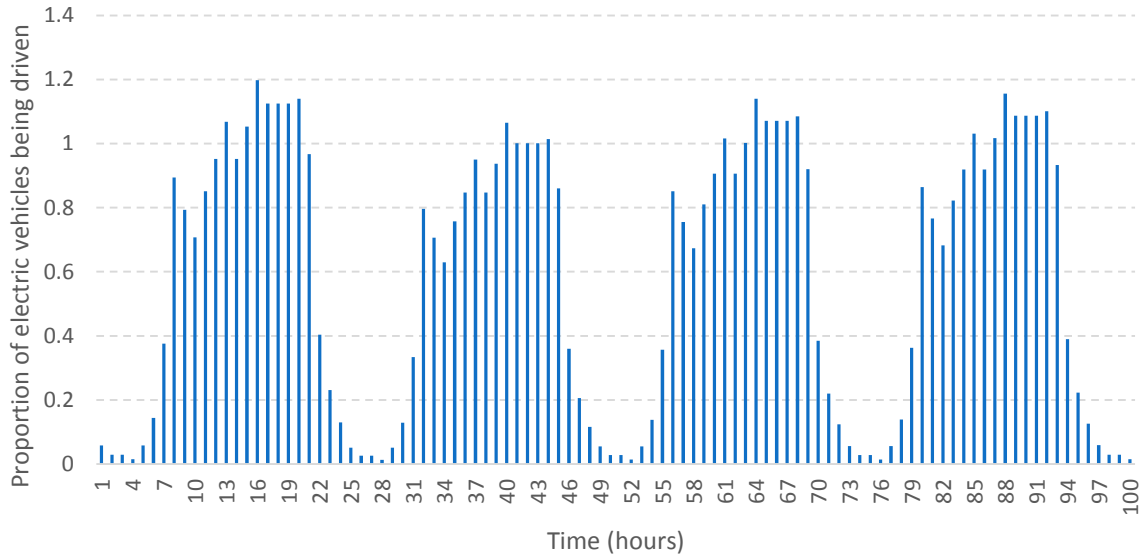


Figure 3-4: Distribution of the first 100 hours of Smart Electric Vehicle electricity consumption (vehicles driving) based on US conditions (extracted from EnergyPLAN)

The distribution profile shows the hours when the vehicles are consuming the electricity, i.e. when they are driving. For example during the day from 9am to 9pm is the period of highest demand. Peak demand is at about 4pm.

The entire distribution profile is provided in a .text file in the web link in Appendix A.

**3.2.5.2 Ethanol/biodiesel**

In New Zealand a large amount of research was carried out into converting woody biomass to ethanol during 2007-2009 (Scion, 2007) (Scion, 2008) (Scion, 2009a) (Scion, 2009b). It was proposed that the woody biomass would be sourced from already planted pine forestry where a large amount of forest residues are already available. Plus purpose-grown pine forestry would be planted in marginal land. Based on a conservative estimate, 40 TWh of forest biomass energy could be harvested by 2040 (0.8 million hectares), if the purpose grown forests are planted now (Scion, 2009a). Recently the research into this area has started again (Scion, 2013) therefore it is assumed in this scenario that this energy pathway would be suitable to use in this study. Although the forest biomass quantifications have been carried out, the conversion process is less clear. Therefore the data for the conversion process is taken from EnergyPLAN.

Based on EnergyPLAN, for 1 TWh of ethanol, 2.77 TWh of biomass and 0.03 TWh electricity are required.

In this scenario there is a small amount of biodiesel required for replacing the diesel fuel in the light vehicle fleet. In this study it was assumed that biodiesel would be produced from first generation crops, for example corn or rapeseed. Based on EnergyPLAN, for 1 TWh of biodiesel, 1.04 TWh of biomass is required.

**3.2.5.3 Methanol/DME**

The specification for methanol production was taken from EnergyPLAN and from the CEESA project from Denmark. This project investigated the possibility of Denmark becoming 100% renewable by 2050. The study used methanol as the biofuel for the calculations for a 100% renewable energy system. Methanol was selected for this present study since it provides an alternative fuel that has not been assessed in New Zealand yet. It is more dependent on the electricity system than ethanol, thus providing a good option for dumping excess

electricity. In addition, methanol can be utilised by modifying an ICE with minor changes and the fuel is only slightly less efficient than petrol (Mathiesen BV, 2011). DME can be used as a replacement for diesel and the conversion from methanol to DME is relatively straightforward (Mathiesen BV, 2011).

The energy and mass balance for converting biomass to methanol through hydrogenation is described below (Mathiesen BV, 2011).

$C_6(H_2O)_5$	+	$6H_2$	+	$H_2O$	$\rightarrow$	$6CH_3OH$
Biomass (Cellulous)		Hydrogen		Water		Methanol
2823 kJ		1452 kJ		0 kJ		3778 kJ
162 g		12 g		34 g		192 g

The simplified steps to produce methanol are as follows: Biomass is gasified in order to release the carbon. Hydrogen is split from water through an electrolyser. This hydrogen is then combined with the carbon from the biomass in a hydrogenation process to produce syngas. This syngas is then converted into methanol through chemical synthesis and the methanol can then be turned into DME.

Based on EnergyPLAN, for 1 TWh of methanol, 1.05 TWh of biomass is required, plus 0.6 TWh of electricity. The same data is assumed for Dimethyl Ether (DME). Since methanol is less efficient than petrol in an ICE vehicle, the efficiency of converting syngas to methanol is conservatively set at 80%, and it is also set at 80% for DME.

### 3.2.6 Critical Excess Electricity Production and Import requirement

Two critical aspects for modelling the different energy systems is to make sure that for each approach that Critical Excess Electricity Production (CEEP) and the Import requirement are as close to zero as possible. CEEP occurs when too much electricity is produced at a point in time in the year and it exceeds the demand. When this threatens to occur then power production units must be switched off. This results in wasted opportunity to produce and sell electricity, and it means less revenue for a power production unit. CEEP was tried to be avoided in this study by increasing and decreasing the amount of electricity produced by wind. When wind power is installed, the purpose is to generate as much electricity as possible from the turbines to increase the capacity factor. Therefore in EnergyPLAN, electricity production from wind is maximised as much as possible. However wind electricity production throughout the year is highly variable and largely uncontrollable. And if there is too much wind capacity entered in EnergyPLAN there can be occasions when too much wind is produced than what is required, thus causing CEEP in EnergyPLAN. Thus, to decrease CEEP, the capacity of wind needs to be decreased.

The Import requirement for electricity is the opposite of CEEP meaning that less electricity is produced than is demanded. When not enough electricity is produced in EnergyPLAN, then the tool will assume that some electricity is imported in order to balance the system. However in New Zealand it is not possible to import electricity since it is an isolated island country, therefore having an import requirement is not possible at any occasion. If an import of electricity is required in real life, then there could be black-outs. Both these technical elements are closely observed when assessing each alternative scenario since they both must be 0.

### 3.2.7 Electricity and primary energy demand

For each alternative scenario the total electricity and primary energy demand and mix are quantified and compared. These provide the most basic metrics for comparison. The electricity demand simply shows how much electricity is required by each scenario. The electricity mix shows how the electricity is produced. The primary energy demand shows how much primary energy is required for each scenario and shows how much of it is fossil fuel or biomass primary energy.

### 3.2.8 Carbon dioxide equivalent emissions

Carbon dioxide equivalent emissions are quantified for the entire energy system for New Zealand for the reference scenario and alternative scenarios. This includes the emissions from the power plants and the light vehicle transport assessed in the scenarios, plus the emissions from households, industry, and so on. The emissions from the entire energy system are assessed in order to understand how much impact each scenario has on the total emissions level. The comparison of the emissions levels between each scenario is focused on the difference in emissions, rather than the absolute emissions of each scenario.

### 3.2.9 Costs

An important consideration when assessing the alternative scenarios are the total costs of the energy system. This would be carried out in strategy two of the Choice Awareness Theory, in a feasibility study grounded in institutional economics. This study does not aim to assess the other strategic steps but it was considered important in this initial study to present a preliminary annual cost breakdown for each scenario to illustrate the difference between them. It is recommended that a full analysis of the costs is carried out in a separate feasibility study.

