Empowering Energy Innovation in the Communities of Aotearoa

A thesis
submitted in fulfilment
of the requirements for the Degree
of
Masters of Engineering
at
The University of Waikato
by

Michaela Jane Kerr

THE UNIVERSITY OF
WAIKATO
Te Whare Wānanga o Waikato

2024

Abstract

> Technological change is not additive; it is ecological. A new technology does not merely add something; it changes everything.
>
> *Neil Postman*

Since the electricity grid began connecting more and more areas of Aotearoa New Zealand, we have been relying on technology that was fit for purpose for a 1980s future. In the last ten years, the New Zealand power system has seen an increase in non-dispatchable generation and an accelerated rate of electrification, creating supply and demand volatility. Aotearoa New Zealand uses more electricity in homes, cars, factories, and devices than ever, yet the generation currently installed around the country is not increasing at the rate of usage or predicted usage. As a result, the national grid operator, Transpower, runs closer to constraint limits on cold evenings every year, has recently been fined over handling a low-generation event in 2021, and subsequently has been issuing more Customer Advisory Notices (CAN) than ever before.

Through a combination of technology-driven development and energy infrastructure, the energy sector has the potential to find new ways to access more electricity through the use of existing generation, or through infrastructure predicted to exist, in more innovative and efficient ways. While companies are working on specific solutions, many of these are required to have an economic benefit for the company by bringing in revenue, as opposed to providing relief to the communities these companies operate in and have been supported. Technology-driven change should support these communities.

This research focuses on how technology driving change in the energy space can be used more effectively to provide security of supply to communities that have yet to be considered when energy policy was written.

The first phase of this research analysed small-scale and medium-heat processes in a beverage factory with solar panels to understand and show how solar generation can be used to offset a factory's electricity load from the grid. Case Study One analysed how this approach could reduce demand and reliance on the grid by allowing electricity to go where it is required on cold evenings. A monitoring system was custom created for Chia Sisters as a way to provide a deeper understanding of their electricity and solar usage. The system has been available as an open-source project on GitHub for use by other companies in a similar position to Chia Sisters.

The second phase of this research simulated the electricity storage potential in electric buses by applying Vehicle to Grid technology advancements to school buses in the Wellington region through Case Study Two. This simulation took advantage of stationary school buses, which sit idle during school hours and evenings. Nationally, school buses are changing and are required to become electric in the next decade, with electric school buses expected to be a part of the transport system by 2035.

By combining these two community-centred approaches to improving existing infrastructure, smaller communities have potential to gain generation opportunities through a deployable system that would monitor microgrids and monitoring systems. The theorised Community Energy Management System (CEMS) looks at all the inputs (generation and electric vehicles), usage times, and electricity usage trends in remote, rural, or isolated communities to allow electricity to be used more effectively in our communities. These communities often need to be at the forefront of legislation planning. Such a system shows how supply and demand has the potential to change in communities across New Zealand over time by using a community management system. Approaches such as the CEMS theorised have been seen in emergency climate response situations already in New Zealand, so by applying these more resilient microgrid systems with generation stemming from factory roof solar, storage from school buses, and being used in communities, this overall process could become a crucial part of our energy future.

Acknowledgements

Five years ago, I was a second-year engineering student trying to find an internship around Hamilton with a company who would take on a software engineer for an engineering placement. Mercury took that step, appreciated my ability to try to bluff my way through an interview about how turbines generated electricity (yes, an actual interview question!) and consequently, jump-started this energy journey which seems to have taken over my entire life and engineering career.

I remember going to my first dam in my second week on the job, feeling very out of place in my fluro vest and steel cap boots, a long way from what I had known as a wannabe software engineer. Over the next ten weeks, I went to every dam down the Waikato River and all the geothermal power stations operated by Mercury. To say the least, I fell in love with the energy industry, and five years later am authoring a thesis for a master's on the topic.

This journey has highlighted how your high school education does not need to define your career, I did not do NCEA electricity papers, and yet somehow here I am. I would like to say thank you to Mercury and my control systems team for taking a software engineer on two placements, showing me how small the industry is, and giving me some great references to Transpower, where I currently work, and to Counties Energy, where I am about to work. A huge thank you to Transpower, and my manager Sangita, for allowing me to embark on this endeavour during work hours and for understanding how easily I get bored with the same task.

But my biggest thank you goes to my supervisor, Mark Apperley, who believes in most of my crazy ideas and has helped me through my honour's thesis and now a master's thesis. I cannot express how much gratitude I have for you Mark; this two-year journey would not have been possible without the belief you have in my writing (too much) and the will to back up my ideas at conferences or in a Zoom call. So, thank you, may someday we meet again that is not over zoom.

Of course, thank you to my family and friends who have listened to many lectures about substations and the power grid, how black starts work, and frequency keeping, and how a holiday must always include looking at the

nearby power stations. By now, I think all of them have a support group for how to deal with being bored while looking at dams!

Without all these people, interactions, and adventures, there would be no Michaela interested in Aotearoa's energy future, so here it is, along with a large cup of coffee, an evening with a gin and lime, a cheeseboard, a cheesecake, and a lecture about my latest new favourite dam, I raise a glass to all of you. Thank you.

Contents

List of Figures

List of Tables

Chapter 1

Introduction

1.1 Context of Study

Electricity and energy usage in New Zealand has evolved from powering mining equipment to where it now powers entire industries and residential homes. With decarbonisation goals in mind for the next thirty years, generation companies are expanding their renewable energy networks to decrease the size of their thermal generation portfolios. As a result, there has been a significant increase in the exploration and implementation of new wind and solar infrastructure to replace thermal generation. However, medium, and large-scale industrial partners, which rely steadily on thermal generation through high-temperature processes, are finding it harder to electrify these processes due to existing technology limitations. Smaller industrial partners have had a slightly easier time as they can electrify more of their operations with existing technology. However, this can be expensive.

New Zealand's electricity users, including industrial and residential, are set to require more electricity over the next thirty years, a predicted demand increase of 68% (Transpower, 2022b). Current government legislation has targeted a decarbonisation goal of a lower emissions grid with more renewable sources of generation, along with a low emissions transport system, and many industrial partners are looking for ways to remove reliance on generation companies and support those communities around them.

It is essential to acknowledge the te ao māori viewpoint, which recognises we exist in an ecosystem, with each system interconnected with other systems. This viewpoint also recognises we aim to build up the ecosystem to provide a more circular and sustainable economy, which, to achieve, requires a transition for all ecosystems and systems involved, as well as enabling maintenance and building well-being throughout Aotearoa.

The long-term decarbonisation strategy for New Zealand is outlined in the Climate Change Commission (CCC) report (CCC, 2022) and highlighted by the Ministry of the Environment (2022) as providing shared outcomes, and while government policies and actions are moving towards providing an overall framework, motivations, and incentives for the country to move in the right direction, much of the required change falls on industry, business and individuals to move in the direction of sustainability.

1.2 Problem Statement

Aotearoa, New Zealand, has outlined a path to lower emissions and produced commitments to reducing emissions by 30% below 2005 levels before 2030, as well as being 100% carbon neutral by 2050. While we contribute only 0.3% to overall global greenhouse gas emissions, New Zealand has the 12th highest emissions per capita in the developed world (MftE, 2021). We currently have 1 in 3 people classified as obese, ranking third globally. At any one time, our water is 78.6% drinkable across every category (bacteriological, protozoal, chemical, water safety plan) (MoH, 2020), which is monitored across all water providers who provide water for more than 100 people and reported on by the Ministry of Health every year.

As a result of more severe weather events, our land resources are being lost at around 1.8mm due to sea levels rising per year, resulting in erosion on beaches, which presents issues for council infrastructure, personal residences, and land used for business or industrial purposes. Aotearoa also sees more sewage overflow into the oceans due to longer dry spells followed by intense rainfall (MftE, 2008), increasing the pollution to our oceans and waterways.

Climate change is bringing about less drinkable water, rising sea levels, an increase in floods and droughts, changing wind and rainfall patterns, increased temperatures, reduced frosts, more pressure on our ecosystems, and an increased threat of pest species becoming established here as a result of more favourable conditions for them. The average temperature in Aotearoa has increased yearly for the last four years. Changes to our climate are, therefore, likely to affect everyone (MftE, 2021) from ourselves, our whānau, our workplaces, our industries, exports, imports, and lives. By recognising that the ecosystem of our lives is being affected and changed by our actions, we can recognise that we need to change our habits and systems to help decrease our lives impact on our planet.

The first part of this study focuses on how communities in New Zealand and how existing infrastructure in the energy space can be used more effectively to provide more energy security to the communities that should have been considered when the energy policy was written. This is investigated by identifying and analysing the electrification occurring in an industrial processing factory in New Zealand, which has installed a solar array to decrease its carbon emissions and reliance on the grid. This study intended to develop and implement an open-source system that could be re-used in factories across Aotearoa and provide a way for them to monitor and analyse their electricity usage efficiently and logically. Additionally, the developed software has the potential to future-proof expansions to the system to provide necessary storage capabilities for receiving and storing solar or battery data.

This second phase of this thesis investigates infrastructure expected to exist in communities in line with the 2035 climate change goals by identifying heavy electric vehicle infrastructure that could benefit from using Vehicle-to-Grid technology. There is potential for the expansion of such technology by providing a more comprehensive range of focus than traditional residential users of electric vehicles. Wider-use areas include potentially remote or isolated communities which have the potential to be more affected by climate change. As a result of this study, there is potential for advancements to occur in the aforementioned areas.

1.3 Thesis Overview

Chia Sisters are an company with a small, industrial, processing factory, and with an eye for sustainability, they installed a solar array to generate electricity for their processing factory. They have been using this generation for a few years, and a case study was completed with them to show how they use electricity in a factory setting, which can be traditionally hard to decarbonise or aid in decarbonising. As a result of the case study, which can be read in Chapter 3, a monitoring system was implemented to analyse their processes and systems, which allowed some recommendations to be made to the Chia Sisters for their factory.

Furthering on from Case Study One investigating industrial solar generation, Chapter 4 focuses on how existing infrastructure in the transport and industrial sectors can be utilised more efficiently through analysis and management of factory processes by using heavy electric vehicle technology in the form of buses to provide electricity security to communities that may have yet to be considered when energy policy is written.

Chapter 5 combines the two case studies and theorises an overall community management system for electricity management on a community-based level to guide communities on the path of decarbonisation or at least provide the potential to record valuable data and analyse their energy usage.

There is no one size fits all approach to providing solutions in an average way across New Zealand. However, through resource sharing and policy support from local and central government, Aotearoa will be able to create and share solutions to problems faced by climate change. Within our context, our solutions may differ from other countries as we face our unique challenges. Nevertheless, this should encourage people to think ahead, know their emissions, and identify ways they can decrease, on average, by 1% per year to reach Aotearoa New Zealand's decarbonisation goals.

1.4 Thesis Structure

Chapter 3 identifies and analyses a small-scale and medium-heat process beverage factory called Chia Sisters, which has installed solar panels to offset their factory's electricity load from the grid. Case Study One (Section 3.2) analyses how the Chia Sisters' approach to decarbonisation makes the most of their solar generation by operating during sunshine hours. To investigate potential changes to help further decarbonise their processes, an open-source monitoring system was developed for Chia Sisters, and has the potential to be used in other companies in a similar position to Chia Sisters as a way to aid in their decarbonisation process and monitor when they use electricity.

The second phase of this research in Chapter 4 investigated potential extensions for Vehicle-to-Grid technology, a type of microgrid support that can benefit traditional individual households or owners of electric vehicles. Case Study Two (4.3 simulated the electricity storage potential in electric school buses by applying Vehicle-to-Grid technology advancements to school buses in the Wellington region. This simulation took advantage of stationary school buses, which sit idle during school hours and evenings. Nationally, school buses are changing and are required to become electric in the next decade, with electric school buses expected to be a part of the transport system by 2035 (MoT, 2023).

Chapter 5 combines these two community-centred approaches in Chapter3 and Chapter 4 to theorise a Community Energy Management System (CEMS).

The CEMS would identify all the inputs (generation and electric vehicles), usage times, and electricity usage trends in remote, rural, or isolated communities and allow electricity to be used more effectively or directed where it is needed, much like a Virtual Power Plant. Such a system can change how electricity is used and monitored across Aotearoa and not just used in emergency response situations. By applying these more resilient microgrid systems with generation stemming from factory roof solar, storage from school buses, and being used in communities, this overall process could become a crucial part of our energy future.

From these main chapters, there are conclusions which have been identified and presented in Chapter 6. Consequently, there is a collation of future work which is identified in each individual chapter conclusion, but is also summarised in the final chapter at the conclusion of this thesis.

Chapter 2

Energy Concepts Background

> The electricity you are using to read this right now, was 1 second ago, a drop of water.
>
> *The Fraying Wires - Gretchen Bakke*

This chapter provides context into concepts discussed in this thesis. While these concepts are discussed more in-depth in their respective chapters, they introduce the topics covered in the research. Each section covered in this chapter has more related literature associated with it which is discussed in more detail in the background section of their respective chapter.

2.1 Energy

Over time, how we use energy and the way we harness energy has changed. This change has allowed technology to develop and spark new inventions; from the sun providing heat, wind moving air allowing us to move sails or windmills, or rivers flowing through the countryside, we have always harnessed the environment around us. The discovery of fossil fuels has allowed leaps and bounds of engineering and industry to occur and has aided society in being developed into how we know it today.

Climate change has been the brutal response to such an exponential growth of fossil fuel usage globally. As well as polluting our environment, one day, fossil fuels will eventually run out. The transition from fossil fuels to more renewable energy sources is a global process towards a more sustainable future. The transition to renewable sources of generation ensures that energy remains available for future generations. Supporting industries globally to convert to renewable energy sources will ensure that we cause less harm to the places we call home.

2.1.1 Renewable Energy

Renewable energy allows the global population to continue progressing with technological development more sustainably. Solar, hydro, geothermal, wind, ocean energy, and bioenergy are all types of renewable electricity generation that can renew themselves through repeating weather conditions or as a bio-product of the environment, produced at a faster rate than consumed.

The New Zealand electricity grid is powered by predominantly renewable generation sources already. On any given day, around 80% of the electricity grid is powered by renewable sources, with a full detailed breakdown produced by Transpower (Transpower, 2023).

Wind and solar have been identified as the best way to increase electricity generation by 66% in New Zealand in the next 27 years (MBIE, 2019). There have been more grid connection requests to the New Zealand grid in the past year than in the last ten years, most of which are wind or solar (EECA, 2021). Predominantly new connection requests leading to new generation in Aotearoa is coming from larger generators with wind and solar, as well as some large-scale battery projects. Transpower estimates that over 40 new power stations will be connected to the grid by 2035, more generation development than has occurred in the last 40 years (Transpower, 2022b). This also implies the grid will need to be developed and invested in, with 30 new connections to the grid needed, this is about the same that has occurred by Transpower over the last

30 years (approx. 1-2 per year). Widespread electrification comes together with a common direction, and finally, the future is happening now for the energy sector, with major reforms in pricing, policy, and markets well on their way to becoming a reality for New Zealand's energy future.

Wind and solar are types of renewable generation which are widely viewed as suitable investments as they are scalable and relatively low cost, particularly when compared to more alternative generation types like hydro generation, which involves dams or tunnels and the underlying landscape to be appropriately formed, or geothermal which requires heavy maintenance and geothermal fields which are historically easy to upset the enthalpy (DiPippo, 1993). From a grid perspective, wind and solar provide more challenges than, for example, a typical geothermal station, as these are large-scale systems that have some advantages over solar and wind. They rely on people controlling them, which is great for the balance of the electricity grid. When demand increases, generation can increase by a small margin allowing large turbines to be used for inertia, voltage support, and frequency keeping (typically hydro stations). These large, spinning turbines are therefore referred to as a dispatchable generation.

Non-dispatchable sources of generation, and therefore generation types without large spinning turbines, do not provide inertia to the grid, which has been known to cause reliability issues across the grid (Denholm et al., 2020). Non-dispatchable sources of generation are wind and solar, which are far more reliant on real-time weather conditions, such as the sun shining or the wind blowing, meaning they cannot be reliably dispatched in a market situation (Wolfe, 2023). For example, when compared to hydro generation which can be turned on or off to increase or decrease generation output, wind and solar cannot supply the grid with the same consistency or controllability. Hence they are known as non-dispatchable.

Both wind and solar generation are predicted to play a vital role when building new generation sources to provide for the expected increase in electricity demand. Hydropower and geothermal are also important, as they provide instantaneous generation when everyone in New Zealand boils their jug in the middle of the Rugby World Cup Final (Radio New Zealand, 2015).

2.1.2 New Zealand's Energy System

Three essential issues relate to the New Zealand Energy System which are referred to as the energy trilemma - Security of Supply, Emissions, and Cost (Purdie & Telfar, 2019). The energy trilemma identifies the key issues which have been acknowledged and are resulting in industry-wide changes across the energy sector. Transpower predicts energy demand is going to increase in the next thirty years (Transpower, 2022b) as a result of needing to electrify and decarbonise transport and industries, how New Zealand manages that transition is a part of the evolving energy trilemma.

