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Taking the Power Back: Designing a Replicable Neighborhood Grid

Anavat Siamwala
Worcester Polytechnic Institute

Deanna M. Rice
Worcester Polytechnic Institute

Rishi Gupta
Worcester Polytechnic Institute

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Abstract

Transitioning to alternative energy can help the environment and lower energy bills, but the process can be complicated, and the up-front costs can be high for individual homeowners. In collaboration with the Australian Energy Foundation, our team worked with residents of Halpin Street in Brunswick West, VIC, investigating the path they might take and the options they might consider in setting up a neighborhood microgrid. Through the literature review, interviews with local companies and residents, and solar mapping software, we identified the best options for energy generation, storage, monitoring systems, and AC/DC inverters, sharing our recommendations with residents and outlining our process so other neighborhoods might work together to pursue this path.

Team Members

Rishi Gupta

Deanna Rice

Anavat Siamwala

B term

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Advisors

Professor Lorraine Higgins

Professor Lindsay Davis

Sponsor

Australian Energy Foundation

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Transitioning to Renewable Energy

Conventional energy sources, like oil, coal, and natural gas, have proven to damage the environment and human health because of the emissions produced, leaving society with a need to transition to non-fossil fuel energy technologies. While these "alternative energy" options have been sought after for the last two decades because of environmental, social, and financial incentives, the related technology is still slow to develop into an affordable alternative. Moreover, Richard York, a professor in the department of sociology and environmental studies at the University of Oregon, found that alternative energy sources such as solar, hydropower, and wind cannot currently replace fossil fuels given our current energy demand (2012). At the moment, alternative energy systems cannot completely replace the energy produced by fossil fuels until we commit to the development of these alternatives (*ibid.;* Dincer, 1999) to reduce cost. While in the long run alternative energy is less expensive per kilowatt-hour (kWh), the initial purchase and installation typically cost $200-$2,700 higher than the installation of conventional natural gas (Wales, 2018). This leaves scientists, electrical companies, and consumers wondering whether alternative energy is affordable and sustainable in a climate of high demand.

Despite being a developed country with a high potential for solar generation, Australia has a high reliance on fossil fuel energy via coal, diesel, and natural gas (AEMO, 2019). From 2015 to 2019, wholesale electricity prices in Victoria rose steadily from 33 AUD to 166 AUD/MWh, the highest price on record (*ibid.*). At the same time, the installation cost of small-scale solar panels in Victoria is at an all-time low (Solaray, 2019), creating a strong financial incentive for home solar generation. As the cost is still prohibitive for many at the household level, the Victorian government has invested in the development of several microgrids, localized networks of electricity sources, loads, and storage devices, to reduce communities' reliance on fossil fuels. One strategy for reducing initial costs is to utilize a neighborhood setting and to pool the group's collective resources into a distributed generation and storage system known as a "microgrid." This project explored the potential and assisted with the planning of a neighborhood grid on Halpin Street, an approximately fifty-home community in a suburb of Melbourne, Victoria. The project was developed by the Australian Energy Foundation (AEF), a national organization dedicated to clean energy solutions after an organizer within the community engaged a group of residents interested in saving money and reducing their carbon footprint. There were attempts by Halpin Street residents to bring the concept of a microgrid to life; however, fluctuating government incentives had stymied the process. Whenever small-scale incentives are created, they are very quickly used up and discontinued, and the cost is clearly important to Halpin Street residents.

Therefore, our main focus centered on reducing the consumer cost of initial neighborhood grid installation. This was done by exploring the most affordable options while persuading the residents to collectively buy into the grid to aid in price reduction. In addition to researching the best options for Halpin Street, our main deliverables included materials and guides to help facilitate the implementation of a neighborhood grid. This guide is aimed at other Victorian residents who are interested in installing a neighborhood grid. By designing the initial stages and providing a clear path to implement a neighborhood gird on Halpin Street and documenting our research and design process with the community, we were able to create tools to educate others on community neighborhood grid planning. To achieve this goal we set three primary objectives:

1. Identify the options for and essential components of microgrids.
2. Assess the Halpin Street residents' knowledge about, interest in, and resources for working towards a neighborhood grid.
3. Create appropriate materials that will help neighborhoods implement alternative energy generation and monitoring systems- with specific recommendations for Halpin Street.

Switching to Renewable Energy

We have broken down the background into five significant sections to describe the process of understanding microgrids, their components, and how they can be implemented into neighborhoods to replace the current conventional energy system.