There are a number of different elements in the cost breakdown in EnergyPLAN. But in general the costs comprise of fuel, operation and investment costs. The cost for fuels includes the price of the fuel, and handling costs like distribution and refining. A price for carbon can also be set but this is not included for New Zealand at present. The operation cost for producing electricity includes both variable and fixed operation and maintenance costs. Investment costs include the costs per annum of servicing initial capital investment. Further details about the cost data is provided in the EnergyPLAN tool. The total annual cost data for each scenario in this study can be sourced from the EnergyPLAN models which can be found in the web link in Appendix A.

All cost data used in this study was taken from an analysis by the Danish Energy Agency (DEA) on future costs for 2020. The data was in Euros therefore it was converted to New Zealand Dollars.

An example of a total annual cost breakdown is shown below in Table 3-2 for a 1200 MW biomass condensing plant (in Euros):

Table 3-2: Price breakdown for biomass condensing power plant

Fuel	Distribu- tion to power plants	Opera- tion	Investment	Years of operat- ion	O & M % of invest- ment	Total investment cost	Interest	Annual investme nt costs	Annual fixed O & M
7.3 Euro /GJ	1.58 Euro/GJ	2.654 Euro/M W-e	0.89 Million Euro/MW-e	26	1.822	1068 Million Euro	3 % per annum	<b>60 MEuro</b>	<b>19 MEuro</b>

#### 4 Results: The alternative scenarios

In this section the results for each alternative scenario are presented. Each of the scenarios are assessed by investigating four main metrics, which include:

- Total electricity/primary energy demand and mix;
- Total carbon dioxide equivalent emissions; and
- Total annual costs

The results section begins by describing the different electricity grid mixes of each approach, since each scenario consists of a different electricity mix. For example the methanol/DME scenario requires more electricity than the other pathways and thus the grid mix is different.

Although the heavy transport and air travel were not modified in the alternative scenarios these are still included in the results for carbon dioxide equivalent emissions and costs. All other elements in the energy system, such as the residential heating and industry energy demands are also included. This is to illustrate the complete situation in New Zealand and to show how much difference these new alternatives would make to the complete system.

For each of the scenarios described below the CEEP and Import were tried to be kept at 0. When this did not occur then this is pointed out and this is discussed further in Section 5.2 (Discussion: Hydropower influence on Import and CEEP).

##### 4.1 Electric vehicles scenario

This scenario involved turning the electricity grid into a 100% renewable system and replacing 50% of the current light vehicle stock (1,500,000 vehicles) with electric vehicles.

##### 4.1.1 Electricity grid capacity

In this scenario it was possible for the electricity grid to be modified to reach 100% renewable electricity and to enable 50% of the light vehicles to be electric vehicles. There was a small import problem of 0.01 TWh which is discussed in Section 5.2 (Discussion: Hydropower influence on Import and CEEP). The change in electricity grid is presented below in Figure 4-1 and Figure 4-2.

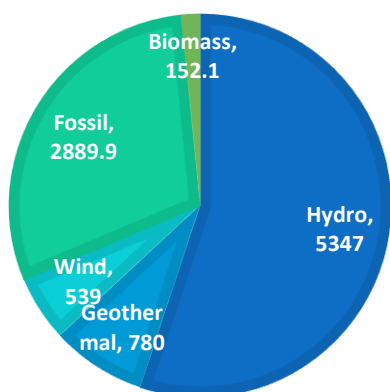


Figure 4-1: Reference system (2011) electricity grid capacities by type (total capacity: 9708 MW)

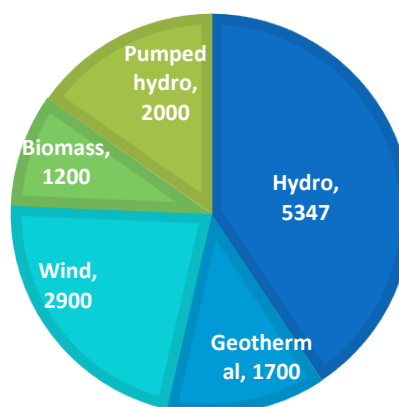


Figure 4-2: Electric vehicle scenario electricity grid capacities by type (total capacity: 13,147 MW)

As shown in the figures, the fossil fuel power plants are removed and are replaced with renewable energy sources. A 1200 MW biomass power plant is required in order to deliver electricity on short notice for peaking power supply. Hydro power remains the same capacity but wind and geothermal are both increased to 2900MW and 1700MW, respectively. The total electricity generation capacity rises from 9708 MW to 13,147 MW.

The electric vehicles scenario requires a 2000 MW pumped hydro station to be installed to store enough electricity from wind and to supply electricity for the electric vehicles when it is in demand. Without some form of electricity storage there would be CEEP meaning that less wind could be installed. Without the pumped hydro station, more biomass and geothermal power plant capacity would be required and it was found that this would be over capacity most of the time. With pumped hydro it allowed more wind to be installed and the capacity factor of the wind to be higher. The pumped hydro would require an extra water storage of 500 GWh or an extra 11% over the current storage level in 2011 (4541 GWh).

**4.1.2 Energy demand**

This section presents the energy demand of the electricity sector and the light vehicle fleet as it changes from 2011 to 2040, and it excludes the other energy elements such as residential heating and industrial energy demand, and so on. In this study these other elements remain constant and do not change therefore it is not necessary to include them in this particular section.

EnergyPLAN automatically quantifies the total electricity produced by each electricity configuration in order for the energy system to be stable throughout the year. The results presented below show the amounts of electricity produced by each generation type, e.g. hydro power, to make sure the demand is met and that the system is stable in 2040. The results also show the energy demand of the petrol and diesel light vehicles. The change in energy demand of the system from 2011 to 2040 is presented in Figure 4-3 and Table 4-1 below.

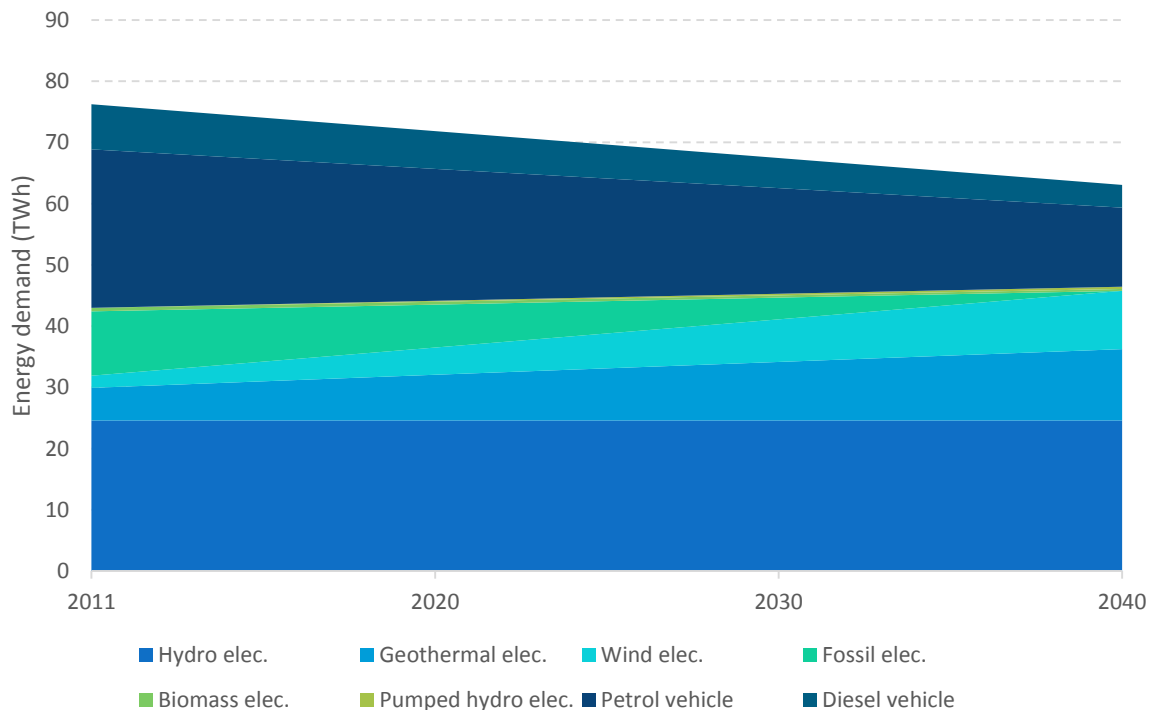


Figure 4-3: Change in energy demands from electricity generators, and light vehicle fuels from 2011 to 2040

Table 4-1: Change in energy demands from electricity generators, and light vehicle fuels from 2011 to 2040

TWh	2011	2040
Hydro electricity	24.6	24.6
Geothermal electricity	5.34	11.63
Wind electricity	1.94	9.52
Fossil electricity	10.5	0
Biomass electricity	0.55	0.31
Pumped hydro electricity	0	0.37
Petrol vehicle fuel	25.89	12.945
Diesel vehicle fuel	7.38	3.69

The results show that from 2011 to 2040, hydro power accounts for a large proportion of the production of electricity, and wind and geothermal electricity production increases. Total electricity demand rises from 43 TWh to 46.43 TWh. The electricity produced from fossil fuels decreases to zero by 2040.