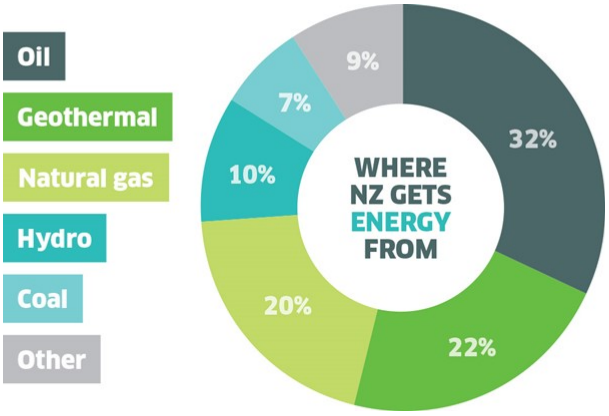


Figure 2.1: Energy composition in New Zealand (Energy Resources Aotearoa, 2020).

Aotearoa's overall energy usage currently uses a 60:40 split of non-renewable versus renewable energy sources, with 60% of its energy sourced by coal, oil, and gas and only 40% produced from renewable sources such as hydro, solar, wind, and geothermal (Energy Resources Aotearoa, 2020).

Climate goals and actions aim to flip the current energy ratio in the next decade, but more than just sources of electricity need to change. The existing users of non-renewable energy (60% of overall energy usage) are broken down to include transport (36%), agriculture (4.7%), industrial (34%), domestic energy use (11%), and commercial (9%) (Energy Resources Aotearoa, 2020).

The Climate Change Commission recommends that 50% of all energy consumed by 2035 should be from renewable sources (CCC, 2022). This includes all the previously mentioned systems, including process heat, transport, buildings, and electricity generation. Within this report there was also a recommendation for the publication of Total Primary Energy Supply as a total share of total final energy consumption which is not currently reported, however it should be as this number acknowledges all wasted head from fuel combustion in generators, boilers, and conversion of methanol. In line with this, a revised target of renewables should be around 95% instead of 100% renewables due to the higher cost of conversion to electricity at this level, however as renewable systems become more manageable, this number will decrease and 100% will become a likely scenario.

The largest sectors, such as transport, are being targeted early by policy changes as they require more time to transition and for technology to evolve to a more economically viable place where more people are able to access the technology. Solar is an example of a technology which has evolved and has seen a significant increase in uptake (EECA, 2022) and decrease in costs. The same is true for electric vehicles.

2.2 The Electricity Grid

The New Zealand Electricity Grid began its inception in the late 1800s by powering mines, and since then has continued to expand with upgrades, grid connections, generation, and people connecting to it. Now, electricity is a way of life; we need it to do our jobs, drive on roads with traffic lights, operate electric cars, or communicate with our friends and family. As a society, we are now highly co-dependent on electricity. New Zealand is invested in continuing to operate large, transmission assets which transport electricity from the South

Island to where many people live in the North Island (half of the New Zealand population lives north of Lake Taupō). However, over half of the country's electricity generation comes from below Lake Taupō.

The grid is composed of predominantly grid-forming synchronous machines, which help to contribute to voltage, inertia, and frequency which are all critical parts of operating a grid without significant issues.

2.3 Communities of Aotearoa

Communities exist in many forms, and we are parts of the interconnecting weave of humanity, which is collectively trying to find its place in the world. Whānaungatanga embraces all that we are, and maintains that all elements are interrelated. Our whakapapa, family, iwi, and lives are joined in the energy journey to move towards a more sustainable future to protect future generations. Every community is essential in this way, and it is important to acknowledge that some communities have been ignored or misrepresented in the policy around climate change in Aotearoa.

Small and rural communities in Aotearoa are at the mercy of the changing climate, frequently missing out on developing technologies and funding opportunities while being more strongly threatened by the impact of climate change (MftE, 2022). During the consultation phase of a Ministry for the Environment analysis, one identified area was the investment in regional infrastructure to strengthen community resilience and lessen climate change's impact.

Rural communities are defined as a subset of an urban environment and are considered a population between 200-999 people with at least 40 dwellings (Stats NZ, 2023) (Stichbury, 2018). Rural communities are often a forgotten subset of New Zealand when considering climate change targets, public transport, and funding opportunities in small, rural or isolated communities. An example of this was during the country-wide fibre rollout which was planned in 2011. This policy has forgotten and left behind 13% New Zealanders, meaning they must arrange their internet connection. When considering one of the strategies for farms responding to climate change targets, is for farms to decrease emissions by analysing their existing emissions, something requiring an internet connection, this policy seems like a remarkable oversight.

Traditionally, these communities are not considered when considering climate change targets, funding, public transport or more urban activities such as rubbish collection, water, and sewage. As a result of this oversight, there has been underinvestment in rural or isolated areas. These communities are critical users in potential microgrid opportunities, as they already tend to be self-sufficient and less reliant on governing bodies for everyday needs.

Communities in New Zealand define who we are, big or small, remote or urban, and all are a part of the energy transition.

2.4 Microgrids

Historically, *'the grid'* came to fruition through the interconnectedness of necessity between people who had electricity with people who needed it. Initially called *'isolated power systems'* (Tehranian, 2016), these small pockets of electricity grew larger and larger until they eventually overlapped, and a more structured, interconnected, and consistent system was born.

New Zealand began its commercial electricity journey in the late 1800s and interconnecting regions in the 1910s. This electrification journey brought more people electricity and allowed consumers greater usage flexibility. Over the next century, the grid expanded to be the length and width of the country, allowing New Zealanders access to more generation than ever before. Since about 1997, there has been minimal investment in major grid assets for transporting electricity around, and it is problematic when considering how much electricity is used in the upper North Island compared to how much electricity is generated in the lower South Island (Transpower, 2022b).

As a result of decreases in the cost of solar, and the increase in solar and battery technology accessibility, there has been an uptake in solar systems and microgrid interest in New Zealand. Microgrids take their name from being a small or micro version of the larger grid which allow consumers to pool their resources and collectively access the resources to fulfil their energy requirements. The advantages of a microgrid include reducing the reliance on the electricity grid by functioning independently, as well as taking advantage of more available small-scale renewable generation, such as solar and battery storage. Disadvantages include the cost of initial setup as well as maintenance costs.

An example of a microgrid that currently exists in New Zealand is the PowerNet microgrid in Southland, which exists due to a large user of electricity being frequently cut off from the PowerNet network due to poles being washed away from erosion (PowerNet, 2020). PowerNet installed a microgrid at the lodge, powered by two 6kW solar arrays, a 27kWh battery storage system and a diesel generator as a backup to the Rowallan property.

This example shows that microgrids have multiple use cases, and may be beneficial for more than one reason. As a result, microgrids are likely to become a more significant part of the New Zealand grid as the grid changes to include more distributed generation sources.

2.5 Limits and Barriers to Adaption for the Energy Transition

When discussing the changes to communities, we must understand that at the end of the day, people are still people and have a variety of rules and norms which are each influenced by their own beliefs (Moser & Ekstrom, 2010). Figure 2.2 conceptualises different elements that may prevent community adaptions and identifies three primary considerations.

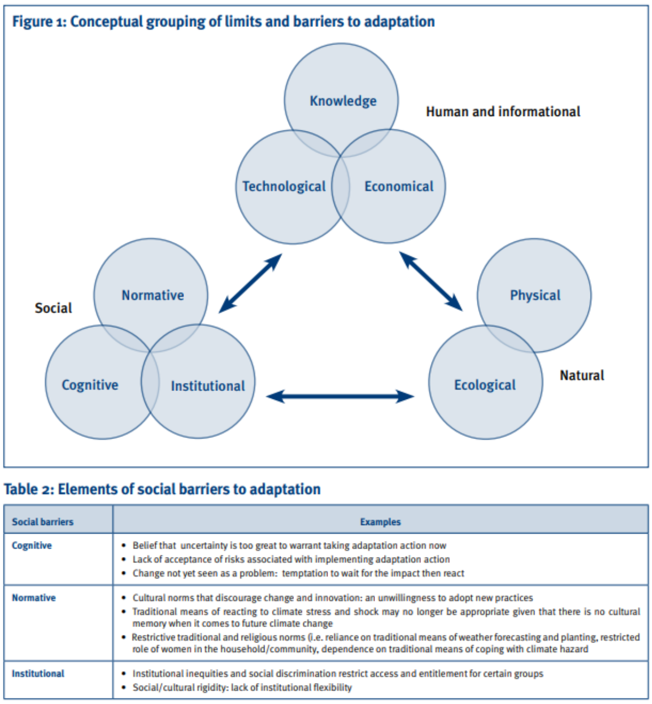


Figure 1: Conceptual grouping of limits and barriers to adaptation

Table 2: Elements of social barriers to adaptation

Social barriers	Examples
Cognitive	• Belief that uncertainty is too great to warrant taking adaptation action now • Lack of acceptance of risks associated with implementing adaptation action • Change not yet seen as a problem: temptation to wait for the impact then react
Normative	• Cultural norms that discourage change and innovation: an unwillingness to adopt new practices • Traditional means of reacting to climate stress and shock may no longer be appropriate given that there is no cultural memory when it comes to future climate change • Restrictive traditional and religious norms (i.e. reliance on traditional means of weather forecasting and planting, restricted role of women in the household/community, dependence on traditional means of coping with climate hazard
Institutional	• Institutional inequities and social discrimination restrict access and entitlement for certain groups • Social/cultural rigidity: lack of institutional flexibility

Figure 2.2: Limits to adaptions as defined by Moser and Ekstrom (2010).

A primary consideration of barrier to adaption is the social element of path dependency (Barnett et al., 2015). The past tends to guide current decisions and impact discussions, as this is a resistance to change or moving away from normative behaviour. It is important to involve communities from the initial planning stages in projects that could impact them or their families.

Another consideration discussed is the natural, ecological and physical impacts of changes to environments or people.

A third consideration to resistance to change is cost considerations (economic), knowledge about the changes, technological resistance, and agreements about who should pay.

Considerations such as these do not have a mitigation strategy, nor should they; adapting to change is part of a learning journey for all involved and requires social guidance, discussion, and funding (Moser & Ekstrom, 2010).

2.6 Summary

Both nationally and globally, there are some substantial problems associated with minimising the impact of climate change in our communities. Through shared understanding, funding, communication, and collaboration, we can step in the right direction to achieve the decarbonisation goals in the communities of Aotearoa.

Chapter 3

Industrial Solar Case Study and Monitoring System Development

> The obstacles to powering the world with wind, water, and sunshine are primarily social and political, not technical or economic.
>
> *Delucchi and Jacobson 2013*

Solar and Distributed Systems (DS) offer significant opportunities to the industrial and commercial sectors to aid Aotearoa's decarbonisation journey, particularly when solar generation is used with the electrification of commercial or industrial processes. Distributed Systems which include a primary generation source of solar, are becoming more prevalent across the globe (Distributed Solar PV, 2019) for two main reasons - cost and accessibility. The initial investment cost of solar panels and batteries has decreased globally as production materials have decreased in cost, and the products have become more accessible due to the decrease in setup costs.

Generally, solar is installed on the roofs of buildings that will use the electricity generated themselves, as well as having the ability to return excess generation to the grid for a specific buyback price, allowing a small return on investment to be had where possible. However, turning a profit through solar buyback schemes is opportunistic as the buyback cost is generally considerably lower than that of the purchase price for the business. Minimising buying generation from the grid or altering when electricity is used to best benefit the solar setup is a better way to decrease the power bill. Another strategy is to add a battery to the overall setup, however, this would introduce a higher upfront cost.

This chapter introduces and discusses distributed systems which are predominantly solar, through case study one using a system array to power a small processing factory. Case study one is furthered by identifying potential issues in the system, and improving the monitoring system of the factory. This allows significant opportunities to provide insight to other industrial or commercial companies looking to decarbonise their processes through electrification. Furthermore, analysing the system after the improvements allows for an in-depth analysis which provides more insight into how solar can be used in an industrial setting to aid in decarbonising Aotearoa. The analysis also provides an outlook into future developments of solar arrays for the industrial sector and how excess energy can be monitored and managed in a commercial or industrial factory.

3.1 Background

3.1.1 Solar in New Zealand

Every year the sun provides an average of over 2300 sunlight hours across the country in Aotearoa (this is how long the sun shines in New Zealand - up to 15 hours and 10 minutes of daylight a day (NIWA, 2007)) and makes New Zealand a perfect place for solar panels to be used. However solar provides many unique challenges compared to other renewable types of electricity generation. Generation through solar panels is weather permitting and is restricted to hours when the sun is shining in an optimal position on the panels. As a result, generation can change rapidly second-to-second from obstructions such as clouds passing in between the panel and the sun. Generally, solar is predictable around its overall generation when averaged across the year and accounting for seasonal variation.

While the uptake in New Zealand has been particularly slow for solar photovoltaic (PV) installations, distributed solar systems (DS) for residential households have now become a relatively well-defined system (solarZero, 2022). There are more commercially viable systems on offer in the New Zealand market, and there are many solar installers in New Zealand, as well as retailer competition for the buyback of solar generation. One company of particular interest in the New Zealand market is solarZero, which offers solar as a Service and has been listed on the NZX as a Virtual Power Plant (VPP) using residential batteries from their installed solar systems spread throughout New Zealand (solarZero, 2022).

VPPs are valuable tools for adding renewable generation to the grid as they monitor and account for predicted generation and demand in their system. This allows operators to better estimate potential generation for market and bidding purposes (Naval & Yusta, 2021) when trading with the electricity market. Unpredictability has become a common problem with the recent increases of non-dispatchable sources being more prevalent on the grid (Wolfe, 2023).

3.1.2 Distributed Generation

In general, distributed generation refers to three main types of technology which generate electricity and can optionally inject this electricity into a distribution network. One of these technologies is solar panels; others not covered in this section are wind turbines and V2G (vehicle-to-grid) (Vector, 2023).

Distributed solar generation is generally an array of solar panels connected to a roof via a mounting structure and connected to an inverter via down leads and cables. Many residential installs may also contain a large battery, which can charge from any excess generation or when prices from the grid are low, such as in the evenings (off-peak). In these cases, there is less opportunity to return excess electricity to the grid, as there is a higher likelihood that the battery will be charged instead of discharged to the grid.

Some advantages of distributed solar systems include localised faults having less of an impact such as during power outages due to self-sufficiency of generation. Additionally, saving money in the long term for the installer and knowing the owner's electricity usage is from renewable generation instead of relying on the grid's generation and the market. Furthermore, DS can reduce the load on the grid, transmission, and distribution facilities, requiring fewer larger-scale infrastructure upgrades. Large-scale grid investments are costly and can take time to be installed.

Some disadvantages of DS are the initial cost. Price inclusive of a battery, solar installs can range from $15,000 to $30,000. While they pay for themselves over time, the payoff requires being in the installed location rather than making an array worth it if the owners plan on selling or moving.

3.1.3 Commercial or Industrial Distributed Systems

Commercial or Industrial DS installed at an existing industrial or commercial participant are defined by a company's electricity usage and the company type, according to the Electricity Authority (EA). Distributed Systems or Distributed generation from industrial or commercial participants in New Zealand currently have 1255 and 1649 ICP (Installation Connection Point) connections respectively, which have an average installed capacity of 165kW, much higher than residential systems, which average about 4.6kW (Electricity Authority, 2023). In the future, the EECA predicts industrial and commercial solar DS to provide approximately 6% of New Zealand's overall electricity supply (EECA, 2022). This solar generation is less than 5% of industrial participants' total electricity generation, as shown in Chapter 2.

Other challenges to consider when discussing distributed generation are both physical challenges and policy challenges. Connecting large arrays of solar panels to the grid from industrial participants tends to be in more rural or less urbanised areas, which is one such issue identified by grid operators Transpower (2022b). The issue surrounds how close large solar arrays are to medium voltage (MV) lines (11kV or 22kV) or where transformers are located for grid re-injection. Significant under-investment in electricity infrastructure in rural areas has led to large-scale grid injection not being an option in all areas of New Zealand (the PowerNet microgrid discussed in Chapter 2 is an example of this). Challenges stemming from under-investment in rural areas significantly disincentive the industrial sector in rural areas to invest in solar or more electricity-based opportunities, as there is no buyback opportunity when the generation is not in a place of interest or security of supply. Examples include poultry farms, dairy milking sheds, and large processing factories such as breweries.

Due to the limited number of large, installed solar arrays, or the small number of companies offering industrial installations to the market, there are even fewer monitoring systems that can monitor electricity and solar usage in residential and industrial environments. Open-use software allowing such a monitoring system to be installed and created for industrial participants to aid in decarbonising their overall energy footprint would help the industrial decarbonisation effort.

3.2 Case Study One: Chia Sisters

Case study one introduces a company in Nelson, New Zealand who have a strong ethic for sustainability. Chia Sisters installed a solar array in 2018 to become a solar-powered Juicery. Case study one is an investigation into the benefits of a solar system in a factory, as well as any problems that may have arisen.

3.2.1 Introduction

A solar array is currently installed at Chia Sisters Juicery in Nelson, New Zealand. In 2018, Chloe and Florence Van Dyke (the Chia Sisters) purchased an old brewery to make their Chia drink instead of contracting this process out. As a company that values sustainably, Chia Sisters wanted to be an industry leader, and as a sustainably focused company, they installed a series of 32 Sumec solar panels, which at total capacity is expected to provide about 16kW per hour. This value usually is twice the amount that the factory requires (8kW per hour at maximum capacity, plus some systems using LPG - case study one identifies this is not correct). On a sunny day, any excess generation gets exported back to the grid.