Replacing Conventional Energy

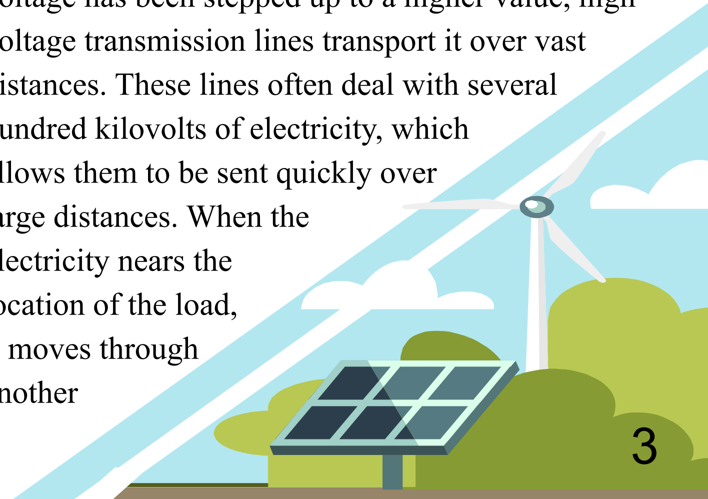
Renewable energy is energy created from resources that naturally replenish after use, including sunlight, wind, rain, moving water, and geothermal heat (Ciolkosz, 2009). Renewable energy systems are in demand because of their potential environmental, social, and financial benefits, but there are some barriers to making them sustainable. Henrik Lund, Professor of Energy Planning at Aalborg University, states that sustainable energy consists of three qualities: "energy savings on the demand side, efficiency improvements in the energy production, and replacement of fossil fuels by various sources of renewable energy" (2006).

Energy savings through renewables may be possible, but there are some barriers. The most inhibiting reason why people do not switch to renewable energy is the up-front cost of installing these components. Typical residential scale, non-fossil fuel alternatives cost between $200-$2,700 more than conventional sources of energy, such as coal and natural gas, for their installation (Wales, 2018). Instead of everyone owning personal solar panels, sharing solar panels between neighbors in a microgrid setting decreases the upfront cost. Additionally, some governments, such as in the United States and Australia, have stepped in to provide funding through grants and incentives for the installation of microgrids to mitigate the cost concerns.

Part of sustainability also includes how much energy is produced by renewables and how efficient they are to measure whether they can completely replace fossil fuels. York (2012) found that renewable energy sources such as solar, hydropower, and wind cannot currently replace fossil fuels at a one-to-one ratio; current energy production from renewables cannot meet consumer demand. He argues that "each new unit generated from green energy sources displace[s] less than one-tenth of a unit of fossil-fuel-generated energy" (York, 2012). However, when communities work together to generate energy from renewables and then store the excess energy produced for all to share, a sustainable solution can be found in the form of a neighborhood grid, as we will discuss below.

A Beginner's Guide to a Microgrid

The main electrical grids which power most of the world have existed for decades in their basic design. Steve Kaplan (2009), in a report to the Congressional Research Service, discussed the four main components of an electrical grid: power plants, substations, high voltage transmission lines, and distribution lines. Power plants generate electricity with a variety of methods to do so. The most common method uses a type of fuel to create kinetic energy and converting that energy into electricity with the use of magnets. Faraday's Law states that rotating magnets will generate reactionary electricity; most traditional generators use this concept. Fuels range from coal and natural gas to more renewable sources such as hydro. Other sources include nuclear reactors and renewable energy farms, including wind and solar power. Substations are crucial for converting electricity into a form that is easy for transportation over vast distances. They most often change the voltage from a low value from the generators to a high value for transmission through a transformer. There are usually several of these voltage stations before the electricity reaches the intended load. After the voltage has been stepped up to a higher value, high voltage transmission lines transport it over vast distances. These lines often deal with several hundred kilovolts of electricity, which allows them to be sent quickly over large distances. When the electricity nears the location of the load, it moves through another



substation to step down the voltage and then uses distribution lines to send the electricity to the final load, frequently to a building which will control the electricity further based on its specifications.The entire system, all four components mentioned above, is illustrated below (Figure 1). A microgrid takes this concept and shrinks it to encompass a handful of loads, often residential homes or a collection of buildings. Discussed below are the key benefits and characteristics of the microgrid.