The biomass peaking plant does not provide much electricity during the year (0.31 TWh) with a capacity factor of 3%, but the power plant needs to be 1200 MW in size in order to deliver electricity during high demand periods such as in August, September and October when hydro lake levels are low. Full capacity of 1200 MW is required in September due to low hydro storage at this time.

Pumped hydro is not required very often throughout the year, providing only 0.52 TWh of electricity from 2000 MW of capacity. This is a 2% capacity factor.

However by having these peaking power plants it allows wind and geothermal to increase and to provide enough electricity for the electric vehicles. To replace 16.6 TWh of fossil fuels (petrol and diesel) only 3 TWh of electricity is required for 1,500,000 vehicles, based on a 90% charge efficiency from grid to vehicle.

The effect of pumped hydro on the distribution of production and consumption of electricity is shown in Figure 4-4 and Figure 4-5 below.

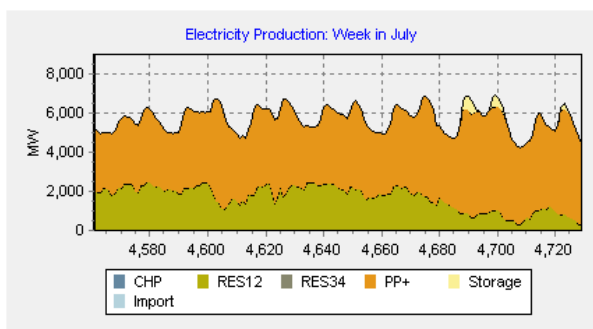


Figure 4-4: Electricity production by type for a week in August (extracted from EnergyPLAN model)

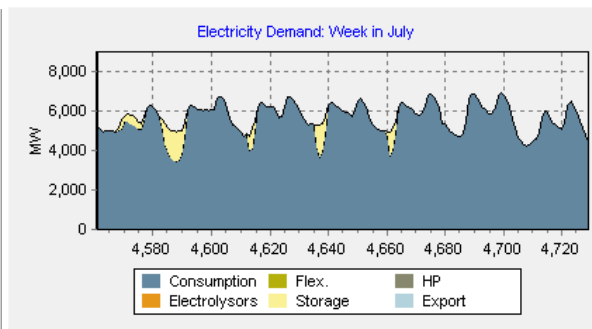


Figure 4-5: Electricity demand by type for a week in August (extracted from EnergyPLAN model)

Figure 4-4 shows a week from July where electricity is being produced by the traditional electricity generation systems such as wind (“RES12”) but it also shows the electricity production from pumped hydro (“Storage” in light yellow at hour 4690 - 4700). This electricity would have been stored in a previous week when there was surplus electricity. The surplus electricity being stored is shown in the same week in Figure 4-5. This figure shows that the pumped hydro demands (stores) electricity (“Storage” in light yellow). This storage is required because the electricity produced to meet the consumption demand (in dark blue) has been met and the excess needs to



be stored. Both the production and demand profiles are in balance which is the case for every week throughout the year.

## 4.2 Ethanol/biodiesel

This scenario involved turning the electricity grid into a 100% renewable system and replacing 50% of the current light vehicle stock fuel consumption (petrol and diesel) with ethanol/biodiesel.

### 4.2.1 Electricity grid capacity

In this scenario it was possible for the electricity grid to be modified to reach 100% renewable electricity and to enable 50% of the light vehicles to be fuelled by ethanol/biodiesel. There was a small import problem of 0.02 TWh which is discussed in Section 5.2 (Discussion: Hydropower influence on Import and CEEP). The change in electricity grid is described below in Figure 4-6 and Figure 4-7.

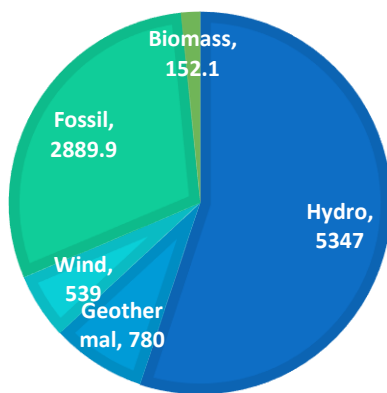


Figure 4-6: Reference system (2011) electricity grid capacities by type (total capacity: 9708 MW)

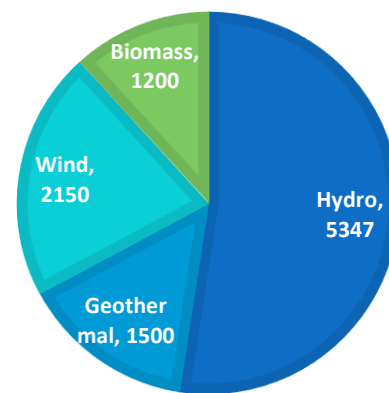


Figure 4-7: Ethanol/biodiesel scenario electricity grid capacities by type (Capacity: 10,197 MW)

As shown in the figures, the fossil fuel power stations are removed and a 1200 MW biomass power station is added. Hydropower capacity remains the same but the geothermal and wind capacities increase to 1500 MW and 2150 MW, respectively. This is lower than for the electricity vehicles scenario. The total capacity of the system increases from 9708 MW to 10,197 MW.

This scenario does not require much electricity for the production of biofuels, only 0.3 TWh, therefore this grid mix is actually indicative of a 100% renewable electricity grid, with only a small amount of electricity produced for transport.

### 4.2.2 Energy demand

This section presents the energy demand of the electricity sector and the light vehicle fleet as it changes from 2011 to 2040, and it excludes the other energy elements such as residential heating and industrial energy demand, and so on. In this study these other elements remain constant and do not change therefore it is not necessary to include them in this particular section.

EnergyPLAN automatically quantifies the total electricity produced by each electricity configuration in order for the energy system to be stable throughout the year. The results presented below show the amounts of electricity produced by each generation type, e.g. hydro power, to make sure the demand is met and that the system is stable in 2040. The results also show the energy demand of the petrol and diesel light vehicles and the demand of energy from biomass to produce biofuels. The change in energy demand of the system is presented in Figure

4-8 and Table 4-2 below. The results below show the energy demand of the electricity generators, light vehicle fuels, and the biomass for the biofuels. The energy demand for ethanol and biodiesel is counted twice in the results below, since the energy demand of the ethanol and biodiesel is included AND the energy demand of the biomass is included. In reality the energy demand of the biofuels already includes some of the energy from the biomass thus it is double counting. But the purpose of presenting the results this way is to illustrate the amount of energy demanded by the biomass in the results. The absolute total energy demand of all these elements shown is not that important in these results but rather the individual results are important.