With regards to the cost of their solar installation and based on current power bills, the Chia sisters estimate that they will have paid off the up-front cost within ten years and will save money in electricity usage afterwards. Considering their system has been installed a little over four years and is still going strong, their investment is well on its way to being paid off. It is also in their future missions to electrify their LPG processes and investigate allowing their neighbouring businesses to use their excess electricity on sunny days.

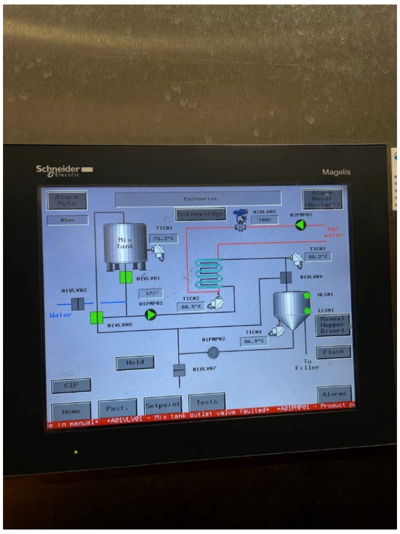
3.2.2 Factory Details

The Chia Sisters production factory is on the small side of the manufacturing process, with around 1500 bottles of drink bottled per hour on total capacity production runs. This heavy running occurs on weekdays during business hours for one week in every three, with the two other weeks being non-chia seed-related bottling (sparkling water), and overall less hot water is used in this process.

Figure 3.1: Chia Sisters Factory in Nelson with a solar array on the roof.

Figure 3.2: The boiler in the Chia Factory in Nelson.

Inside the building and as shown in Figure 3.2, sits a large boiler that contains approximately 2000L of water and is set on an analogue timer to heat up every day at 4 am and 12 pm, depending on daylight savings. This boiler is heated to above 65 degrees and below 70 degrees for sterilisation work and is used for producing chia-seed-based products instead of a pasteurising machine, and in off weeks is used for cleaning and sterilising plant equipment between production runs.



e in manual* *A01VLV01 - Mix tank outlet valve faulted* *A01PMP01 - Product p

Figure 3.3: The flow of product through the thermaflo machine.

Keeping this boiler hot also ensures minimal natural gas is used in the entire process, which is used in the thermaflo machine for heating the mix tank product, as seen in Figure 3.3.

3.2.3 Existing Monitoring

Existing monitoring of the processes in the factory was extremely minimal and only came once a month in terms of their power bill from Meridian, this data is shown in Table 3.1. Due to being an industrial user of electricity, the distributor of the region (Network Tasman) has not installed a monitorable smart meter at the site, and therefore, electricity usage amounts are only valued on a month-by-month basis.

Date	Usage (kWh)
30/8/21	4272.66
29/9/21	4078.98
28/10/21	3972.06
26/11/21	3930.54
23/12/21	2609.46
28/1/22	4724.46
3/3/22	2295.54

Table 3.1: Load data from the Meridian meter for the Chia factory site, collected in April 2022.

The interest in undertaking case study one by Chia Sisters was to understand and improve to improve the monitoring system for their solar panels, show their energy usage, and identify how a battery could impact their use or savings.

The solar array is currently monitored by Fronius, who provide a small monitoring system, however, most of the features are held behind a paywall, through an expensive, monthly subscription service. Daily monitoring is free, but does not provide a detailed view, or allow viewing or downloading of historical data more than three days old when using the free tier.

3.2.4 Identified Issues

Distributed solar systems such as the Chia Sisters system are shown to be very advantageous to companies that operate electric processes, particularly when there is minimal impact on the business concerning installation and operational losses. Advantages of this particular site include the factory is located in a sunny region of the country, which receives many hours of sunshine annually. Additionally, the Chia Sisters factory is close to a grid exit point (GXP) for exporting electricity back to the grid. The industrial area in Nelson is located relatively centrally to the Stoke GXP and therefore did not require upgrades to the surrounding transformers on the grid side to return this to the grid.

However, some issues identified with this installation show how a system that *'is well on its way to being paid off'* can be improved. Chia sisters were quoted for installing a system, but there was no particular way to monitor the system and how it was helping offset their load, if at all.

Fronius, which is the brand of the inverter and panels, offers a premium subscription and a free tier. The premium tier offers access to all solar generation data on a 5-minute basis, as well as a history of this data. However, the free tier offers only access to the current month's solar data, not the last 30 days, just the current month.

Chia Sisters have a significant focus on sustainability and ultimately have the goal of being able to put a number on the bottles of how much percentage of solar went into making each bottle of branded beverage. Finding this value became a focus area for Chia Sisters and this chapter.

3.2.5 Potential Improvements

Overall, the following outcomes have been identified throughout case study one and provide an overview of the factory and the factory's electricity usage. These are issues that have been identified through case study one with C. Van Dyke and F. Van Dyke, identifying some problems that Chia Sisters would benefit from being solved to allow their processes to be improved to help decrease their overall carbon emissions.

Outcomes to investigate further include:

- Understand the efficiency of the existing solar array.
- Identifying fundamental factors of energy usage from how much energy the system is producing versus how much is used by the factory processes.
- Have a publicly available monitoring system to monitor near real-time loads to understand how electricity is used.

These outcomes guide the rest of this chapter and show how breaking down a significant problem into smaller steps can benefit everyone involved.

3.3 Significance of Case Study One

Case study one of this thesis on the Chia Sisters' solar array identified that even though they have solar monitoring for their array, other than their monthly electric bill, they still need to learn their solar array's impact on their overall energy usage, particularly on sunny days and across the different seasons.

Case study one provided valuable insights into common issues that may be seen throughout the sector due to decarbonisation. The significance of having a partner such as Chia Sisters, who allowed further work to occur at their site, allows technology to be developed and learning opportunities to happen as a result. What was developed for Chia Sisters to monitor their usage by using a combination of software, hardware, and connectivity to bring together a monitoring system that integrates with their existing system and brings online the figures of how much energy they use on a 5-minute basis.

The visibility of a system allows users to determine how they are using their energy and in what way. This visibility will make them curious about what they do and encourage them to observe trends and how they could benefit from changing their work habits.

3.4 Implementation of a Monitoring System

The essential aspects of the software solution for a monitoring system designed around the issues identified in the case are shown in Figure 3.4. The centre bubble shows the monitoring system as a whole, while the outside bubbles show the features of the system as identified in case study one.

Each of these bubbles represents a part of the software implementation to help Chia Sisters monitor and analyse the factory.

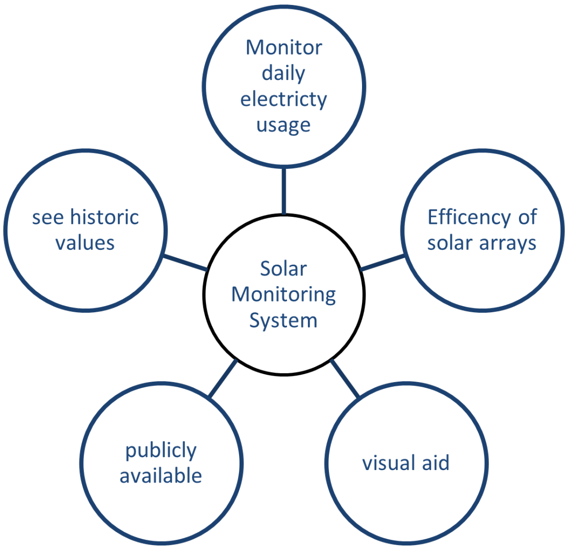


Figure 3.4: Key features of a solar monitoring system which were identified as a part of case study one.

3.4.1 Building a Monitoring System

The first step in the solution to the Chia Sisters monitoring system was finding a way to record the electricity usage of the factory as a smart meter was not present on the site, and one of the solution requirements was to create an overall picture of electricity usage was required, therefore, the developed system needed a way to record and process data that could be recorded from the factory. In this case, a data logger and recorder are required, as well as a low-cost solution that is easy to retrieve saved data from and integrate and monitor a 3-phase power system.

While there were a few solutions for data recording, many required shutdown periods for installation; however, the most straightforward and available to the University of Waikato was a clamp-on data logger, which gives the benefit of not requiring re-cabling 3-phase power in a factory.

Hioki produces the data logger and is the first non-metal contact measurement device available for sale. The PW3365-20 clamp-on data logger is shown in Figure 3.5 and Figure 3.6, allowing 3-phase monitoring of power, phases, voltage, and frequency while saving internally to an SD card. The benefit of the modern PW3365 is that it can be accessed via LAN (Local Area Network)

Figure 3.5: The Hioki Data logger used for monitoring.

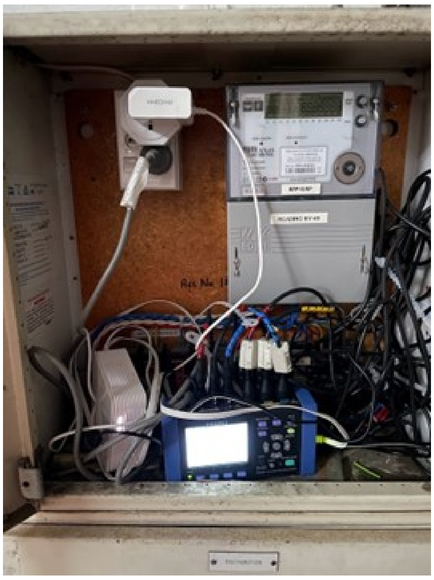


Figure 3.6: A view of the completed setup installed at Chia. This figure shows the data logger and the Linux box installed at Chia Sisters.

through an FTP server, which earlier models considered could not do. When used via a LAN connection, the data logger can monitor and control the device, enabling it to be operated remotely through a web interface.

Once this was discovered, it was decided that it would be beneficial for Chia Sisters and this study if the data could be accessible offsite, as Chia Sisters would then be able to inform their customers or their generation numbers on a sunny day. For example, if they return to the grid (100% generation), they can observe and share this with their customers.

The second requirement is for this system to be accessible remotely and publicly. Traditionally a control system would be used to complete this task, and then it would interface with a more traditional system such as SCADA to become remotely available. However, these are all expensive systems that small companies like Chia Sisters do not own, so a low-cost system needed to be implemented via microcontroller/processor, which would be able to upload data to the cloud for remote access and public monitoring.

Initially, a Raspberry Pi was chosen to complete this task as there is a lot of available documentation and open-source projects for reference. However, due to COVID-19, there was a considerable shortage (2021), and a reasonably priced Pi which offered Wi-Fi could not be obtained. Direct connection through ethernet was not an option as the data logger connected via a LAN cable that used this port.

Instead, an alternative product was obtained. A Linux box is a readily available device chosen as a second solution for connecting to the data logger and Wi-Fi. A LAN connection was tested between the two devices, which included setting the IP addresses of each device for connection via LAN.

A Python script was developed and ran every evening at 11 pm through a Cron scheduler. The Linux box connects to the data logger, downloads the latest files from the FTP server using a Linux package called GNU Wge and commits to a private GitHub repository for ease of reading back later. GitHub was chosen as it requires a security key to sign on and upload to a private repository.

For the Linux box to be accessed remotely, Tailscale was installed locally so the Linux box could be monitored in the future, restarted, accessed, and changed in the future. Tailscale provides a VPN (Virtual Private Network) between another device and the Linux box to monitor uplink and remote availability, subsequently allowing command-line accessibility.

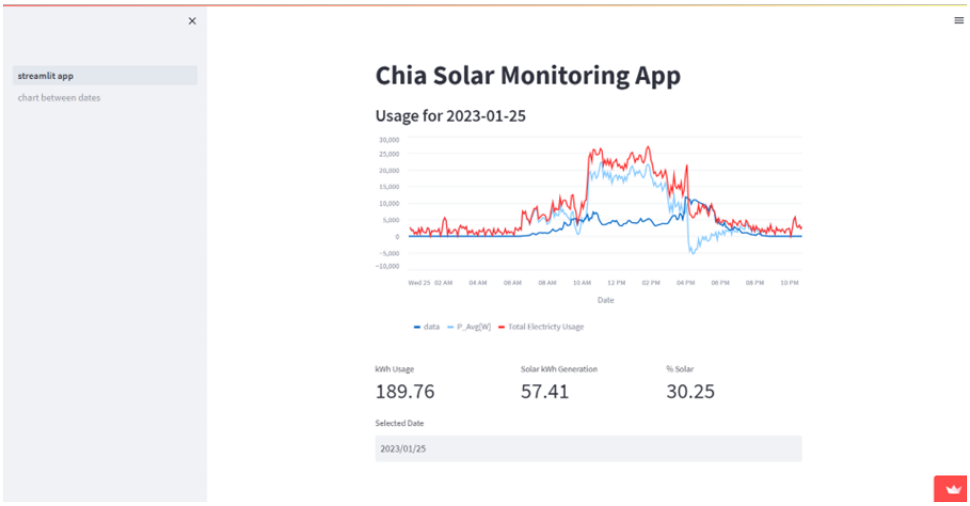
The solar data recorded by Fronius is behind a paywall and is hard to access without a subscription. To get around the subscription paywall, a custom screen scraper of Chia's Fronius system was developed in JavaScript, using the python package *requests* and the login Chia Sisters has for the free tier. The scraper applies the latest cookie and today's date to the URL and pulls the Fronius webpage, enabling the code to extract, create a CSV, and upload it to the GitHub repository. Once the initial download of the previous few months of solar generation happened, the script was loaded into the Linux box and run on the same Cron scheduler script as the evening uploads of the data logger data.

3.4.2 Visualising Monitoring System Data

The factory data for electricity usage and solar data is now accessible and remotely available; the next step was making this accessible to both Chia for monitoring and data analysis. Because the data comes out of the monitor in a new CSV file day, python was chosen for data analysis as it can use a package called pandas which contains data frames, a valuable data science package for dealing with and formatting large datasets. Python is a widely used programming language containing a lot of documentation and open-source frameworks that make large-scale data analysis more accessible.

One of case study one's outcome requirements was having a publicly available visual tool. Initially, this was chosen to be developed in a web application that makes use of the React framework. However, React proved to be too heavy duty for this application which contains repositories of data. Instead, a developing Python framework called Streamlit was used.

Streamlit is an open-source framework typically used for data science web apps that require Python processing and accessibility of data. Streamlit provides a convenient wrapper for multiple web app components and allows an easy way to write features to a file and release them to a URL. Streamlit uses existing GitHub actions and repositories to access and commit code con-



Chia Solar Monitoring App

Usage for 2023-01-25

kWh Usage: 189.76

Solar kWh Generation: 57.41

% Solar: 30.25

Selected Date: 2023/01/25

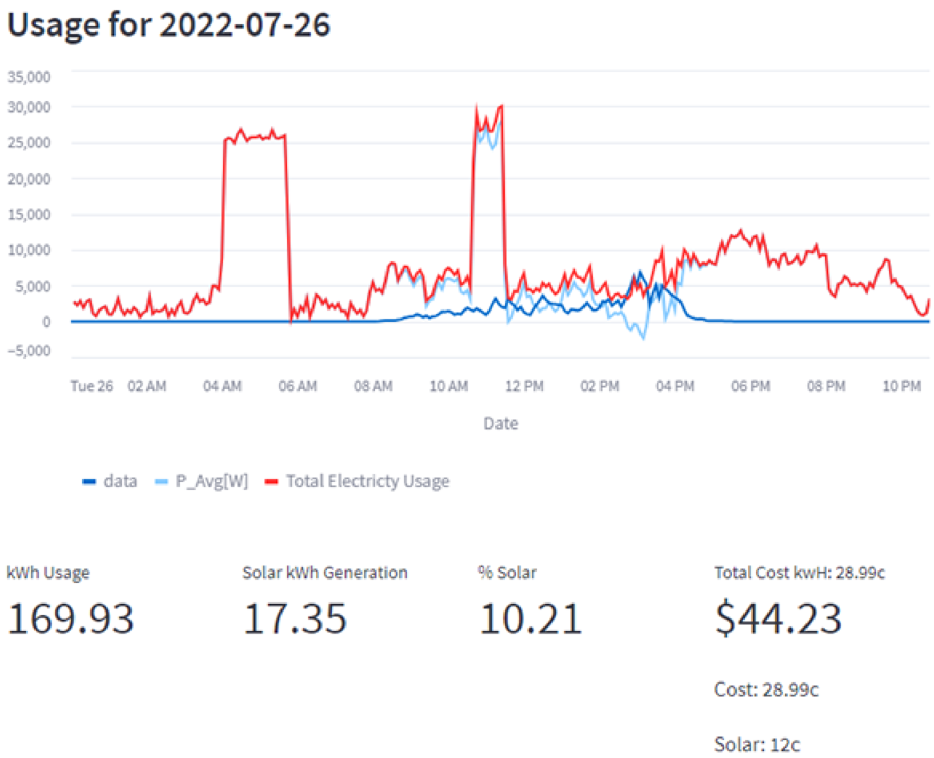
Figure 3.7: The developed monitoring app with an initial date loaded for analysis.

veniently and quickly. The Streamlit framework also handles pipelines and deployments, which is extremely useful for small-scale applications. This app was developed with helpful analysis features for Chia and this thesis, including a day-by-day viewer, a between-date viewer, and a general dashboard page.