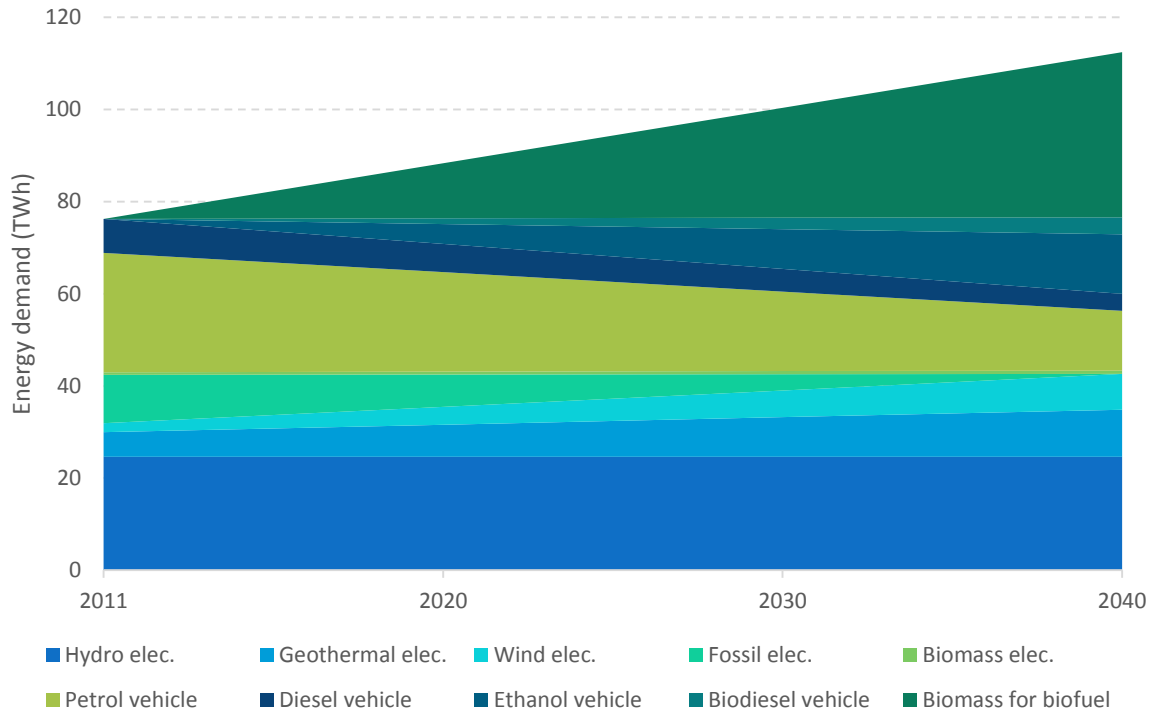


Figure 4-8: Energy demands from electricity generators, light vehicle fuels, and biomass for biofuels

Table 4-2: Energy demands from electricity generators, light vehicle fuels, and biomass for biofuels

TWh	2011	2040
<b>Hydro electricity</b>	24.6	24.6
<b>Geothermal electricity</b>	5.3	10.3
<b>Wind electricity</b>	1.9	7.7
<b>Fossil electricity</b>	10.5	0
<b>Biomass electricity</b>	0.6	0.8
<b>Petrol vehicle fuel</b>	25.9	13.0
<b>Diesel vehicle fuel</b>	7.4	3.7
<b>Ethanol vehicle fuel</b>	0	13.0
<b>Biodiesel vehicle fuel</b>	0	3.7
<b>Biomass for biofuel</b>	0	35.8

Overall the electricity grid requires less wind than the electric vehicle scenario since less electricity is required for the production of ethanol/biodiesel. Total electricity demand rises from 43 TWh to 43.33 TWh. However the ethanol/biodiesel production requires a lot of biomass, just under 36 TWh. This would produce enough biofuel to replace 50% of the light vehicle fuel consumed in 2011.

This scenario does not require pumped hydro since less electricity is required from wind compared with the electric vehicles scenario. However it still requires the 1200 MW biomass peaking plant for periods of low hydro storage levels and electricity production. The peaking plant produces 0.75 TWh in this scenario with a capacity factor of 7%.

### 4.3 Methanol/DME

This scenario involved turning the electricity grid into a 100% renewable system and replacing 50% of the current light vehicle stock fuel consumption (petrol and diesel) with methanol/DME.

#### 4.3.1 Electricity grid capacity

In this scenario it was possible for the electricity grid to be modified to reach 100% renewable electricity and to enable 50% of the light vehicles to be fuelled by methanol/DME. There was a small import problem of 0.03 TWh which is discussed in Section 5.2 (Discussion: Hydropower influence on Import and CEEP). The change in electricity grid is described below in Figure 4-9 and Figure 4-10.

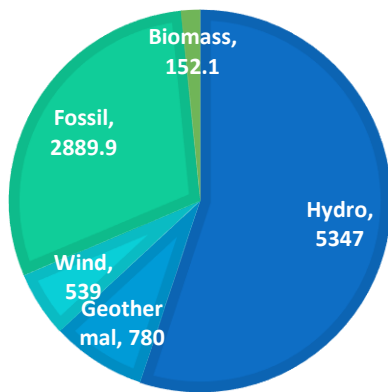


Figure 4-9: Reference system (2011) electricity grid capacities by type (total capacity: 9708 MW)

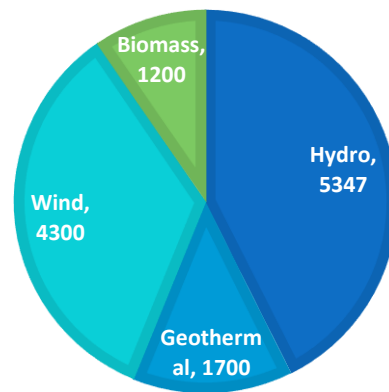


Figure 4-10: Methanol/DME scenario electricity grid capacities by type (Capacity: 12,547 MW)

As shown in the figures, the fossil fuel power stations are removed and a 1200 MW biomass power station is added. The hydro power capacity remains the same but the geothermal and wind increase to 1700 MW and 4300 MW, respectively. The total capacity rises from 9708 MW to 12,547 MW.

#### 4.3.2 Energy demand

This section presents the energy demand of the electricity sector and the light vehicle fleet as it changes from 2011 to 2040, and it excludes the other energy elements such as residential heating and industrial energy demand, and so on. In this study these other elements remain constant and do not change therefore it is not necessary to include them in this particular section.

EnergyPLAN automatically quantifies the total electricity produced by each electricity configuration in order for the energy system to be stable throughout the year. The results presented below show the amounts of electricity produced by each generation type, e.g. hydro power, to make sure the demand is met and that the system is stable in 2040. The results also show the energy demand of the petrol and diesel light vehicles. The change in energy demand and production of energy of the system is presented in Figure 4-10 and Table 4-3 below. The results below show the energy demand of the electricity generators, light vehicle fuels, and the biomass for the

biofuels. The energy demand for methanol/DME is counted twice in the results below, since the energy demand of the methanol/DME is included AND the energy demand of the biomass is included. In reality the energy demand of the biofuels already includes some of the energy from the biomass thus it is double counting. But the purpose of presenting the results this way is to illustrate the amount of energy demanded by the biomass in the results. The absolute total energy demand of all these elements shown is not that important in these results but rather the individual results are important.