3.4.3 Analysis

The beauty of completing this thesis part-time for the first time, I had time on my hands. Both to be able to author a thesis, but also to monitor a factory for just under one year. By analysing this data through bespoke software developed for Chia Sisters, we can better understand how an industrial participant uses solar, how electricity is used and when, and how their energy profile can be altered through new infrastructure by changing their energy usage. A bespoke system described in Section 3.4.1 could be written and made available for the company to look at their usage and evaluate how their solar is being used by what machines. While this is a feature of many solar installs, software typically has costly subscription costs. By making general, non-smart meter data accessible for analysis and insight into a commercial setting, this data can be used for Chia's future planning, for understanding the impact machinery has on the grid, and to know how genuinely controllable it has the potential to be. This software is available here for the dates described in this chapter (July - May): https://chia-monitoring.streamlit.app/.

3.4.3.1 Daily



kWh Usage
169.93

Solar kWh Generation
17.35

% Solar
10.21

Total Cost kwH: 28.99c
$44.23

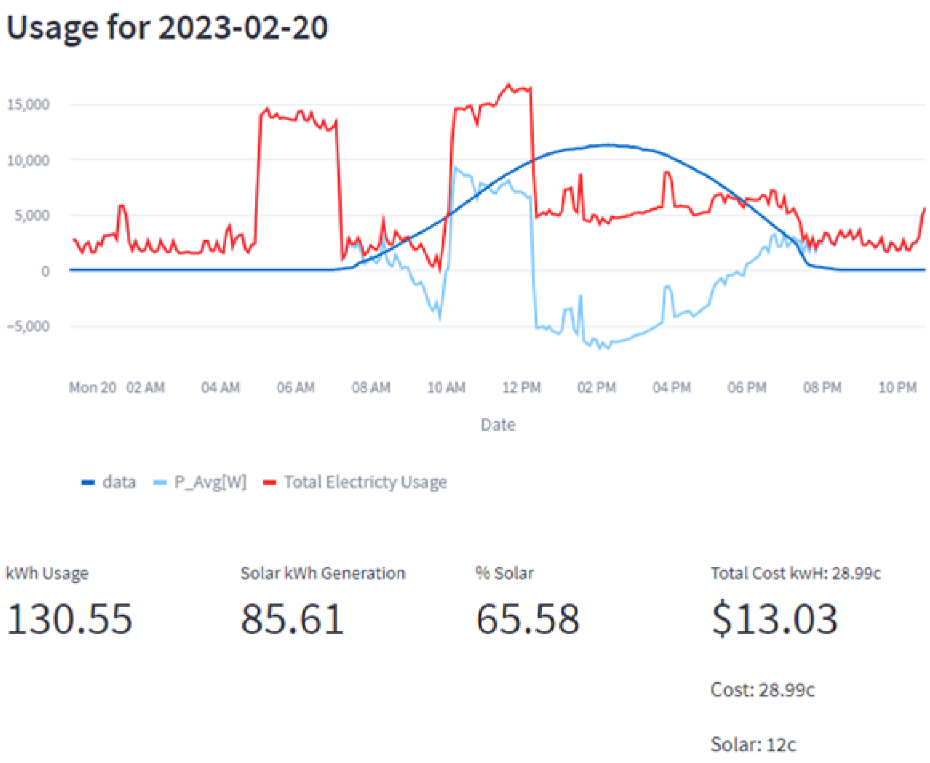
Cost: 28.99c

Solar: 12c

Figure 3.8: Data recorded by the system on 26 July 2022.

The typical usage pattern for the Chia Sisters production line is shown in Figure 3.8. The 2000L boiler turns on at 4 am and off at 6 am from an analogue timer which is continually set year-round for this time, regardless of when or if the factory requires hot water. From the data, the boiler again turns on around midday for an hour, between 10 am and 2 pm. With this day being winter (26 July 2022), Chia is shown to have generated approximately 10% of their generation from their solar array, with the rest of their electricity coming from the grid.

Figure 3.9 shows a typical summer workday for the factory. As the days became longer and the seasons turned to summer, the solar array provided



kWh Usage
130.55

Solar kWh Generation
85.61

% Solar
65.58

Total Cost kwH: 28.99c
$13.03

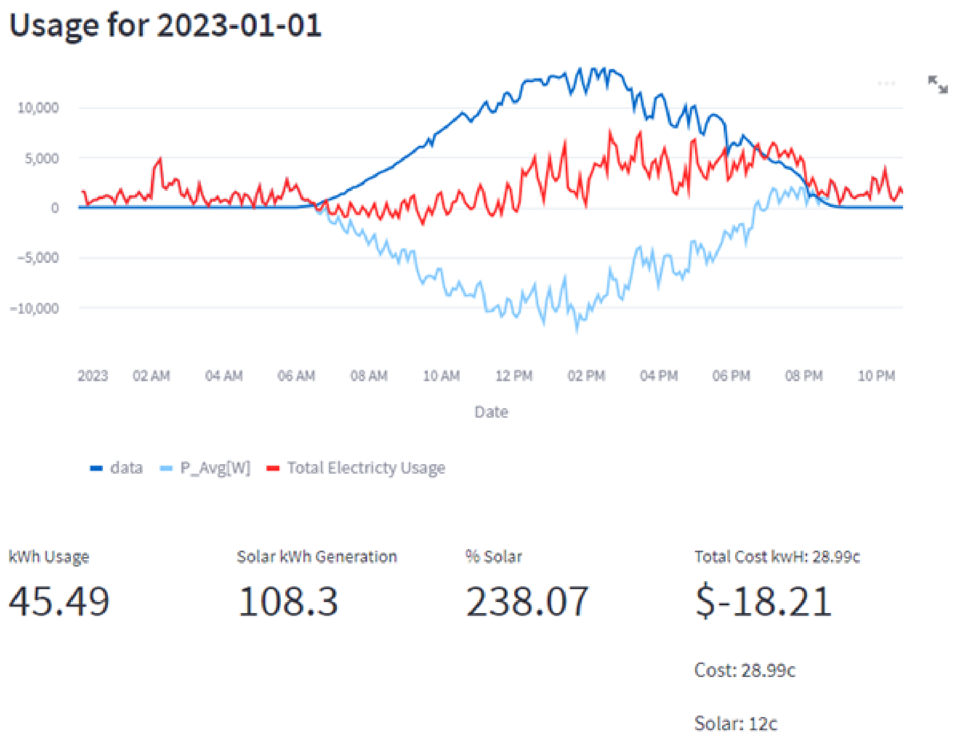
Cost: 28.99c

Solar: 12c

Figure 3.9: Data recorded by the system on 20 February 2023.

more generation and supplied the factory with more electricity. During this typical summer's day, the solar array is operating at almost maximum capacity for a significant proportion of sunlight hours. During these days, when the return to the grid is also occurring, it could be beneficial for Chia to add a battery and charge it for use in the following mornings, 4 am-6 am boiler temperature increase.

A day with more return to the grid than usage, in the holidays where solar is very high in solar generation. On days like this which tend to be weekends and holidays (no production on these days), is where there is a benefit from Chia to store this generation or return to the grid on these days. Observation in Figure 3.10 shows that due to the day being a public holiday and no work occurring at the factory, there was less usage, except for refrigeration cycling, whose load noticeably increased as the day became warmer.



kWh Usage	Solar kWh Generation	% Solar	Total Cost kwH: 28.99c
45.49	108.3	238.07	$-18.21

Cost: 28.99c

Solar: 12c

Figure 3.10: Data recorded by the system on New Year's Day 2023.

3.4.3.2 Monthly

In the app created in Python, there is a day-to-day evaluator to inspect each day in 5-minute detail, and there is also a period comparison to evaluate data between two dates. This results in looking at each month of recorded data and calculating how much electricity was used in contrast with how much solar was used.

A large amount of data has been collated from the original recording of five-minute intervals and allows more accessible monthly and daily analysis, across approximately nine months of data recording (July 5th 2022- May 11th 2023). This data has been summarised in Table 3.2, and is charted in Figure 3.11, the total usage is calculated in kWh of the factory is 45,587.89 kWh, with the overall solar generation 18,332.67 kWh. Approximately 36.8% of Chia Sisters' overall electricity usage comes from their rooftop solar for those nine months.

By using Chia Sisters retailer buyback information, with a general anytime kWh cost of 28.99 cents and a solar buyback price of 12 cents per kWh, every

Month	Usage (kWh)	Solar generation (kWh)	% Solar	Cost ($)
July 2022	3696.36	595.9	16.12	898.82
August 2022	4971.63	1079.82	21.72	1128.23
September 2022	3340.01	1513.81	45.32	529.41
October 2022	4740.69	2198.38	46.37	737.01
November 2022	5035.16	2478.89	49.23	741.06
December 2022	4727.86	2854.64	60.38	543.04
January 2023	5212.22	2347.40	45.04	830.51
February 2023	4005.80	1930.22	48.19	601.71
March 2023	3688.84	1981.06	53.70	495.09
April 2023	4421.96	1203.06	27.21	933.16
May 2023 (1-11th)	1746.89	149.49	8.56	463.09
TOTAL	45587.89	18332.67	AVERAGE 36.814%	$7901.13
Cost without Solar				$13215.79
Savings				$5314.66

Table 3.2: Total load and generation data from the improved monitoring system.

interval recorded by the system, it can be calculated how much that interval cost or gained, and for each month can be attributed an overall cost analysis. The costing evaluation shows that Chia has saved $5314.66 from solar generation in just nine months. Considering their system initially cost nearly $30,000, they will have paid back their system in close to 6 years. Considering this system is already five years old (installed in 2018), there is only a short time to go before it is paid off, and their business will save money on their power bill.

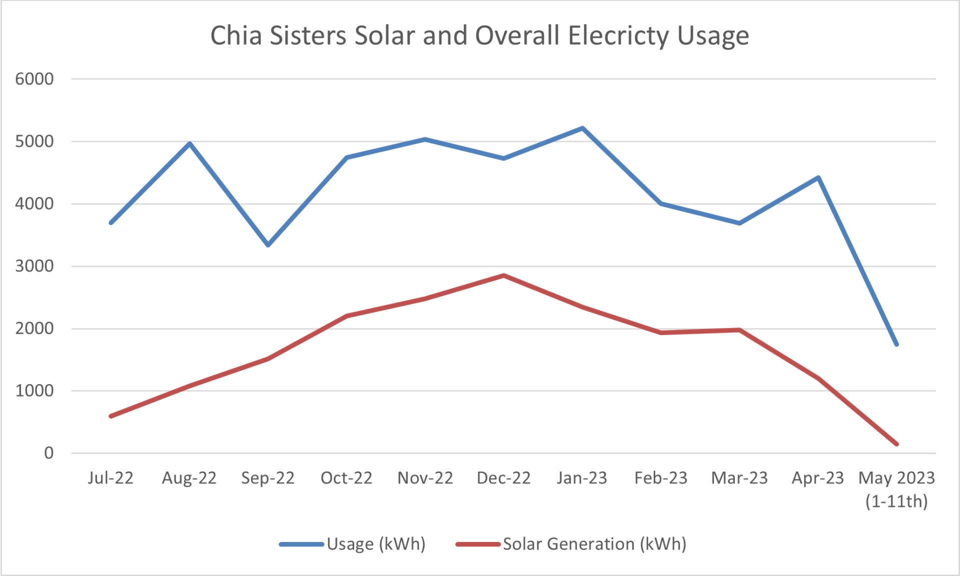
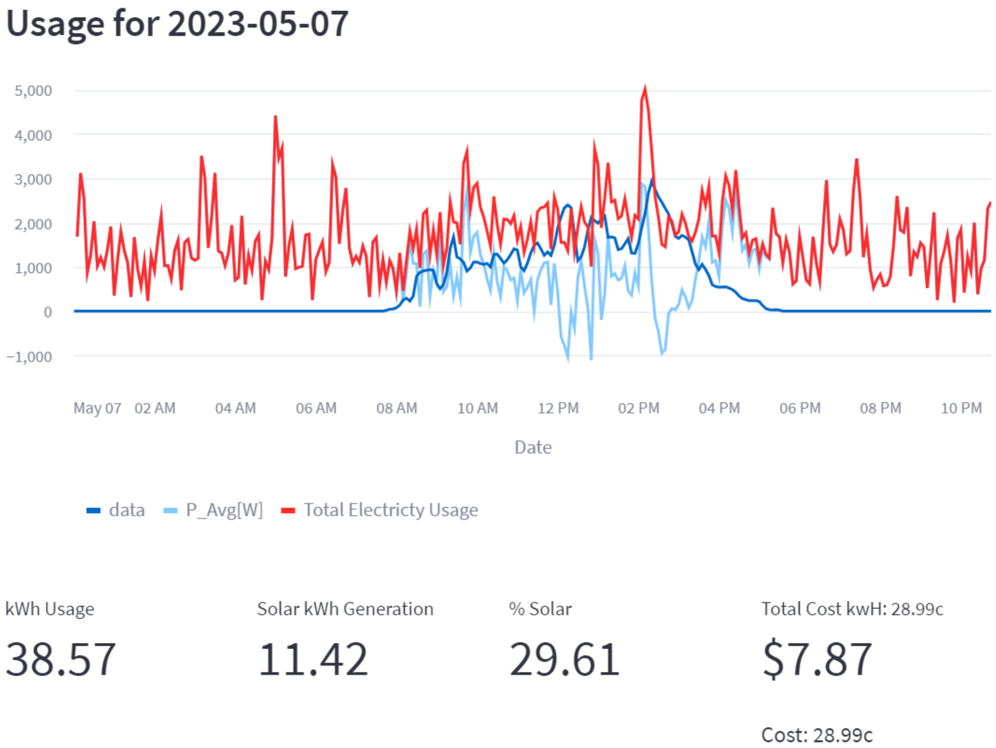


Figure 3.11: Data recorded across all nine months of installation.

3.5 Discussion



kWh Usage
38.57

Solar kWh Generation
11.42

% Solar
29.61

Total Cost kwH: 28.99c
$7.87

Cost: 28.99c

Figure 3.12: Visualising the solar generation for 7 May 2023.

The Chia factory uses electricity almost constantly, using their boiler in the mornings on a timer, with refrigeration and production processes also using electricity during daytime hours. However, the analysis showed that the factory needs to utilise its solar in the most efficient way for the processes, which are predominantly electricity driven, except for a single Natural Gas process in heating water for product mixing instead of pasteurising the product.

We recommended to Chia Sisters to make their processes more efficient and change the scheduled timer of the boiler to not run in the mornings before the sun rises unless required, adding in a digital, programmable timer instead of an analogue one, which was implemented after some discussions with their Engineer. The factory is in the process of adding a second layer of insulation to the boiler to hold heat when it is not turned on for extended periods.

kWh Usage
241.47

Solar kWh Generation
3.72

% Solar
1.54

Total Cost kwH: 28.99c
$68.92

Cost: 28.99c

Solar: 12c

Figure 3.13: A typical usage day for 9 May 2023.

As seen in Figure 3.12, the usage in the weekends changed quite dramatically, when compared to weekends earlier in the figures. During the week, the boiler's duration was decreased to only be on later in the morning and when required, as shown in Figure 3.13.

Overall, the system was only implemented for eleven days of May (the system is still installed, but this thesis has taken a subset of data for analysis, resulting in eleven days of May being recorded and included), with May so far having had lower solar generation than other months, so it is hard to make conclusive comments about the effect of the changes. The recorded values do show decreases in overall usage in any case.

3.6 Conclusion

Industrial solar generation is an unproven industry, intending to make money far more achievable than saving the planet. Companies such as Chia Sisters should be commended more for taking a chance in choosing the future yet-to-be-implemented legislation instead of being purely financially driven. Through completing case study one with Chia Sisters, creating a piece of monitoring software, and a product for future company installations who wish to save money through solar, this has shown it is possible to use solar in an industrial setting, provide analysis based on energy profits, and save money from saving electricity usage.

Chapter 4

Case Study Two: Heavy Vehicle-to-Grid Simulation

> There are things done today in electrical science which would have been deemed unholy by the very man who discovered electricity, who would themselves not so long before been burned as wizards.
>
> *Bram Stoker*

Heavy electric vehicles (HEV) are becoming more commonplace on New Zealand roads. New technology has allowed the introduction of electric trucks such as Milk-e from Fonterra (Fonterra, 2022) which have a larger battery capacity than cars. Additionally, many of these heavy vehicles operate on a regular schedule, meaning their patterns of usage are entirely predictable and regular, particularly when compared to personal electric vehicles (EVs). This predictability can be leveraged through the use of Vehicle-to-grid (V2G) technology, which conventionally relies on smaller car storage capacities, that are normally not able to be predictable for when they are plugged in and connected to the grid. Furthermore, these HEV are commonly parked or stored in predefined locations with existing grid connections, close to population centres.

This chapter discusses and analyses how existing heavy electric vehicle infrastructure and planned infrastructure in the form of electric school buses can be theoretically used to shift load in communities around Aotearoa by using the principles defined in V2G technology.

4.1 Introduction

Electricity and the grid revolve around the known constant factor of requiring equal supply and demand. While other conditions and factors affect this equality of supply and demand, generally the equation stays true and ensures the lights are kept on around New Zealand and the world.

A large part of what help to keep the lights on is the vast amounts of large storage mechanisms, which are predominantly the hydro lakes around the country. However, as new non-dispatchable renewables such as wind and solar become more prominent, the management of the grid and how electricity is distributed with the appropriate frequency and voltage becomes of more significant concern. So begins the argument for storing electricity in more ways than just water to increase the grid's resilience.