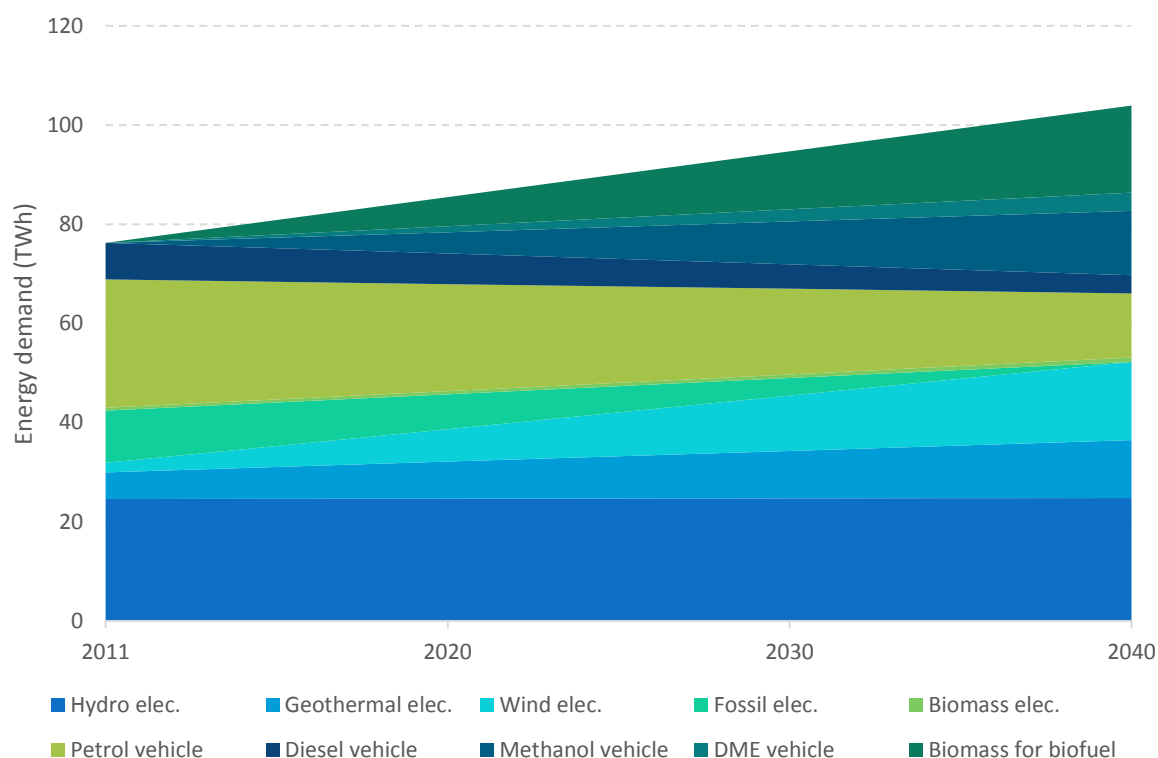


Figure 4-11: Energy demands from electricity generators, light vehicle fuels, and biomass for biofuels

Table 4-3: Energy demands from electricity generators, light vehicle fuels, and biomass for biofuels

TWh	2011	2040
Hydro electricity	24.6	24.8
Geothermal electricity	5.3	11.6
Wind electricity	1.9	15.8
Fossil electricity	10.5	0
Biomass electricity	0.6	0.9
Petrol vehicle fuel	25.9	13.0
Diesel vehicle fuel	7.4	3.7
Methanol vehicle fuel	0	13.0
DME vehicle fuel	0	3.7
Biomass for biofuel	0	17.6

This scenario requires the greatest amount of electricity compared with the other scenarios, rising from 43.134 TWh to 53.1 TWh. Electricity produced by geothermal and wind increase the most. The increase is due to the demand for methanol/DME production. The methanol requires less biomass than ethanol (17.6 TWh compared

with 35.8 TWh for ethanol/biodiesel) but it requires more electricity. A large amount of electricity is required when producing hydrogen with electrolyzers.

One and half million vehicles are able to be fuelled with methanol/DME by 2040 using the addition of electrolyzers. The effect of the electrolyzers is shown in Figure 4-12 and Figure 4-13 below.

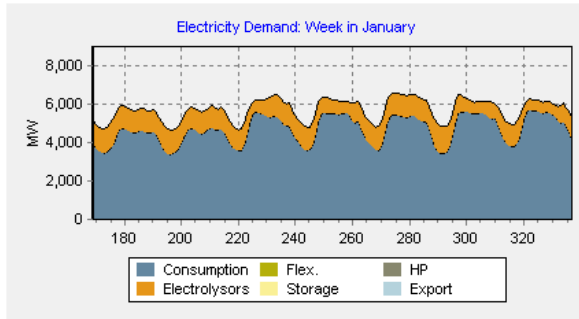


Figure 4-12: Electricity demand by type for a week in January (extracted from EnergyPLAN model).

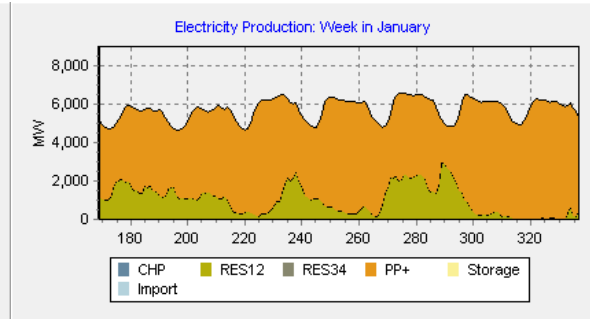


Figure 4-13: Electricity production by type for a week in January (extracted from EnergyPLAN model)

As shown in Figure 4-12, the demand for the week in January is for electricity consumption (dark blue) and the electrolyzers (orange). The electrolyzers would run constantly throughout the year in this scenario since it is consuming surplus electricity all year. Having the electrolyzers allows the use of much more wind, sometimes over 50% of production, as shown in hour 290 in Figure 4-13 (gold colour). By having both electrolyzers and high wind it is possible to balance the system and supply the methanol/DME for the vehicles. As shown in the figures both the demand and production are balanced which is the case for every week through the year.

#### 4.4 Primary energy demand from biomass and fossil fuels

The primary energy demand of each scenario is quite different since some scenarios depend more on fossil primary energy and some on biomass primary energy. To illustrate the primary energy demand of each scenario more clearly the split between primary energy from fossil fuels and biomass is shown in Figure 4-14 and Table 4-4 below.

The primary energy demand data shown below is for the entire energy system of New Zealand, including the residential heating, industrial energy and so on.

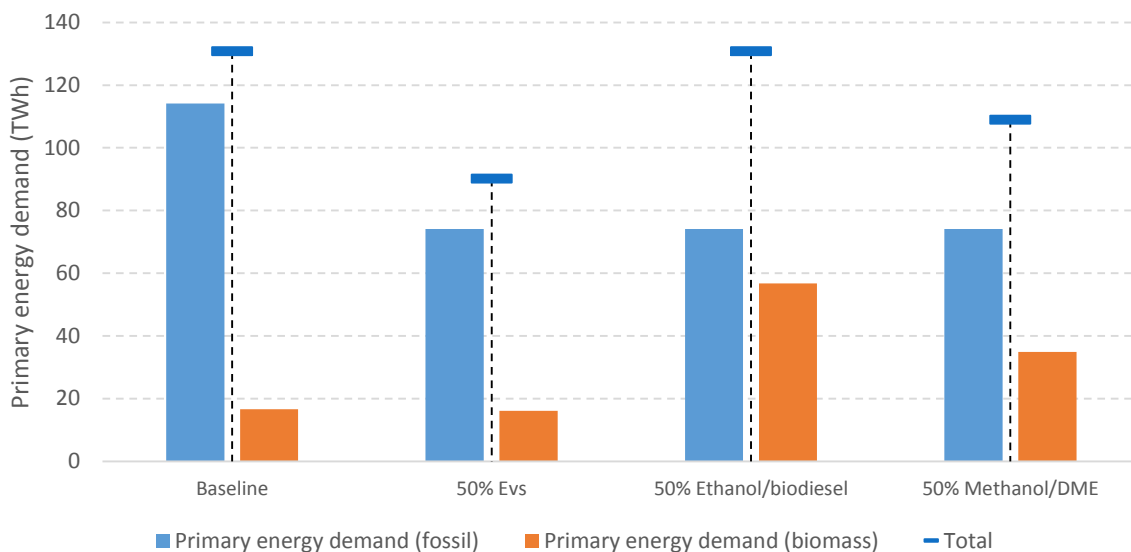


Figure 4-14: Primary energy demand for each energy system from fossil fuels and biomass

Table 4-4: Primary energy demand for each energy system from fossil fuels and biomass

Primary energy (TWh)	Reference	Electric vehicles	Ethanol	Methanol
<b>Fossil fuels</b>	114.12	74.09	74.09	74.09
<b>Biomass</b>	16.64	16.09	56.71	34.88
<b>Total</b>	<b>130.76</b>	<b>90.18</b>	<b>130.8</b>	<b>108.97</b>

As shown in the data, the reference system has the highest dependence on fossil fuels and the lowest dependence on biomass primary energy. The ethanol/biodiesel scenario has the highest primary energy demand of all the scenarios and this is caused by a high biomass demand for producing the ethanol/biodiesel. The methanol/DME scenario has a lower primary energy demand than the ethanol/biodiesel scenario which is due to less demand for biomass for the production of methanol/DME. The electric vehicle scenario has the lowest primary energy demand of all the scenarios since it requires less primary energy from fossil fuels and biomass.

All the alternative scenarios require the same amount of primary energy from fossil fuels since they all reduce the demand for fossil fuels by the same amount (50% of the light transport demand from 2011).

#### 4.5 Carbon dioxide equivalents

The carbon dioxide equivalent emissions from each scenario are presented in this section. The emission of carbon dioxide equivalents is an important consideration when comparing the scenarios since the ultimate aim of a 100% renewable energy system is to decrease the overall greenhouse gas emissions. This is important to achieve in the coming decades in order to avoid catastrophic climate change.