Batteries and battery technology have shown increasing importance (Choi et al., 2021) as a grid storage solution for non-dispatchable electricity generation by allowing electricity to be used on demand instead of when it is generated (supply and demand equation). Economically, there are fewer transmission losses when electricity is stored near where it is generated, particularly when considering storing solar or wind generation. In contrast, New Zealand currently relies on hydro lakes storing water far from most urban centres and distribution networks. This chapter explores how batteries can be used for storage of non-dispatchable electricity generation, what existing infrastructure of large batteries is currently available to the grid, and how this has the potential to benefit some communities in Aotearoa.

4.2 Background

Large-scale energy storage or Battery Energy Storage Systems (BESS) (Su et al., 2016) have been proven globally to be an effective storage strategy to alleviate the ailments and quirks that non-dispatchable renewable energy offers in a large transmission grid (Faunce et al., 2018).

The most prominent example is the 100MW Lithium-ion grid-support battery at the Hornsdale wind farm in South Australia (SA), which finished commissioning in December 2017 (Csereklyei et al., 2021). The Hornsdale Power Reserve is the world's first big battery, installed in 2017 by Tesla, with an expansion completed in 2020 to add an additional 50MW of capacity. The battery now provides inertia and incident support in SA and has been estimated to have saved over 14 million dollars (AUS) (Aurecon, 2022) by providing islanding support to the state. The battery was installed in SA as the grid had an infamous blackout in 2016 due to transmission and generation faults, and SA is a state primarily powered by wind turbines that do not provide inertia support to the grid. The battery is an excellent example of being used to help with traditional grid supply and demand problems.

Over the past few decades, the costs of materials of battery storage components and the storage itself have decreased (Lazard, 2021). As a result of this, both globally and locally in Aotearoa, there has been an increase in the uptake of batteries in residential houses and investments in non-dispatchable generation by generation companies, such as wind. Furthermore, the uptake is expected to grow as the cost decreases and electricity storage becomes more accessible (U.S. Energy Information Administration, 2021). As seen with the Hornsdale Power Reserve, when BESS are paired with wind or solar generation, the systems can be placed in an area with non-dispatchable generation nearby, and the battery can provide instantaneous reserves for the market, as well as voltage and frequency support for such areas.

BESS are widely gaining traction across New Zealand, where increased generators, distributors, and local factories are bringing online BESS for marginal gains in energy saving and cost saving associated with electricity price increases. For the same reason, many residential solar installations have a battery installed simultaneously, allowing batteries to play a significant role in the security of supply for individual households. Very rarely do residential solar users uses have no use for electricity in the evening, and without a grid connection, they have no way to generate electricity for consumption by their household.

4.2.1 Understanding Existing EV Infrastructure

In one form or another, Electric vehicles (EVs) have been travelling our roads since the early 1900s; by needing to invest in overhead cables to be powered or by having long wait times to charge, the technological limitations as to why the internal combustion engine (ICE) rapidly overtook the market share of EV's is no surprise. Today, EVs are being presented as a solution for the transport industry to aid in lowering emissions and offer cheaper and quieter transport options. The New Zealand Ministry of the Environment and Government has committed to a goal of decarbonising the public transport fleet of buses by 2035, making way for a new wave of electric buses to be introduced to the New Zealand public transport network, which can be funded through community and government grants (NZGIF, 2023).

Historically, New Zealand has relied on overseas vehicle manufacturers to provide necessary vehicles to fulfil electric vehicle orders. However, in this emerging new field, the Wellington bus operator Metlink recently partnered with Tauranga bus builder to provide several new buses to its fleet, removing the reliance on overseas manufacturers.

Additionally, New Zealand can improve its uptake in electrifying public transport through pre-existing local infrastructure in main centres where the grid can assist by supplying recharging stations for electric buses. Previous papers have highlighted issues with the increase in demand for charging many new buses and the impact that could have on the grid (Jarvis et al., 2023); in the same way, there are concerns with many private vehicles charging in the evenings and the impact that would have (Monigatti, 2017). Trials are being run globally on V2G technology, which aims to minimise the impact of charging EVs simultaneously (Turker & Bacha, 2018).

By exploring how the existing public transport system currently operates using electric buses, there is the potential to minimise the impact of low, residual generation. By using electric school buses which are used due to the predictability of their scheduling, could be used to create a distributed battery to provide relief to the grid during evening peaks and potentially provide peak-shaving benefits.

4.2.2 What is V2G, or alternatively, what is HV2G?

In general, vehicle-to-grid (V2G) technology is the bidirectional transfer of energy between an electric vehicle (large or small) and the grid (Monigatti, 2017). While predominantly implemented in electric cars, success is yet to be determined in other variations of electric vehicles, namely buses or heavy vehicles such as trucks (HV2G - Heavy Vehicle-to-Grid), with startups such as Synop starting to provide real-time solutions to these problems (Synop, 2023).

HV2G technology has the potential to be implemented in communities both globally and nationally but has been considered in electric school buses as they operate a predictable schedule, do not operate in the evenings when the load is larger and are already a part of the planned infrastructure in communities, both big and small. Electric school buses are going to be located in communities, both rural and urban, being charged in depots on the edges of larger towns which is where infrastructure is going to be built by 2035 (MoT, 2023).

4.2.3 Cost of Batteries

Traditionally there have not been heavy electric vehicles being grid-connected due to the cost of lithium-ion batteries (Nykvist & Olsson, 2021). In 2023, batteries are more of an economic need for a changing grid and are being made available commercially through companies such as Tesla, and can be seen being made more commercially available in buses and trucks. Currently, there are five existing on the roads in New Zealand already, the most popular - Milk-e - operated by Fonterra in Waitawa (Fonterra, 2022).

Early adoption of this technology allows for studies to investigate potential HV2G opportunities using these larger batteries in a commercial and real-world setting, as well as an investigation into the real world of batteries, which includes how the battery is made, its degradation over its lifetime, and the end-of-life options.

Alongside non-dispatchable generation, batteries could be essential to see how these can support communities with lower access to resources, from both a funding perspective and an infrastructure perspective, to aid in mitigating climate change.

4.3 Methods

4.3.1 Overview of Simulation

This chapter develops a basic simulation to understand where and when buses are used in a public transport system - namely, a school bus system. The examination of typical characteristics of HV2G batteries in school buses, such as when they are sitting idle, gives an idea of when the school buses could be grid connected.

The model uses historical, actual load data from Transpower during a period when there was an abnormally large load on the grid. The simulation models two parent states by considering whether the buses are ‘in use’ or are 'at home'. The at-home state also has three child states, 'charging', 'discharging' or 'idle'.

The model compares two data series, the load data from Transpower compared to the school buses in their different modelled states, such as when they are available for use ('idle') and when they could provide peak shaving support to the grid. This analysis results in peak shaving potential values and can be exported and charted using spreadsheet output from the simulation.

4.3.2 Simulation Inputs

4.3.2.1 Peak Load Profiles

As described by Transpower in NZGB (Daily time window) (Transpower, 2022a), morning load (referred to as peaks due to their peaking nature) occur between 6 am and 11.30 am, and evening peaks occur from 4 pm until 8 pm. These peaks require careful management as significant ramp rate changes need to occur during these times, as residential and commercial loads typically increase rapidly. Peaks on the grid require careful load management from the System Operator to communicate with the generators who inject electricity into the grid as required.

In summer, there is typically less demand on the grid, so lower peaks occur, and subsequently, less overall generation occurs (Transpower, 2022b). In winter, more generation is required due to trends in electrical usage such as heating costs, shorter days requiring more street lights, and more inside hours using electricity. Over the next 30 years, Transpower predicts that peak electricity consumption will increase by around 66% (Transpower, 2022b), an additional two-thirds more load than our existing peak, a jump from 8600 MW to around 13,700 MW. Predicted increases are due to various sources, including greater reliance on electricity for heating and cooking, population growth, electrifying transport and reducing natural gas usage.

4.3.2.2 Data

Several data sources, including load profiles from maximum load days and network school bus schedules, were used to develop the output of this simulation. The timetables of the school bus network in Wellington have been used, which are published as per Metlink (**a2020˙metlink**). These timetables ensure predictable operation for the network and its users, allowing this study to focus on predefined use cases and regulate when electricity is required to charge or be returned to the grid.

4.3.2.3 School Buses

Some additional inputs were required to ensure accurate predictions for electricity usage in buses and were used as inputs for the simulation. The school bus data is unique to Wellington, New Zealand, as the buses used in the simulation are made in Tauranga. The unique characteristics of these buses, including but not limited to bus capacity, usage times, charging times, and location data of depots, should be provided on a case-by-case basis in alternate simulations.

The specifications for school buses are provided by Metlink, a bus subsidiary based in Wellington, New Zealand. Of the buses in the fleet in Wellington, the single-decker buses (eT12-max) contain a 350kWh battery, can run the whole day and are typically slowly charged in the evenings, taking about 5.5 hours to charge fully (Metlink, 2020). The double-decker buses (UT200RHDF) use fast charging throughout the day, with a seven to ten-minute fast charge providing three hours of additional charge along with an overnight slow charge. These double-decker buses contain a 508kWh battery.

4.3.2.4 Chargers

Charging for buses in the Wellington region is currently available at bus depots as slow chargers, which are 60 kW/h, giving the 350kWh buses a charge time of 5.5 hours to reach maximum capacity (as the buses arrive at the depot with around 50-80kWh of charge remaining. The Wellington region also has two fast chargers at 450kW and 1080kW, respectively, providing top-ups to larger capacity buses throughout the day.

4.3.2.5 Timetables and Routes

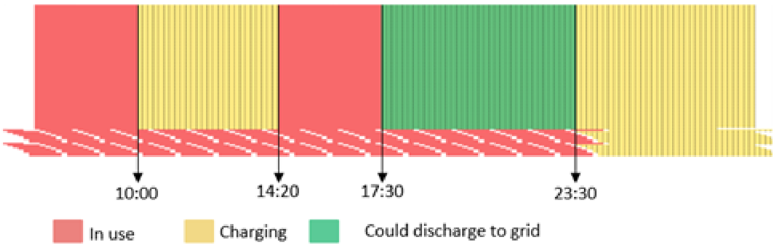


Figure 4.1: A typical schedule for a school bus in the Wellington region.

Metlink, a subsidiary of the Greater Wellington Regional Council, operates the Wellington public transport network and currently has three contracts with three bus companies to operate 150 individual and unique school bus routes to Wellington schools all around the region. School bus routes operate in two split shifts, between 7.30 am and 8.50 am and 3.15 pm - 5 pm, which are visualised in Figure 4.1. Currently, approximately 14% of the total number of buses in Wellington are electric; however, as the government has set a goal of 2035 being 100% electric, it is worth analysing future year scenarios (MoT, 2023).

This study contacted Metlink via email about specific school buses and what happens with school buses around the region. Metlink advised that *"The bus will either return to the depot to be picked up by another driver to perform another school run or possibly a public service depending on the number of vehicles available at different periods. They may continue with a public route after the bus has completed their school run, or the bus will be returned to the depot - this can change every day depending on the number of drivers and buses available to complete services."*

School bus batteries will not be depleted once they have completed their routes, providing ample opportunity to provide excess electricity back to the grid. Currently, some will not be electric buses, and the model will only ever count a maximum of 75% of electric bus capacity.

4.4 Simulation

Using the inputs defined previously, the charging times, usage times, and excess times can be found. These times indicate bus availability and existing trends in the data, which can be used for evaluating usage times. This information could be exploited to highlight areas of potential grid support when electricity can be returned to the local network. The model's output is a distributed battery's overall modelled capacity in the bus depots' locations. This capacity value can then be compared against grid usage for specific times when the buses are available for usage (inputs). The resulting output calculates the virtual battery capacity and how it would decrease over time.

A system model of the community school buses is produced as the overall result and, for a weekday, can show how much energy can be stored and subsequently used from bidirectional charging school buses for peak shaving in population-dense areas. These areas could have high transmission costs to get electricity to or be rural areas with a more significant reliance on individual grid exit points and distribution networks, meaning transmission losses are high due to lower voltage over longer distances.

4.5 Software

The model evaluation software could be written in most programming languages for scalability. However, this proof of concept was completed in Excel to provide immediate feedback, allowing variables to be changed quickly and inputs to be exported and changed as required.

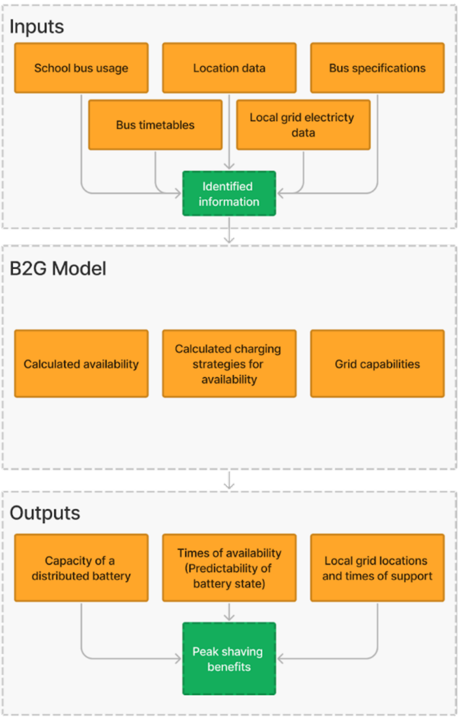


Figure 4.2: The simulation process which was developed to simulate a school bus-to-grid system.

By using accurate timetables, real charging times, and actual fleet sizes, the simulation can demonstrate how load and charging profiles have the potential to change over time.

The software process can be seen in Figure 4.2, and imports the example load profiles from the GXP (grid exit point) to understand the peak electricity usage in the area. The simulation can evaluate the peak shaving result as rows of data that can be exported to a CSV, charted appropriately, and compared to the input load profile. This output produces data in 10-minute intervals across 24 hours. The model has the potential to implement different charging strategies for the buses. The buses will never drop below 20% state of charge, which is a requirement of the bus company as a mitigation strategy where a bus may be required to be transferred to an alternate depot at late notice.

What is unique about this simulation is that it does not make assumptions about charging times when buses are charging and relies on fully charged batteries (as done in this model by M. Elliott and N. Kitten (Elliott & Kittner, 2022)). Instead, it uses known schedule information to predict when the buses are used and works backwards to identify areas of time in which buses and their batteries are available for usage in an HV2G capability and how much capacity remains and can be utilised for peak shaving benefits.

4.6 Results

The schedule for a non-school bus is a 19-hour all-day timetabled run, operating at around 30km of travel per hour where the 350kWh battery uses about 0.56kWh per kilometre of travel, implying approximately 4.86% of battery capacity use per hour of travel as shown in equations 4.1 and 4.2.

$$330kWh/19hours = 17kWh \tag{4.1}$$

$$(17kWh/350kWh) * 100 = 4.86\% \tag{4.2}$$

It is assumed that only single-decker buses have been used on school routes, not double-decker buses, because of the many tunnels with low ceilings in Wellington. Buses must charge overnight and be fully charged for the next day. As mentioned earlier, the school bus schedule is a split shift, between 7.30 am until 8.50 am and 2.30 pm until 5 pm. The capacity of the battery of the single-decker buses is 350kWh. For the bus to be a part of the model, it is estimated that it has been running for two-three hours on the school run (first red section in Figure 4.1, allowing some leeway for travel in between).

Metlink estimates the buses use around 0.56kWh per kilometre of travel. We confirmed this in the model by a bus charged for around five hours overnight, leaving nineteen ‘working hours’. Assuming the bus is not completely discharged, the value for discharge for around 30km of travel can be confirmed.

The results from three different simulations follow. Simulation One considers the existing load and electric school bus saturation levels. Simulation Two and Simulation Three consider future scenarios (existing load usage + 20%) and predicted usage for 2035 (50%), respectively.

4.6.1 Simulation One: Existing School Bus Characteristics

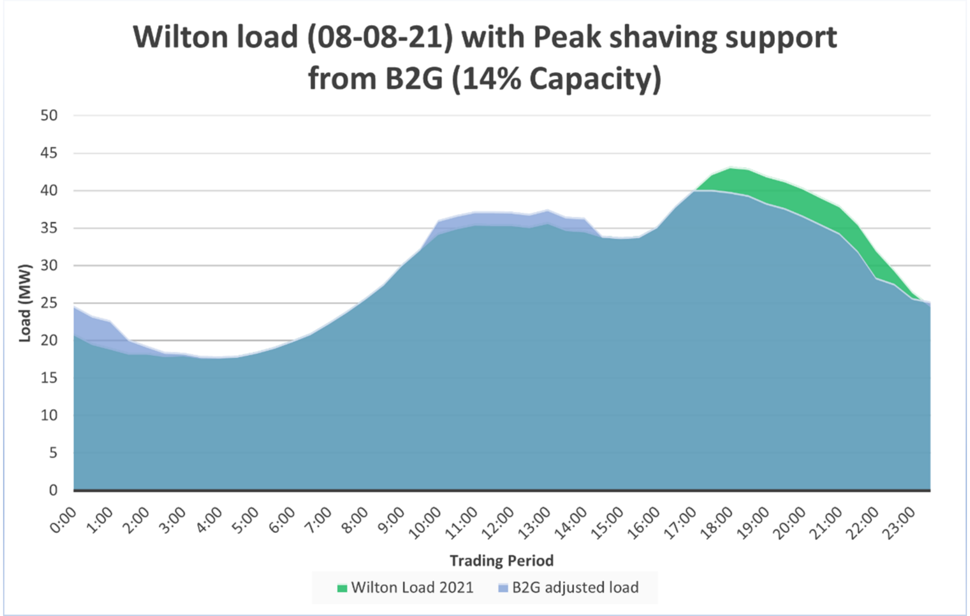


Figure 4.3: The simulation run using the existing school bus characteristics.