The carbon dioxide equivalent emissions for each scenario are presented in Figure 4-15 and Table 4-5 below.

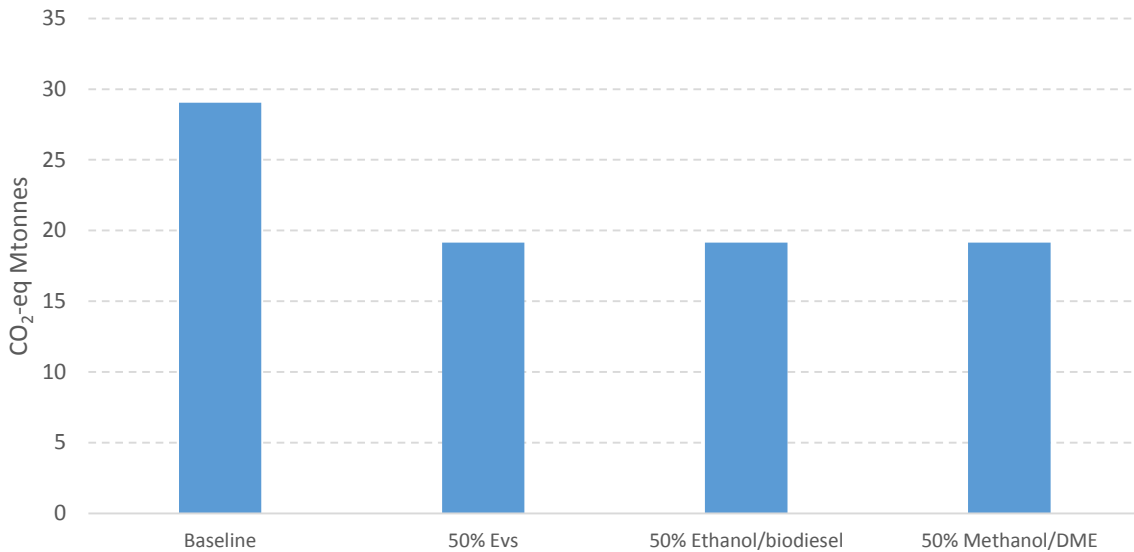


Figure 4-15: Carbon dioxide equivalent emissions from each energy system.

Table 4-5: Carbon dioxide equivalent emissions from each energy system.

Carbon dioxide equivalent (Mtonnes CO <sub>2</sub> -eq)	Reference	Electric vehicles	Ethanol	Methanol
<b>Total</b>	29.0	19.2	19.2	19.2

As shown in the data, all the alternative scenarios have the same carbon dioxide equivalent emissions which is lower than the reference scenario, by around 35%. This is because for each scenario the fossil fuel condensing power plants were removed and 50% of the light vehicle transport was converted to renewable energy. The changes to the grid mixes for each scenario do not release more carbon dioxide emissions since they are considered carbon zero, for example wind. And the changes to the transport sector of each scenario do not release more carbon dioxide emissions either, for example introducing electric vehicles or ethanol/biodiesel. Since the electricity is 100% renewable and is carbon zero the production of electricity for electric vehicles or for the production of the biofuels does not increase emissions. The biomass sourced for the production of the biofuels such as ethanol and methanol is assumed to be carbon neutral as well.

#### 4.6 Total annual costs

An important consideration in any EnergyPLAN scenario analysis is to assess the total annual cost associated with the alternative scenarios. In this study the total annual costs for the electricity and transport systems were calculated for the reference scenario and each alternative scenario. In this report the absolute cost data is not so important in this study, but rather the comparative costs are of interest. A full analysis of the cost data would require an entire new study and therefore the analysis below is high level and does not go into much detail.

The total annual costs are split between fuel and all other costs in Figure 4-16 and Table 4-6 below. The other costs include investment and maintenance costs for example.

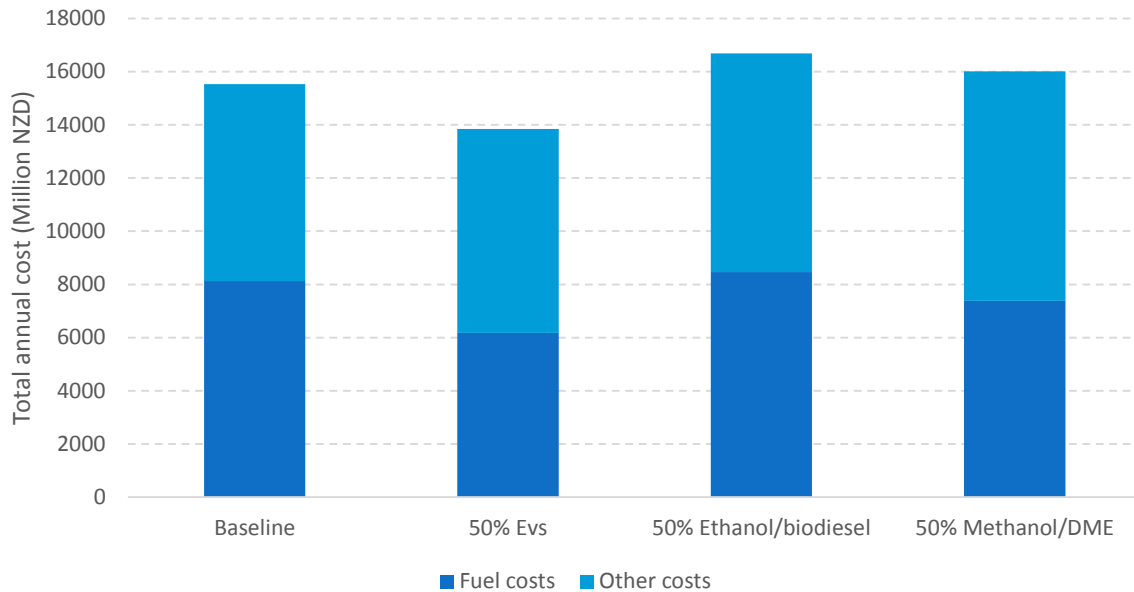


Figure 4-16: Total annual fuel costs and other costs (e.g. investment and maintenance) for each energy system

Table 4-6: Total annual fuel costs and other costs (e.g. investment and maintenance) for each energy system

Total annual costs (Million NZD)	Reference	Electric vehicles	Ethanol	Methanol
Fuel costs	8,126	6,173	8,461	7,377
Other costs	7,401	7,674	8,218	8,630
<b>Total costs</b>	<b>15,528</b>	<b>13,847</b>	<b>16,679</b>	<b>16,006</b>

As shown in the data, all the scenarios have an even split between fuel costs and other costs. The ethanol/biodiesel scenario has the greatest annual costs and the electric vehicles scenario has the lowest annual costs.

The ethanol/biodiesel scenario has a high annual cost mostly due to the large amount of biomass feedstock required for producing the biofuels.

The electric vehicles scenario has the lowest annual costs largely because the electricity being consumed by the vehicles does not require very much capital investment; unlike petrol or diesel that needs to be extracted as oil and refined into the fuels. The electricity is simply sent from the grid, which is in place now, to the vehicles. Also, there is no fuel price for electricity in this calculation since at the moment there are no costs in supplying it to the consumer unlike fossil fuels. Furthermore, the costs of purchasing the electric vehicles is excluded in this assessment and it is expected that the cost of the vehicle would increase the overall investment cost of the scenario. This would need to be investigated further.

For the methanol scenario the capital investment costs included within the other costs are slightly higher than the other scenarios due to the investment in hydrogen storage and electrolyzers.

The cost of the reference system is due to the cost of fuels for the condensing power plants and for transport. The marginal cost of the condensing power plants also contributes to the high cost which is due to the marginal cost of producing electricity, i.e. for maintenance and upgrades.

All the alternative scenarios have slightly higher “other costs” compared with the reference scenario which is related to the new power plants being installed such as the pumped hydro plant, and the other associated facilities such as the electrolyzers and hydrogen storage for the methanol/DME scenario.