Simulation One uses the existing school bus network in Wellington. The simulation was run using the Wilton predicted load values (see the dark blue area in Figure 4.3) and produced data points focused on existing school bus information and real situations across the New Zealand grid. Using the existing school bus infrastructure as it currently exists in the 2022 bus network in Wellington, the input component of the model resulted in approximately 14% of the existing number of buses, equating to 21 school buses. The model output calculates the resulting battery as 4.62MW available in the evening. When this is charted, the green area in the evenings indicates batteries can support the grid in the evenings, as seen by the green area in Figure 4.3. This green area is between 5%-10% reduction in localised load when utilising the bus battery. This virtual battery has to potential to power around 1000-1500 homes, as estimated by the Mercury battery in Auckland (Mercury, 2018).

4.6.2 Simulation Two: Using projected HEV uptake

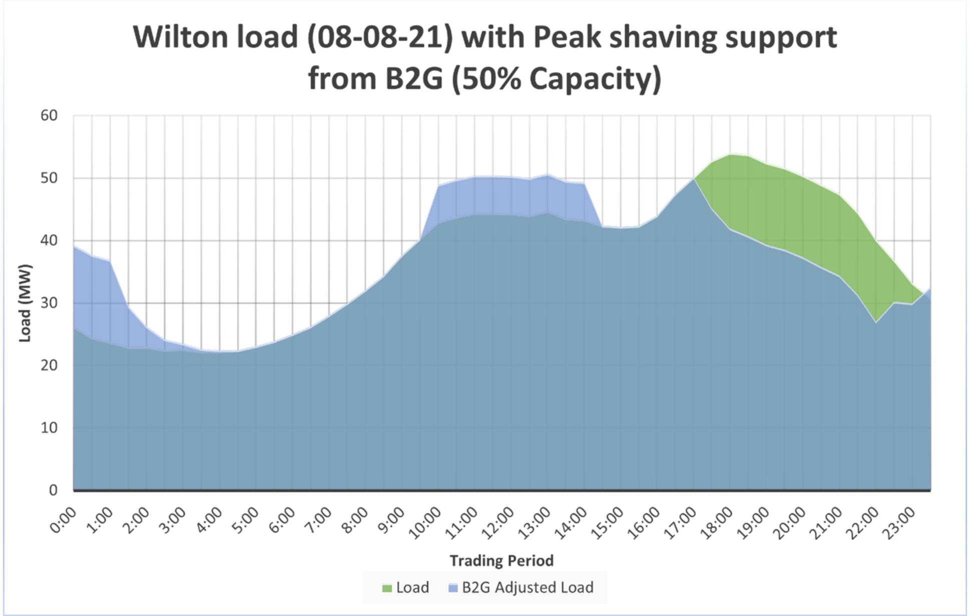


Figure 4.4: The simulation a targeted uptake of HEV of 50% (75 buses) in the Wellington Region.

Simulation Two expands and multiplies the first simulation based on electric vehicle uptake in the Wellington region while aligning with government emissions reduction strategies which can be seen in Figure 4.4. A targeted scenario for 2030 is where 50% (75 buses) of all school buses will be electric in the region, and the estimated load is expected to have increased by 25% (MBIE, 2019). As a result, we have increased the load by 25%. A 50% saturation of electric buses in Wellington provides a 16.5MW battery for peak times.

4.6.3 Simulation Three: Predicted 100% HEV Uptake

The third simulation in Figure 4.5 further expands upon Simulation Two to show by 2035 how a 100% uptake of electric buses in Wellington looks and

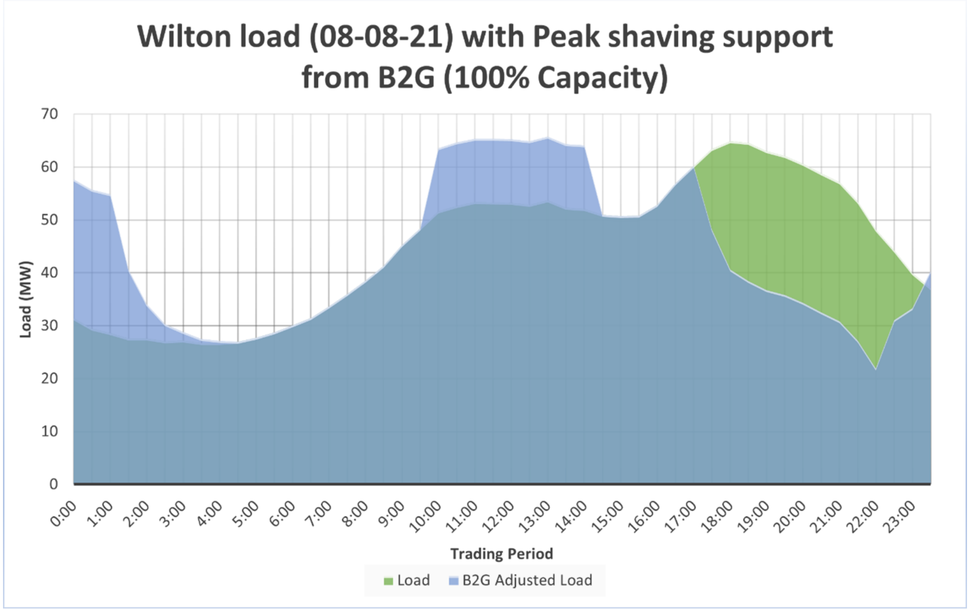


Figure 4.5: The simulation which uses 100% of HEV uptake.

could be used as a virtual battery. This scenario assumes a 100% electric bus uptake in the region of approximately 150 school buses, doubling the capacity for peak shaving. The load is predicted to increase by 25% by 2035, shown in load increases in the blue area in the chart. Overall, a combined 100% electric bus battery would have a combined capacity of around 33MW. Increases in charging requirements are also shown to impact the grid, but due to the expected increase in solar (Distributed Solar PV, 2019) and other forms of renewable generation, this should be a manageable problem over time.

4.7 Analysis and Discussion

This model has explored how to use the school bus network in Wellington for HV2G technologies to minimise the potential impact of overloading and charging buses at similar times to prevent adding demand to the grid during peak load. The model has also explored and examined how school buses could be used to create a virtualised, distributed battery to relieve the grid during evening peaks and provide some peak-shaving benefits.

The model developed considers authentic bus characteristics, accurate usage times, and how they are used across a typical weekday. The three simulations consider how the load profiles in New Zealand are expected to change over time, using predictive load increases from MBIE and Transpower. This model uses controlled and scheduled charging to ensure accurate results instead of relying on assumptions. Using existing fleet sizes from the Wellington region and existing charging points, a potential virtual bus battery can provide 4.62MW of support during evening peaks, using existing counts of school buses for future scenarios. When the number of buses increases, this can provide a 33MW battery, which in localised areas of Wellington provides over 50% of the capacity required in evening peaks.

Allowing existing infrastructure to be utilised for purposes that benefit the supply and generation of electricity in New Zealand increases the grid's resilience. It allows new, non-dispatchable generation sources to be considered viable options for grid connection instead of just residential solar. Interesting considerations will need to be given to grid constraints in specific areas that may not be able to support large-scale batteries. Grid modelling can be completed to do this. During a traditional winter load, having school buses available and grid-connected on a large scale can significantly contribute to peak shaving benefits; assuming appropriate integration with the national grid, a successful HV2G can be set up.

4.8 Significance of Study

Serious consideration should be given to distributed batteries in the New Zealand grid as these have a role to play in how solar is utilised and stored on the grid. Buses, particularly school buses, can be used to store non-dispatchable generation from solar during daytime hours, to be dispatched and used in peak-shaving scenarios. This could be seen by connecting to a central command centre and using Tesla trading software (Autobidder) to be autonomously connected to the New Zealand Electricity Market. An example system would look like Figure 4.6. Largely, this study would play the same role as the Hornsdale Battery, but by leveraging existing infrastructure which is already planned and budgeted for in New Zealand.

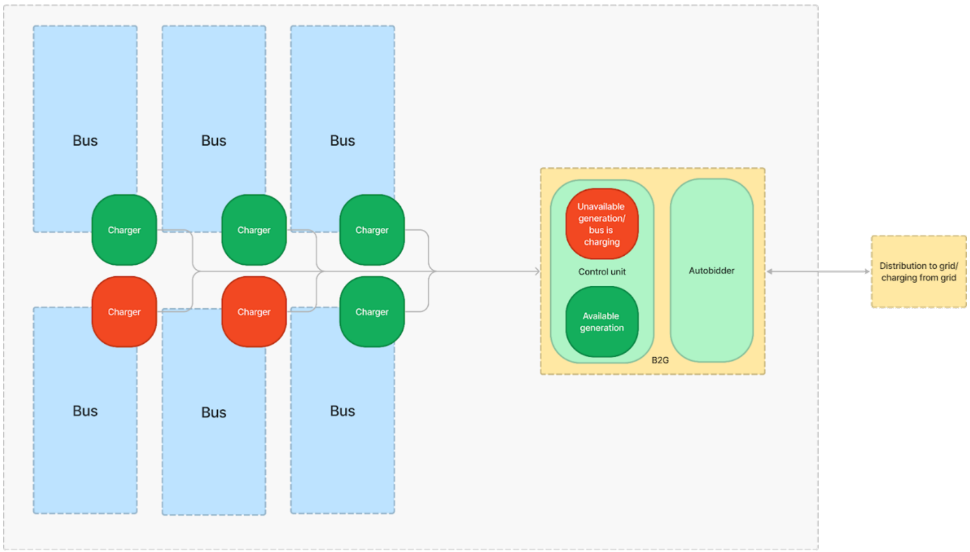


Figure 4.6: An example system which could be used to connect HEV to the grid leveraging V2G technology (HV2G).

4.9 Future Work

Potential practical extensions of the study would explore cost analysis of bus charging vs discharging at peak times and identify any potential electricity pricing revenue.

This project could consider the economic benefit to bus companies for implementing the proposed model in real life, as well as considering the carbon emissions saved or lost over the life of the bus.

Additionally, future work could include a partnership arrangement with a bus company to implement bi-directional chargers and use the Python model in practice, simulating live school bus runs and showing how a return to the grid would work and what the software would look like to achieve that in real life. Creating a system enabling HV2G connections to occur and how that would work is also a piece of future work that could occur.

4.10 Conclusion

The transport sector in New Zealand is set to transition to offer low-carbon alternatives to the buses and ferries which are currently operating around the region to decrease carbon dioxide emissions in line with existing and future decarbonisation policies. Electric buses are becoming more prevalent in the New Zealand public transport system and are expected to be 100% electric or decarbonised (hydrogen or electric) by 2035, including the 150 buses used for school routes in just the Wellington Region.

School buses can be repurposed as an effective virtual battery in the New Zealand grid, providing much-needed resilience to the volatile grid environment as school buses run on a predictable schedule, making their usage times known. The schedule in which school buses run allows a charged bus battery to return power to the local grid through 60kWh chargers through HV2G technology.

The simulation developed and described here simulated bidirectional chargers of buses through the utilisation of charging and discharging times of the school buses in the Wellington region by connecting these to the grid through HV2G technologies. The simulation calculated how a distributed virtual battery could have been used on a large load evening from a significant load event on the New Zealand grid.

By using existing bus fleet sizes from the Wellington region and existing charging points, a virtual battery was modelled to provide 4.62MW of support during evening peak times using simulations that model future grid scenarios. When the number of buses increases, this HV2G model can provide a virtual battery of up to 33MW, which in a localised area provides over 50% of the capacity required in evening peaks. Although there is the issue of reduced battery life because of increased charge cycles with HV2G, research has shown that the gains from greater use of the batteries in vehicles far outweigh the costs of earlier battery replacements (Werber et al., 2009).

Chapter 5

Empowering Innovation in Communities

> Alone we can do so little;
> together we can do so much.
>
> *Helen Keller*

Climate change mitigation strategies often need to consider practical technologies or existing ideas and rely on large companies or policy-led changes before making widespread changes. The discussion around the impact of climate change across Aotearoa should include those communities the expected climate changes may significantly impact.

Small and frequently rural communities in Aotearoa are often modelled to be the most at risk of the changing climate, frequently missing out on developing technologies and funding opportunities whilst being more strongly threatened by the impact of climate change (MftE, 2022). During the consultation phase, one identified area was the investment in regional infrastructure to strengthen community resilience and lessen climate change impact in these areas.

This chapter combines the ideas discussed in Chapters 3 and 4 by discussing how solar generation in factories (industrial solar) and electric buses (already announced infrastructure) can be repurposed in smaller areas to help mitigate climate change's effects for these communities. A strategy is also briefly developed so which allows integration into communities and allows the development of the system for future climate goals.

5.1 Utilising Distributed Systems

5.1.1 Solar in New Zealand

The sun provides more energy than the world needs, let alone New Zealand could ever use, so it makes sense that consumers can utilise this energy source. Solar generation for rural communities, in terms of microgrids, residential, and factory solar installations, can reduce the load from distribution networks and the grid, particularly in remote areas. Moreover, many areas of New Zealand have the potential to be used for solar generation, and this is discussed in more detail further in this chapter.

5.1.1.1 Solar Predictions

Solar generation could be predicted by using software models such as Project Sunroof (Google, 2023) to encourage more industry participants to consider installing solar systems. However, predicting future solar generation is currently not possible. Therefore, it is necessary to look at the historic sunshine data, estimate what would have been generated, and overlay it with the participants' current usage to provide a convincing argument for a solar installation.

Solarview is a NIWA model which takes into consideration the amount of solar energy based on orientation at a particular set of co-ordinates. This model also takes into consideration building and landscape heights and obstructions and can be used for predictive modelling for potential solar installation locations. The NIWA model is produced and shown in Figure 5.1 which models five different curves based on 5 different times throughout the year, detailed across the horizontal axis. This model is then compared with the recorded Chia Sisters solar array data, as detailed within Chapter 3 and is

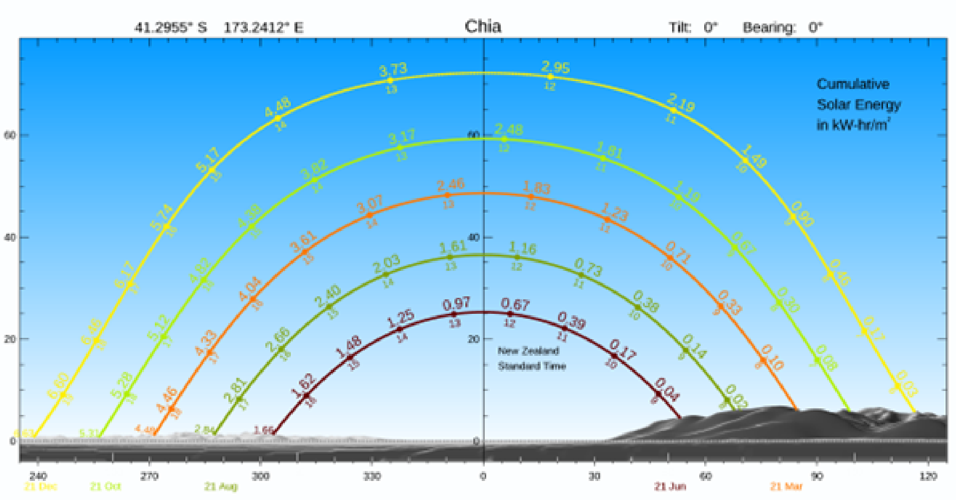


Figure 5.1: NIWA's prediction model for solar generation, based on the co-ordinates of the Chia Sisters factory in Nelson, New Zealand.

compared with the NIWA model, provided to be around 60% accurate. The overall prediction when compared with the generation from Chia Sisters for the same time period can be seen in Figure 5.2. The NIWA model obtained near accurate accuracy, with leeway for real world changing weather conditions as the model uses ten years of historical radiation data. The NIWA model evaluates historic data for a particular area, providing downloadable prediction data which can be used for predicting potential generation over a period.