## 5 Discussion

The aim of this study was to demonstrate that alternative energy systems based on renewable energy are technically possible in New Zealand. The basis for this study was from Choice Awareness Theory that theorises that valid choices are often hidden from the public in order to maintain the status quo. The theory goes further by theorising that alternative choices can be raised and can be initiated, and the theory provides specific counter-strategies. The strategy for this study was to identify some alternative scenarios that are technically valid for New Zealand.

### 5.1 Alternative scenarios

It was found that all the alternative scenarios are technically possible; ignoring all the other aspects such as costs, implementation strategy, micro-management of the grid such as ramping rates, and so on.

It is concluded that the electric vehicle scenario would be an ideal scenario since it requires less biomass and less electricity than the other scenarios. However the barrier to this scenario being implemented is the fact that the scenario depends on citizens purchasing electric vehicles and replacing their old ICE vehicles, which is expensive and resource intensive. In New Zealand it is common to import second hand vehicles (mostly from Japan) and these vehicles remain circling within the economy for many years, up to 20 or more years. Thus it is not expected that 1,500,000 electric vehicles would enter the vehicle fleet by 2040 since citizens do not purchase new vehicles very often and a market for second hand electric vehicles does not exist in New Zealand at the moment. The reality of replacing 1,500,000 cars with electric vehicles by 2040 would need to be researched further in another study.

Furthermore, the electric vehicle scenario would require a pumped hydro facility with a storage area for 500 GWh of energy. This would need to be developed privately or by the government.

It is more likely that the current vehicle fleet would be used in a transition to renewable energy. This would be in the form of consuming ethanol/biodiesel or methanol/DME or a similar type of biofuel. The reason is that the current vehicle stock can be easily converted to use these alternative fuels. This saves the owner money and it saves resources. The ethanol/biodiesel option is a potential scenario for New Zealand since there is the possibility to plant large areas of marginal land in plantation forest, but it still requires a very large amount of biomass. This would require a radical implementation of purpose-grown forestry with associated local businesses, and the Government would likely need to implement policy to encourage this. The wood to ethanol scenario is the current ambition of the Government owned Crown Research Institute called Scion Research, and this scenario is being investigated as of 2013 (Scion, 2013).

The methanol/DME scenario would also require biomass, most likely sourced from plantation forestry, but not as much as for the ethanol/biodiesel scenario. The methanol/DME scenario requires much more electricity in order to produce the biofuel. This can be sourced from fluctuating electricity sources such as wind. Two main benefits come from the methanol/DME scenario in that both unused biomass and marginal land can be utilised, and surplus electricity from wind can be utilised meaning that more wind capacity can be installed in New Zealand. But this would require a radical development and activity in new local business to produce the biomass and the methanol/DME. The methanol/DME option requires gasifiers, hydrogen electrolyzers and biofuel synthesizers. Furthermore there would need to be improved coordination between the biofuel organisations and electricity generation organisations in order to produce the biofuel from excess electricity. This would require careful oversight from the organisations involved as well as the Government who probably would need to implement strategies or policy. These aspects would need to be investigated further in future research.

All the alternative scenarios would require a 1200 MW biomass power plant (as modelled in this study). But this needs to be investigated further to determine if there is a better alternative. The investigation would also need to consider the costs associated with the different options.

This study did not assess a scenario where each of the alternative renewable energy sources were combined in one scenario. For example by splitting the 50% light vehicle fuel transition from fossil fuels to renewable energy by 1/3 ethanol/biodiesel, 1/3 electric vehicles, and 1/3 methanol/DME. This is a scenario that should be considered in future research.

All the alternative scenarios were technically valid except for a small Import requirement problem in each scenario, including the reference system. The aim was to assess these scenarios by balancing the electricity mix and making sure that there was no CEEP and Import requirement problems. However in some cases it was not possible to make the Import requirement 0 and this is because of the hydropower storage level distribution profile for 2011. This is explained further in the next section.

## 5.2 Hydro power influence on Import and CEEP

In EnergyPLAN, in the reference scenario it was possible to have CEEP at 0 but it was not possible for the Import requirement to be 0; it was 0.04 TWh. This should not be the case since the reference scenario was for 2011 which has already occurred, and the system was balanced and stable in this year. Since the reference scenario was not balanced in EnergyPLAN, it meant that all the alternative scenarios were also unbalanced and had Import requirement problems, therefore the Import requirement problem was ignored in all the alternative scenarios. However this should be investigated further. This issue was investigated partly in this study and it was found that 2011 was not a typical year for hydro power production and storage levels as shown in Figure 5-1.

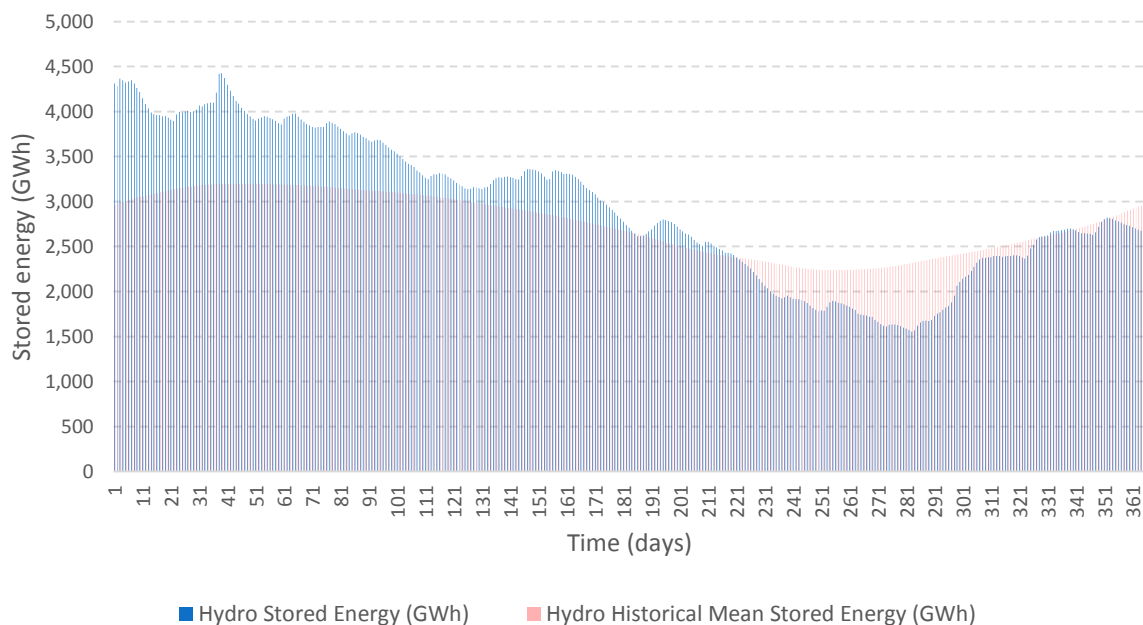


Figure 5-1: Hydro stored energy in 2011 compared with the historical mean stored energy

In 2011 there was a very high storage level at the beginning of 2011 (4428 GWh in 8<sup>th</sup> February) compared to the historical mean stored energy, and this decreased to a much lower level in the later months of the year (day 220 – 300, lowest in October at 1557 GWh) than what is typically seen (pink profile). After this point the water levels increased. However in 2011 the levels on 31<sup>st</sup> December increased only to 2700 GWh which was not the same level as the start of January 2011. In general the hydro storage level should be equal at the beginning and at the end of the year. Therefore when EnergyPLAN calculates the electricity production distribution profile, the tool assumes that the storage level at the beginning and at the end of the year are the same (this is common sense since hydropower storage should be equal every year and each year should have the same, or similar, distribution profile). This means that, in EnergyPLAN, at the beginning of the year the storage level is decreased

and at the end of the year the level is increased, in order to have the same level at the beginning and end of the year. And in the middle part of the year the storage level is decreased as well. The decrease in the middle of the year creates the Import requirement problem. As the storage level gets lower there is a shortfall in electricity generation capacity during the low period (August, September, October). This is when the Import requirement problem occurs. The peaking power plants cannot supply enough power during this period since there is not enough capacity. Mason, Page, & Williamson, (2013) researched how New Zealand could become 100% renewable and as a solution to this issue they combined and averaged the distribution profiles of the years January 2005 to December 2010 which created a more accurate mean profile. It is recommended that this is carried out in future research.