When charting this against solar data, a summary value of how accurate the NIWA model is can be found using Equations 5.1 and 5.2.

$$\text{Solar output / predicted solar output per day} = \text{Daily efficiency value (EV)} \tag{5.1}$$

$$[\text{EV(1st)} + \text{EV(2nd)} + \text{EV(n)}] \text{ / days in month} = \text{Overall EV (OEV)} \tag{5.2}$$

Using the datasets mentioned, the equations produce a value of 0.612171, which can be interpreted as the model is approximately 61% accurate in predicting March 2022's solar output. Therefore, across the whole month of gen-

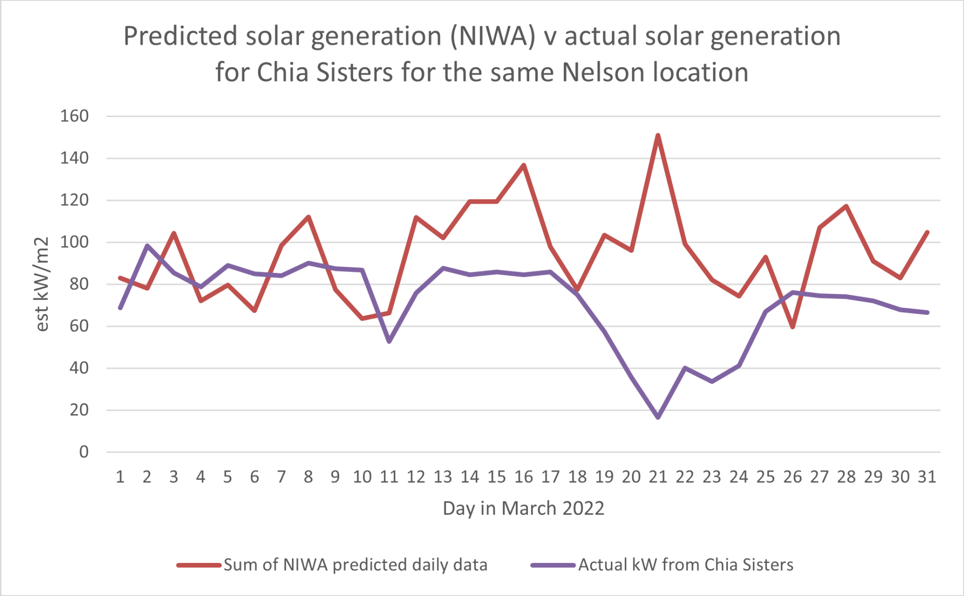


Figure 5.2: Chia generation vs the predicted generation for the NIWA model.

eration, Chia Sisters generated 61% of what they were predicted to, based on previous years of data. Theoretically, this percentage should average yearly in a distributed solar array.

5.1.2 Analysis of Recorded Data

As well as prediction software, NIWA also provides recorded radiation data to show the solar radiation recorded during an area during a specific time. This data can be compared to Chia's data, to gain an understanding of solar conversion rates of turning radiation into solar generation.

The NIWA location and date used was during March at the Nelson Airport weather station, approximately 1km from Chia Sisters. This data was charted against Chia's actual production with reasonable accuracy, meaning that NIWA data can be converted into radiation values, and companies can understand how much generation their roof has the potential to generate with reasonable accuracy. There are many potential use cases for this.

The efficiency of the Chia System can be found by using the radiation data and converting the MJ/h (how radiation data is measured, and converting it into kW/h, or dividing MJ/J by 3.6 as done in Equation 5.3.

$$(MJ/h)/3.6 \tag{5.3}$$

The overall efficiency of the panels is calculated as 24%, and is shown in Figure 5.3. This chart shows that the Sumec solar panels have a high conversion rate and optimal placement.

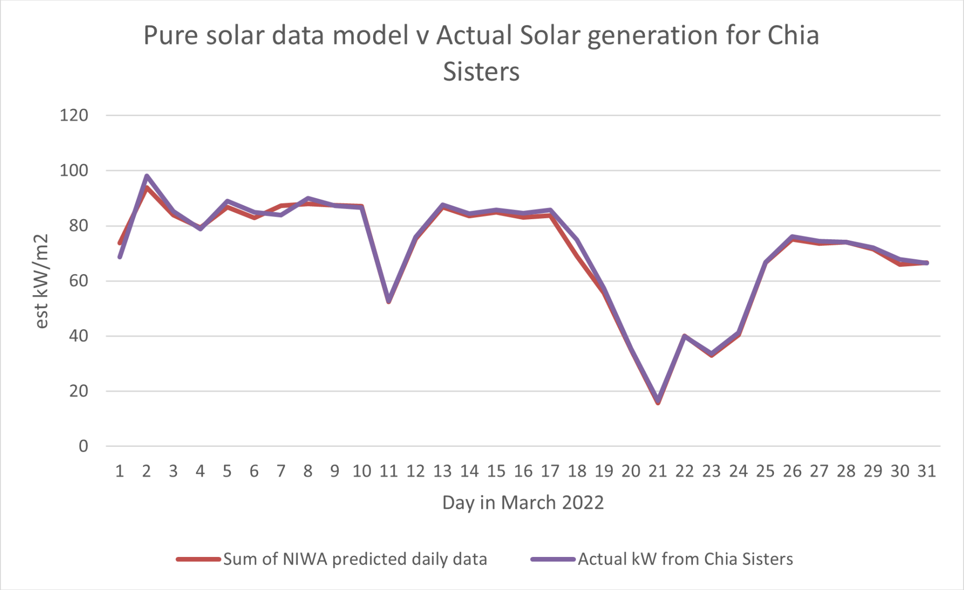


Figure 5.3: Chia generation compared to the recorded radiation data from NIWA.

This is important as it shows the overall efficiency is high for these panels, and optimal placement makes a difference. Communities around New Zealand can use this data to show what they would have been able to generate for the past year by completing a similar analysis on NIWA data for a location close to where they are.

5.1.3 Solar Generation Potential based on Location

Understanding how radiation data correlates with accurate solar data opens the door for more predictable solar output modelling by allowing more companies or households considering solar to use publicly available information to provide analysis on historic radiation data. By using potential solar generation for their location, the analysis can provide them with accurate information on generation values and, as a result, their savings values.

Instead of using land for large arrays, consider using the roofs of existing factories, such as those already large energy users. Solar in factories with large roof areas can provide more localised electricity to potentially significant electricity users. Chia is an excellent example of leading the charge for industrial participants and solar generation. They have utilised ample roof space and relatively low electricity usage (compared to other heavy types of users) and reduced their electricity usage by about 50% annually.

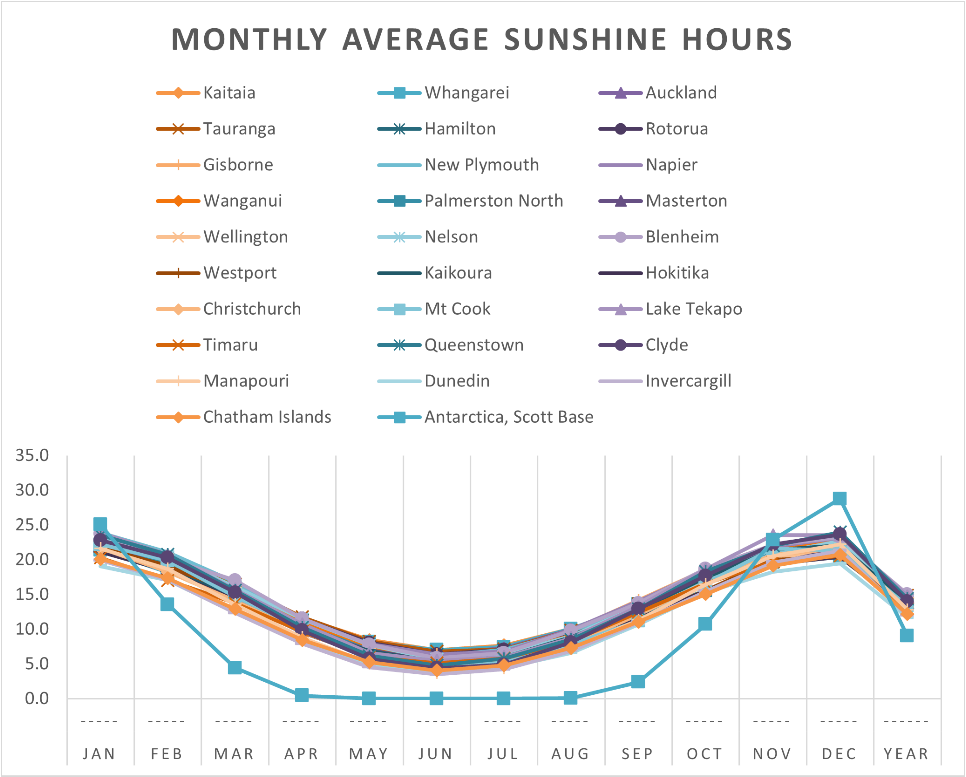


Figure 5.4: NIWA radiation data for the past year across New Zealand and Antarctica.

Many companies have the potential to take on solar panels, inverters, and batteries; it is just a matter of analysing how much their electricity bill could reduce. Places like milk factories, poultry farms, milking sheds, large retail stores like Mitre 10, and many more industrial participants could benefit from solar arrays.

As seen in Figure 5.3, radiation data from NIWA results in around a 24% conversion into solar generation, shows how NIWA data can be used across New Zealand to identify which areas, on average, receive higher daily amounts of radiation as a way to understand how the sun falls across New Zealand. This data is shown in Figure 5.4 and shows on average, many regions are relatively similar in their daily production potential (NIWA, 2007), except for Antarctica for obvious reasons). NIWA monitoring stations further north in the country have a daily average closer to $25MJ/m^2 (1MJ = 0.277778kWh)$, about 27% of a kWh. Therefore, per m^2 is about 6.94kWh/m^2 of potential in many areas.

Based on the research in Chapter 3, by using the NIWA radiation data, and depending on the quality of the solar panel, the Chia solar panels operate at around 24% conversion rate of radiation data; therefore, per m^2 of solar panels, can generate about 1.735kWh per m^2 of electricity.

Overall, the further north a location is in New Zealand, the more radiation they receive and, therefore, the more beneficial solar is to them. More solar generation would also further benefit the grid in New Zealand, as there is less overall generation in general in the North Island than in the South Island. Some places are less known for sunshine and are identified in Figure 5.4. Places like Clyde enjoy more sunshine in the summer and slightly less in winter but remain a good option for solar. Adding solar to a place like Clyde which is located near the national electricity infrastructure could aid in alleviating the dry year problem.

5.1.4 Bus & Electric Vehicle Storage Potential in New Zealand

Electric vehicles are becoming much more copious in New Zealand with the decrease in price and increase in competition and supply. Adding new batteries to the grid offers the potential to help aid with morning and evening peaks by offering storage up to the electricity market to alleviate pressure. This return to the grid from a vehicle is known as Vehicle-to-grid (V2G) (or sometimes called Vehicle-to-load) and has shown to be effective in responses such as during Cyclone Gabrielle (Wade, 2023). The capability is already built into most electric cars, and this research has discussed buses, milk tankers, or other heavy battery vehicles which could have the potential to be used for this purpose as well.

It is estimated that there are around 4.4 million registered vehicles on the roads (Environmental Health Intelligence New Zealand, 2021), and by 2050 most of these are expected to be converted to electric (excluding hydrogen). Using the principles discussed would allow significant country-wide storage potential. By narrowing down to HEV, these heavy vehicles' return to the grid will have concentrated areas of use but will be particularly favourable amongst distributors who monitor residential loads and will have the potential to create a way to manage these loads on their networks. Additionally, there are likely to be concentrations of electric vehicles for personal use around main towns and cities, as well as in rural towns, as these are concentrated where people live.

Regardless of the storage capability of the grid, however, the amount of electricity generation will need to increase, with solar, wind, or geothermal, significantly. 100% electricity is a worthy goal to achieve. However, it becomes a red herring regarding how much more generation the country requires, especially peaking generation, which is likely to be solved by batteries and potentially V2G, allowing more load shifting to occur.

5.2 Open-Source Application for Community Integration

Communities in New Zealand could greatly benefit from data-sharing tactics, such as that by Simply Group, Counties Power, Callaghan Innovation, and Creative HQ as a part of the Lighting Lab Electric Innovation Challenge, or Nau Mai Rā (retailer), which partnered with a Waitomo distributor and with a solar company, Solar Sense, (Sense Solar, 2023) to create a solar buyback scheme and allow a central distribution point of solar to be beneficial in cost return to the retailer customers by providing credit. This sort of data sharing and solar sharing scheme has the potential to enable microgrid communities throughout New Zealand, allowing for less reliance on large grid infrastructure projects such as those by Transpower or Distributors.

Using available information for sunshine, solar, and electricity usage, solar participants in local areas could share data and knowledge of their generation usage and patterns and align better with the solar they use. Integration with the local communities in schools or residential also improves this resilience. Small communities which have already successfully made changes like this include Great Barrier Island and a Halcombe marae (Provincial Growth Fund, 2020).

Communication becomes a critical point of call to 'know your neighbours'. Existing communities such as Great Barrier Island and Kia Whitingia (Provincial Growth Fund, 2020) have all implemented solar and small data sharing schemes. However, as with many small projects, there is a lot of replication and duplication of investigation phases. Data-sharing systems would benefit and enable these schemes to benefit a wider community. Community energy management systems have the potential to be quite distributive to the energy system; however, they may alleviate the strain on national energy resources.

5.3 Community Energy Management Systems

These studies show the potential to include a Community Energy Management System, which could provide insights into community solar generation as well as community ICP energy usage, which partially exists already in WEL and Vector Networks with the introduction of smart metres and WEL network metering. The potential to connect EVs for battery storage and the monitoring system could show how these systems can link together. This sort of system can be beneficial to understanding, monitoring, and overall decreasing residential emissions.

Overall, there are ways to combine new solar generation with existing vehicle storage, which can increase the generation capability of the grid across the country and decrease the reliance on the grid from a residential or commercial perspective. Places that already have large roof areas have an increased potential for solar generation, which can be calculated using NIWA data, as previously discussed.

This means that communities, and at this stage distributors, need to be more energy aware in their monitoring. It is essential to have a transparent network, knowing where their electricity is being used and how the network is configured. Additionally, informing consumers where their energy is coming from and showing how they can buy or sell their generated electricity to the network or to neighbours instead of the larger retailers, may benefit the community more in terms of usage and cost (due to decreased transmission averages).

Community monitoring of water usage, electricity monitoring and how much could be saved through potential solar generation or if the consumer owns an EV through microgrid creation with their EV ensures people and communities are more self-aware of their emissions and how they can decrease usage or change when they are using much electricity.

If distributors partnered with their communities to operate a system that monitored community energy usage, this would provide transparency to communities to show how they can manage their electricity usage. Through self-management of data and generation, combining these changes to help decrease carbon emissions from communities through existing and new resources or generation.

Microgrids have the potential to provide resilience for communities during times of emergency, such as earthquakes or cyclones, when there is damage to the larger grid. A microgrid could also provide more transparency to usage times and self-management of generation, for example, when heavy appliances such as dryers get turned on. Incentives currently, such as 'free hour of power' offered by some retailers, already incentivise electricity monitoring from a residential and personal perspective which is an excellent step in the right direction for monitoring usage. This monitoring has the potential to be expanded to investigate the forming of a microgrid within communities. For example, that 'hour of power' may become two hours if there is cheap power from the neighbour's EV battery while they are away for the week.

A negative of microgrids is during times of heavy load, there is still a reliance on the grid, and as electricity is now relied upon for heating and cooking in many places, that there is not a lot of large generation other than batteries or solar in microgrid opportunities, which all have particular generation times.

5.4 Discussion

Figure 5.5 provides a theorised way of arranging PV systems in residential areas with industrial solar arrays into a Community Energy Management System. Theoretically, HEV storage could offset community generation in the evenings when the sun is not shining or there is a low load. Such systems have been theorised, such as Market Maker (Worthmann et al., 2014), but still need to be developed into usable technology, not on a community level. With existing legislation and the grid organisation, such systems in New Zealand would fall onto the distributors to build, manage and own.

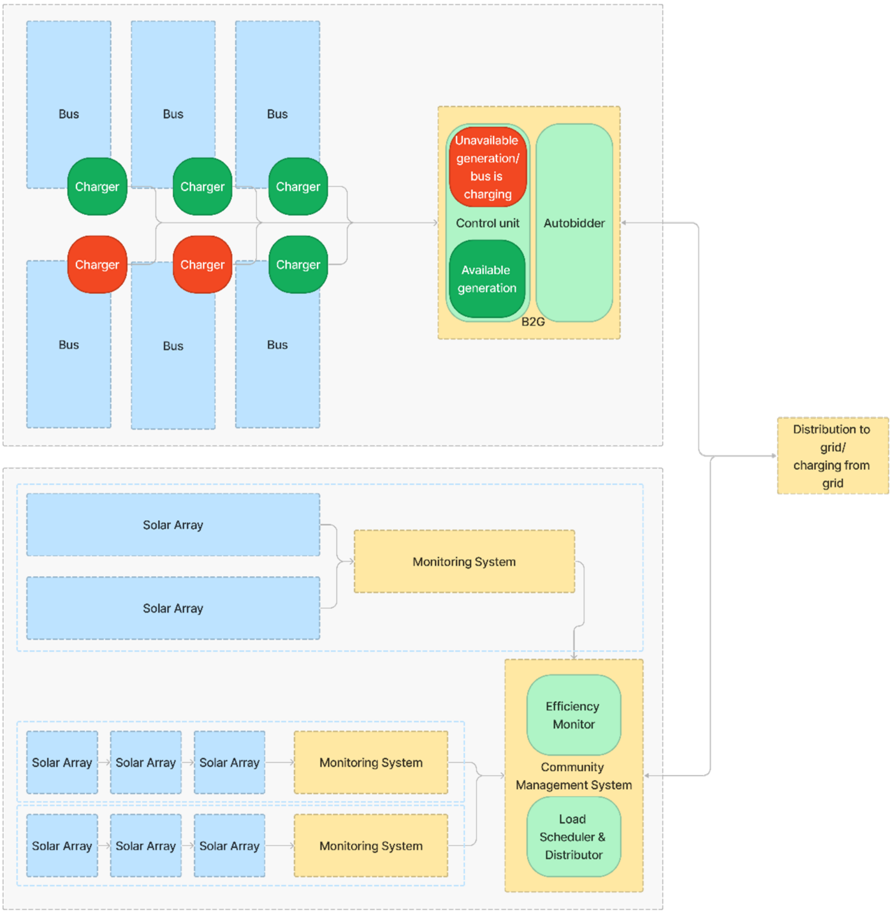


Figure 5.5: A theoretical model of a Community Energy Management System.

A Community Energy Management System provides a theoretical way to manage better the interaction between distributed generation, local demand, and grid supply. An intelligent way should be a part of the solution, but it does not exist. Networks do not benefit greatly from purchasing solar due to its unpredictable nature, yet they would benefit from more generation near where it is being used as a way to minimise transmission losses. Distributed network intelligence devices should help in areas like this.

Community Energy Management Systems also benefit from a national perspective, as this helps monitor community energy usage in more detail instead of using averages and estimates. In decarbonisation efforts, data is knowledge, and by bringing these changes together, there is a chance to help decrease carbon emissions through a large proportion of existing resources while also allowing for the growth of new resources and national solutions.

5.5 Summary

When combined with solar on a large, industrial scale, Community Energy Management Systems can provide quite a disruptive system to the existing electricity model in New Zealand infrastructure. Change is a good thing when it comes to climate change, and understanding both how participants use electricity, how it can be managed more effectively, and understanding that there is no one size fits all solution for monitoring leads to a Community Energy Management System that understands all these factors, and enables the sharing of such data which is highly sought after and required to help decrease demand during high load times on the grid.

Chapter 6

Conclusions and Future Work

> One of the best ways to save the economy of a country is to save electricity.
>
> *P.S. Jagadeesh Kumar*

6.1 Thesis Conclusions

Widespread electricity availability has changed the way industries, transport, and people's lives operate. Through energy innovation, industries have increased many communities' reliance on electricity for utilities such as internet access and water and transport infrastructure and processing in commercial or industrial areas. Electricity is used in almost every aspect of our lives, but due to the increased usage, there is a global initiative to decarbonise economies and countries. New Zealand is no exception. Decarbonisation goals recommended by the CCC see 50% of all energy consumed in New Zealand should be from renewable resources, leaving twelve years to convert around 10% of New Zealand's economy, leaving the other 50% for the following fifteen years.

There is no one-size-fits-all solution to decreasing our non-renewable energy usage. Still, a large part of existing energy usage can be converted to electricity to decarbonise.

This thesis has explored how to utilise existing infrastructure in communities better to decarbonise said communities which may have been marginalised or left out of initial policy planning regarding climate change policy. Infrastructure that currently exists or is predicted to exist in our communities can be adapted to provide more thoughtful strategies in decarbonisation efforts throughout the country by changing how we generate, store, use, and understand our electricity and energy usage.

Chapter 3 identified and explored solar generation with an industry partner in a factory that installed solar panels to decrease their carbon footprint and electricity bill. Analysis shows how Chia Sisters support their factory's electricity usage by generating electricity and achieving their business goals by reducing their carbon footprint. Potential expansions to the Electricity Code could allow any excess generation to be used by the community around them instead of being solar back to the grid. Chia Sisters have shown that reducing their dependence on fossil fuels and exploring how electricity can replace non-renewable generation in the industrial sector can be achieved and successful, with significant payback from their system. While solar generation has been around for a reasonable amount of time, its integration with large grids as non-dispatchable generation sources are still a discussion and research point.

Existing infrastructure funded and planned to exist by 2035 utilised heavy electric vehicles, particularly school buses, to support the grid during heavy load times such as evening peaks. Regions that have invested in heavy electric vehicles are shown in Chapter 4 to have the potential to provide grid support by using high-voltage batteries, which will exist in more significant numbers by 2035. Even a small number of school buses, such as a like-for-like replacement of the number currently operating in the Wellington region identifies the potential for up to a 33MW battery for localised grid support during evening peaks on the electricity grid.

Through a combination of software, planning, and community energy management systems, connecting the ideas discussed in Chapters 4 and 5 could enable interconnected devices among our communities, such as school buses near a local school talking to the houses nearby when they get home in the evening, and the power goes out. CEMSs can potentially reduce peak load times on the grid by analysing when we use electricity the most and how we generate it. Our infrastructure and energy demands and needs are continually changing, and to meet CCC targets, we need to change too. CEMSs are a part of that process.

6.2 Future Work

Solar generation in this thesis is a feasible solution to beginning to decarbonise factories, analysing electricity usage, and offsetting usage with solar. Future work in this area could extend the software to be more of a digital twin and allow for the configuration of the solar array, such as predicting how much money could be saved by including a battery and what times it could be used. Further work could also investigate how microgrids could be implemented in this area by applying for an Electricity Code exception and completing the practical installation of a microgrid.

Future work related to Heavy Vehicle to grid technology could expand this study to undertake a benefit-cost analysis of bus charging vs discharging at peak times and identify any potential electricity pricing revenue. This analysis would allow bus companies to explore the economic effect of this model and consider the carbon emissions saved or lost over the life of the buses.

Additionally, future work could include a partnership arrangement with a bus company to implement bi-directional chargers and use the Python model in practice, simulating live school bus runs and showing how a return to the grid would work in a real world scenario. Creating a system physically enabling HV2G connections to occur and how that would work is also a piece of future work that could occur.

Just as the electricity we are using right now was a drop of water one second ago, we must change and move just as fast as electrons in a wire. Through intelligent and confident decisions, we shall be able to continue to keep making waves in decarbonising Aotearoa.

References

Aurecon. (2022). Hornsdale power reserve: Advising on the world's biggest battery energy storage project. *Aurecon.* https://www.aurecongroup.com/projects/energy/hornsdale-power-reserve

Barnett, J., Evans, L. S., Gross, C., Kiem, A. S., Kingsford, R. T., Palutikof, J. P., Pickering, C. M., & Smithers, S. G. (2015). From barriers to limits to climate change adaptation: Path dependency and the speed of change. *Ecology and Society*, *20*. https://doi.org/10.5751/es-07698-200305

CCC. (2022). Ināia tonu nei: A low emissions future for aotearoa. *Climate Change Commission - He Pou a Rangi.* https://www.climatecommission.govt.nz/our-work/advice-to-government-topic/inaia-tonu-nei-a-low-emissions-future-for-aotearoa/

Choi, D., Shamim, N., Crawford, A., Huang, Q., Vartanian, C., Viswanathan, V. V., Paiss, M., Alam, J.-e., Reed, D., & Sprenkle, V. L. (2021). Li-ion battery technology for grid application. *Journal of Power Sources*, *511*, 230419–230419. https://doi.org/10.1016/j.jpowsour.2021.230419

Csereklyei, Z., Kallies, A., & Diaz Valdivia, A. (2021). The status of and opportunities for utility-scale battery storage in australia: A regulatory and market perspective. *Utilities Policy*, *73*, 101313. https://doi.org/10.1016/j.jup.2021.101313

Denholm, P., Mai, T., Kenyon, R., Kroposki, B., & O'malley, M. (2020). Inertia and the power grid: A guide without the spin. *National Renew-*

able Energy Laboratory (NREL). https://www.nrel.gov/docs/fy20osti/73856.pdf

DiPippo, R. (1993). *Renewable energy*. Butterworth-Heinemann. https://doi.org/10.1016/b978-1-4832-5695-5.50013-5

Distributed Solar PV. (2019). Distributed solar pv. *IEA*. https://www.iea.org/reports/renewables-2019/distributed-solar-pv

EECA. (2021). New zealand energy scenarios times-nz 2.0 - a guide to understanding the times-nz 2.0 model. *EECA*. https://www.eeca.govt.nz/insights/eeca-insights/new-zealand-energy-scenarios-times-nz-2-0-guide/

EECA. (2022). Solar. *EECA*. https://www.eeca.govt.nz/insights/energys-role-in-climate-change/renewable-energy/solar/#:~:text=The%5C%20future%5C%20of%5C%20solar%5C%20electricity%5C%20in%5C%20New%5C%20Zealand%5C&text=This%5C%20decrease%5C%20in%5C%20cost%5C%20%5C%E2%5C%80%5C%93%5C%20which,Zealand%5C%20electricity%5C%20supply%5C%20by%5C%202035.

Electricity Authority. (2023). Installed distributed generation trends. *Electricity Market Information*. https://www.emi.ea.govt.nz/Retail/Reports/GUEHMT?DateFrom=20130901%5C&DateTo=20230430%5C&MarketSegment=Res%5C&_rsdr=ALL%5C&Show=CapacityAvg%5C&_si=v%7C3

Elliott, M., & Kittner, N. (2022). Operational grid and environmental impacts for a v2g-enabled electric school bus fleet using dc fast chargers. *Sustainable Production and Consumption*, *30*, 316–330. https://doi.org/10.1016/j.spc.2021.11.029

Energy Resources Aotearoa. (2020). New zealand's consumption. *Energy Mix*. https://www.energymix.co.nz/our-consumption/new-zealands-consumption/

Environmental Health Intelligence New Zealand. (2021). Number of motor vehicles. https://www.ehinz.ac.nz/assets/Factsheets/Released_2021/Number-of-Vehicles.pdf

Faunce, T. A., Prest, J., Su, D., Hearne, S. J., & Iacopi, F. (2018). On-grid batteries for large-scale energy storage: Challenges and opportunities for policy and technology challenges and opportunities for policy and technology. *MRS Energy & Sustainability*, *5*, E11. https://doi.org/10.1557/mre.2018.11

Fonterra. (2022). Fonterra welcome milk-e, new zealand's first electric milk tanker. *Fonterra.* https://www.fonterra.com/nz/en/our-stories/media/new-zealands-first-electric-milk-tanker.html

Google. (2023). Project sunroof. *Withgoogle.com.* https://sunroof.withgoogle.com/

Jarvis, P., Climent, L., & Arbelaez, A. (2023). *Smart and sustainable scheduling of charging events for electric buses* (EU Cohesion Policy Implementation - Evaluation Challenges and Opportunities). Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-18161-0_8

Lazard. (2021). Lazard's levelized cost of storage - version 7.0. *Lazard.* https://www.lazard.com/media/42dnsswd/lazards-levelized-cost-of-storage-version-70-vf.pdf

MBIE. (2019). Electricity demand and generation scenarios: Scenario and results summary. *MBIE.* https://www.mbie.govt.nz/dmsdocument/5977-electricity-demand-and-generation-scenarios

Mercury. (2018). Kiwi first nz direct grid connected battery. *Mercury NZ.* https://www.mercury.co.nz/news/180823-kiwi-first-nz-direct-grid-connected-battery

Metlink. (2020). Metlink adding 98 more electric buses – 31 will be double deckers. *Scoop.co.nz.* https://wellington.scoop.co.nz/?p=129170

MftE. (2008). Coastal hazards and climate change a guidance manual for local government in new zealand 2nd edition. https://environment.govt.nz/

assets/Publications/Files/coastal-hazards-climate-change-guidance-manual-2008.pdf

MftE. (2021). Climate change. *Ministry for the Environment.* https://environment.govt.nz/publications/statement-of-intent-2008-2011/operating-intentions/climate-change/

MftE. (2022). Climate change and rural communities. *Ministry for the Environment.* https://environment.govt.nz/publications/climate-change-and-rural-communities/

MoH. (2020). Annual report on drinking-water quality 2020–2021. *Ministry of Health NZ.* https://www.health.govt.nz/publication/annual-report-drinking-water-quality-2020-2021

Monigatti, P. (2017). *Smart charging strategies for electric vehicles utilising non-dispatchable renewable electricity generation* (Doctoral dissertation). https://researchcommons.waikato.ac.nz/handle/10289/11441

Moser, S., & Ekstrom, J. (2010). A framework to diagnose barriers to climate change adaptation. *Proceedings of the National Academy of Sciences of the United States of America*, *107*, 22026–31. https://doi.org/10.1073/pnas.1007887107

MoT. (2023). Decarbonising transport action plan. https://www.transport.govt.nz/assets/Uploads/Decarbonising-Transport-Action-Plan-Cabinet-paper.pdf

Naval, N., & Yusta, J. M. (2021). Virtual power plant models and electricity markets - a review. *Renewable and Sustainable Energy Reviews*, *149*, 111393–111393. https://doi.org/https://doi.org/10.1016/j.rser.2021.111393

NIWA. (2007). Mean monthly sunshine (hours). *NIWA.* https://niwa.co.nz/education-and-training/schools/resources/climate/sunshine

Nykvist, B., & Olsson, O. (2021). The feasibility of heavy battery electric trucks. *Joule*, *5*, 901–913. https://doi.org/10.1016/j.joule.2021.03.007

NZGIF. (2023). Budget 2023: Green investment bank receives $300 million capital injection. *NZGIF*. https://nzgif.co.nz/news-and-events/budget-2023-green-investment-bank-receives-300-million-capital-injection/

PowerNet. (2020). Rowallan microgrid. *Powernet.co.nz*. https://powernet.co.nz/future-energy/microgrids/rowallan-microgrid/

Provincial Growth Fund. (2020). Renovation of marae expression of interest. https://www.mbie.govt.nz/dmsdocument/16211-te-hiiri-marae-te-reureu-cluster-expression-of-interest-pdf

Purdie, J., & Telfar, G. (2019). Balancing the energy trilemma -modelling the nz electricity system out to 2050. https://www.otago.ac.nz/oerc/symposia/archives/otago735078.pdf

Radio New Zealand. (2015). Power surge as fans wake early for rugby world cup final. *RNZ*. https://www.rnz.co.nz/news/bites/288609/power-surge-as-fans-wake-early-for-rugby-world-cup-final

Sense Solar. (2023). Solar sense. *Solar Sense*. https://www.solarsense.co.nz/

solarZero. (2022). Solarzero enables world-first trade in the nz electricity reserves market. *solarcity NZ*. https://www.solarcity.co.nz/blog/solarzero-enables-world-first-trade-in-the-nz-electricity-reserves-market

Stats NZ. (2023). *Statistical standard for geographic areas 2023*. https://www.stats.govt.nz/methods/statistical-standard-for-geographic-areas-2023/

Stichbury, G. (2018). New zealand atlas of population change — urban areas. *Waikato.ac.nz*. https://socialatlas.waikato.ac.nz/info/i-urban.html#:~:text=Rural%5C%20centres%5C%20are%5C%20(were)%5C%20defined,rural%5C%20areas%5C%20(district%5C%20territory).

Su, D., McDonagh, A., Qiao, S.-Z., & Wang, G. (2016). High-capacity aqueous potassium-ion batteries for large-scale energy storage. *Advanced Materials*, *29*, 1604007. https://doi.org/10.1002/adma.201604007

Synop. (2023). Synop. *Synop.ai*. https://www.synop.ai/

Tehranian, R. (2016). A brief history of north american power grid - raphael tehranian - medium. *Medium*. https://raphael-tehranian.medium.com/a-brief-history-of-north-american-power-grid-e87baac617b7

Transpower. (2022a). Ug-oc-841 nzgb - application and calculation user guide. https://customerportal.transpower.co.nz/assets/nzgb/UG-OC-841_NZGB_Application_and_Calculation_User_Guide.pdf

Transpower. (2022b). Whakamana i te mauri hiko – empowering our energy future. *Our strategy - Transpower*. https://tpow-corp-production.s3.ap-southeast-2.amazonaws.com/public/publications/resources/TP%5C%20Whakamana%5C%20i%5C%20Te%5C%20Mauri%5C%20Hiko.pdf?VersionId=FljQmfxCk6MZ9mIvpNws63xFEBXwhX7f

Transpower. (2023). Consolidated live data. *Transpower*. https://www.transpower.co.nz/system-operator/live-system-and-market-data/consolidated-live-data

Turker, H., & Bacha, S. (2018). Optimal minimization of plug-in electric vehicle charging cost with vehicle-to-home and vehicle-to-grid concepts. *IEEE Transactions on Vehicular Technology*, *67*, 10281–10292. https://doi.org/10.1109/tvt.2018.2867428

U.S. Energy Information Administration. (2021). International energy outlook 2021. *U.S. Energy Information Administration*. https://www.eia.gov/outlooks/ieo/pdf/IEO2021_Narrative.pdf

Vector. (2023). Connect your distributed power generation (solar, wind, vehicle-to-grid). *Vector*. https://www.vector.co.nz/personal/electricity/distributed-generation

Wade, H. (2023). Evs being used to power homes following cyclone. *NZ Autocar*. https://www.autocar.co.nz/evs-being-used-to-power-homes-following-cyclone/

Werber, M., Fischer, M., & Schwartz, P. J. (2009). Batteries: Lower cost than gasoline? *Energy Policy*, *37*, 2465–2468. https://doi.org/10.1016/j.enpol.2009.02.045

Wolfe, F. (2023). Better options for intermittent forecasting needed – ea. *Energy News*. https://www.energynews.co.nz/news/wind-energy/140709/better-options-intermittent-forecasting-needed-ea?utm_source=newsletter%5C&utm_medium=email%5C&utm_campaign=energy-news-newsletter

Worthmann, K., Kellett, C., Grüne, L., & Weller, S. R. (2014). *Distributed control of residential energy systems using a market maker* (Vol. 19). https://www.researchgate.net/publication/261367369_Distributed_Control_of_Residential_Energy_Systems_Using_a_Market_Maker