In addition, in New Zealand there are minimum hydro lake levels allowable by law and it would need to be investigated to see if these levels are exceeded in any of the scenarios modelled in this study.

### 5.3 Capacity factors of power plants

In the reference scenario the power plants all have a relatively high capacity factor. However when the renewable energy sources increased the capacity factor of the peaking plants decreased. The capacity factor of each of the electricity generators is shown in Table 5-1.

Table 5-1: Capacity factors for each electricity production type for each scenario

	Reference	50% Vehicles	Electric	50% Ethanol/biodiesel	50% Methanol/DME
<b>Hydro</b>	53%	53%	53%	53%	53%
<b>Geothermal</b>	78%	78%	78%	78%	84%
<b>Wind</b>	41%	41%	41%	41%	41%
<b>Fossil</b>	42%	N/A	N/A	N/A	N/A
<b>Biomass</b>	42%	2%	8%	8%	4%
<b>Pumped hydro</b>	N/A	3%	N/A	N/A	N/A

As shown in Table 5-1 the biomass power plant has a low capacity factor in all the alternative scenarios. But having the biomass power plant available it enables the capacity factor of renewable energy sources such as wind and geothermal to remain high. Since the power plant enables these fluctuating power facilities to exist, it would be expected that the biomass power plant would require some form of financial support from these other electricity generators, for example via a subsidy for the construction of the plant or some payment for the production of electricity.

Mason, Page, & Williamson, (2013) investigated a 100% renewable electricity system for New Zealand, and instead of retaining a 1200MW biomass peaking power plant, the study split the geothermal capacity between constant load and switchable load. Having part of the geothermal power on standby effectively means that it could operate as a replacement for hydro power production. When wind production increases in a 100% renewable system, less hydro is required and spillage events could occur. Therefore with the switchable geothermal capacity, part of the geothermal production can be switched off, and instead the hydro power can be utilised, thus relieving the pressure on the hydro storage levels. Instead of hydro storage lake levels being low in the middle of the year (e.g. in the months August, September, October), with the switchable geothermal capacity the lake levels can be kept higher. Thus, in these middle months when usually a condensing peaking power plant (e.g. 1200 MW biomass plant) is normally required, the hydro power can be utilised instead.

The pumped hydro station is required for the electric vehicles scenario and it also has a low capacity factor of 3%. This is because it is required only in some occasions during the year when lake levels are low. Since this station enables a higher penetration of wind and geothermal, and the implementation of 1,500,000 electric

vehicles, this power station would also require some form of financial support from the areas that benefit from its storage capacity and peaking supply.

Mason, Page, & Williamson, (2013) included a pumped hydro power plant in their study as well. But instead of installing a generating capacity of 2000 MW they utilised a 1550 MW power plant with capacity factor of 0.76% as opposed to 3% in this study. The storage capacity in Mason, Page, & Williamson, (2013) was 368 GWh whereas in this study it is 500 GWh. The capacity factor in this study is higher than Mason, Page, & Williamson, (2013) since the electric vehicles are consuming electricity whereas in Mason, Page, & Williamson, (2013) there is no additional electricity consumption from the 100% renewable electricity grid; the pumped hydro is simply used to balance the system and thus it is used even less than in electric vehicle scenario of this study.

#### **5.4 Costs and carbon dioxide equivalent emissions**

A full feasibility study into the costs of these alternative systems should be carried out. Although a preliminary cost assessment was carried out, it needs to be determined if it is cost effective to have power plants on standby or whether it is cost effective to have less wind, for example. Also, the management and economics of these systems in terms of coordinating the institutions and organisations involved to make the system work would need to be figured out. For example if pumped hydro exists to support electric vehicles then the price of electricity for electric vehicles may need to include the cost of having pumped hydro.

In this study the cost for carbon dioxide equivalent emissions is not included. But it is expected that a cost will be introduced in the future, and this also needs to be considered in future research.

In regards to carbon dioxide equivalent emissions, the research showed that by creating a 100% renewable electricity sector and decreasing 50% of the light vehicle fuel consumption from fossil fuels to renewable energy, carbon dioxide equivalent emissions could be reduced by around 35%. This is a large proportion of the emissions from the energy sector but the effort to achieve this would need to start in the next couple of years in order to achieve one of the scenarios by 2040. The sooner the emissions can be reduced, the more costs can be saved if a price for carbon is introduced; and the risk from catastrophic climate change will be lessened.

## 6 Conclusion

The New Zealand Government has provided an energy prediction from the year 2011 to 2029 which predicts an increase in diesel consumption in the transport sector, and continued reliance on natural gas in the electricity sector. However this study has shown that it is technically possible to have a 100% renewable electricity system by 2040. And not only can the electricity sector be 100% renewable but 50% of the light vehicles can run on renewable energy as well.

This study researched three scenarios where the electricity grid was 100% renewable and 50% of the light vehicle energy supply was replaced with either a) electric vehicles, b) ethanol/biodiesel; or c) methanol/DME. An ideal scenario could not be selected from this research since not all aspects were considered or investigated fully, such as cost. However each scenario possesses specific benefits.

In order for all the scenarios to achieve 100% renewable electricity production, each scenario required a 1200 MW biomass condensing power plant in order to meet peaking demands. The electric vehicle scenario requires that a pumped hydro power plant is added to enable the electricity system to be 100% renewable, and to supply electricity to the electric vehicles. This scenario consumes the least biomass and fossil fuels of all the scenarios, and it is more energy efficient. It is the cheapest scenario in terms of total costs, however it relies on the citizens to purchase new vehicles which would be expensive and this was not included in the total cost. The ethanol/biodiesel scenario does not require an addition of pumped hydro and simply increases wind and geothermal to achieve a 100% renewable electricity system. The scenario builds upon the research already done by Scion Research around wood to ethanol. And it is possible to supply enough biomass for this scenario in New Zealand. However much of the biomass would come from purpose grown forests and they would need to be planted very soon in order to achieve this scenario. The methanol/DME scenario requires an addition of electrolyzers for producing hydrogen for making methanol/DME. This requires that wind electricity is increased the most out of all the scenarios. This scenario is similar to the ethanol/biodiesel scenario but it relies more on electricity to produce the biofuel and less on biomass. This means that this scenario could be implemented quicker than the ethanol/biodiesel scenario, since less biomass is required to grow in the next few years. However the methanol/DME technology is less known in New Zealand at this stage and it faces competition from the wood to ethanol option. It also depends on the electricity grid to increase in renewable electricity such as wind and geothermal in order to supply enough electricity for the production of the biofuel.

A fourth scenario where each of the three scenarios are combined was not investigated in this study and it would be recommended to investigate this type of scenario. At present petrol and diesel dominate the liquid fuel supply for light vehicles and in the future it is most likely that a mix of renewable fuels will supply the light vehicle energy.

This study is the first known study to use EnergyPLAN for the energy system in New Zealand and it found that this tool is very effective at determining the technical feasibility of a new energy system. This study serves as a preliminary study into this research space and further research is required. But it should serve as a basis for future research. The study was carried out partly for Generation Zero and the results will be communicated with the organisation in order to support their goals of creating awareness about alternatives energy options to the public.

The recommended next step after this study is to create feasibility studies for these alternative scenarios by researching the current organisational and institutional arrangement of the New Zealand energy system. If these alternative scenarios are to be implemented in New Zealand, a strategy is required to raise the awareness about them and to start the transition to them. Within this strategy, new energy policies should be promoted and implemented in order to begin the transition.

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## 8 Appendices

### Appendix A: EnergyPLAN files

These files can be downloaded from the link below and can be used in EnergyPLAN.

<https://www.dropbox.com/sh/7z94ok64c1aclvg/Lx3xS721sK>

The folder contains:

- Model for the Reference system from 2011
- Model for the Electric Vehicles scenario for 2040
- Model for the Ethanol/Biodiesel scenario for 2040
- Model for the Methanol/DME scenario for 2040
- New Zealand total wind electricity generation distribution per hour for 2011
- New Zealand total geothermal electricity generation distribution per hour for 2011
- New Zealand total electricity generation distribution per hour for 2011
- New Zealand total space heating energy consumption distribution per hour for 2011
- New Zealand total hydro water deposit distribution per hour for 2011
- United States smart electric vehicle electricity consumption distribution per hour for 2001
- Cost data calculated by the Danish Energy Agency for 2020