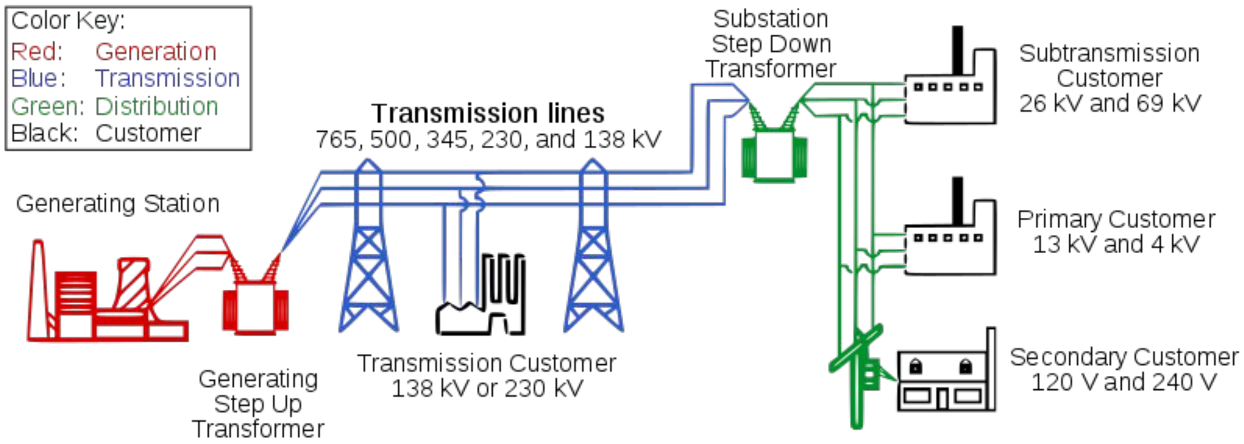


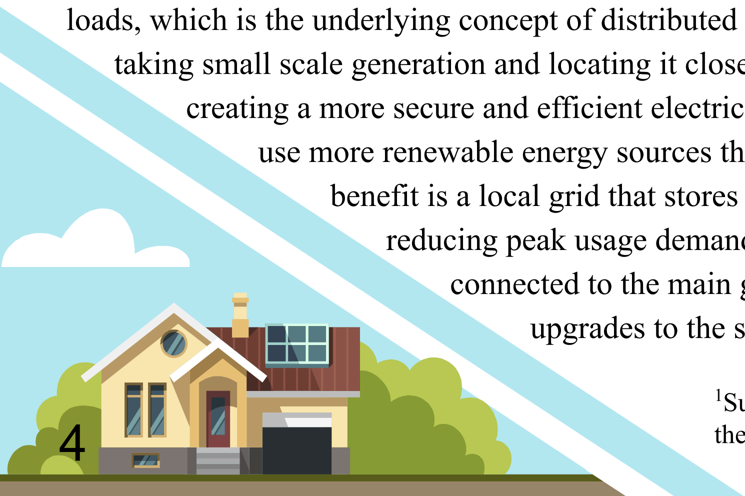
Figure 1: Overview of Main Electrical Grid (Department of Energy, 2003)

Microgrids

Microgrids are localized collections of energy generators, storage systems, loads, and monitoring systems. Microgrids often have generation and storage physically close to their loads, which is the underlying concept of distributed generation. Distributed generation is taking small scale generation and locating it close to the final user of that electricity, creating a more secure and efficient electricity system which also has the potential to use more renewable energy sources than a traditional grid. An additional benefit is a local grid that stores and releases energy locally as needed, reducing peak usage demands, relieving load on local substations connected to the main grid, and offsetting potential expensive upgrades to the substation. These benefits are done by storing excess energy during times of low demand and then using the energy in times of higher demand. Finally, microgrids are also good candidates for combined heating and power (see Supplemental Material A).[1] Only recently have microgrids had practical applications, such as being used in neighborhoods where connections to the main electrical grid are usually tenuous, making the neighborhood able to operate entirely on its own in an "island mode" (Hirsch, Paraga, Guerrerob, 2018).

AC and DC Sources

A significant consideration in microgrids is whether the system should run on DC or AC power. A notable characteristic is that most main electrical grids are AC based, which makes it a compelling choice if the microgrid is meant to have a connection to the main grid. However, DC is appealing because many common renewable energy sources, such as photovoltaics, use DC power, making their integration into a microgrid much smoother. A DC grid is also much more appropriate for the size of most microgrids enabling much more efficient power transfer while also being safer (Hossain et al., 2014). A neighborhood grid will most likely run on AC, meaning that inverters will be needed to convert between the generation sources. An inverter is a vital piece of a microgrid that converts this DC source to AC to power home appliances since they require AC. Further comparisons between AC and DC sources can be found in SM-B.



[1]Supplemental Materials ("SM") for this project may be found at wp.wpi.edu/melbourne/projects/, using the search bar to locate the project report materials.

Generation Sources

The first microgrid component is power generation. Renewable and nonrenewable sources are used to generate energy in microgrids, but we focus on renewable sources for Halpin Street. The energy sources we researched include solar panels, small wind turbines, hydrogen fuel cells, and internal combustion engines. Please see SM-C for a component matrix which details these technologies. From this matrix, solar panels are an optimal choice for a neighborhood grid due to being a relatively inexpensive and environmentally-friendly choice. Even though they have inconsistent power generation, a storage system can be put in place to alleviate the inconsistency.

Storage Sources

The second component is the storage system. The microgrid should store excess energy when there is low demand, and then release it when there is a higher demand. However, storage systems also play an important role in helping a microgrid address any voltage drops or sags, and to ensure that the microgrid will not experience a blackout or similar condition. It essentially acts as a buffer between the main electrical grid, generators, and the loads that draw power (Hossain et al., 2014). SM-D lists several different energy storage options that have been researched and implemented in microgrids. Among the various methods of storage, Li-ion batteries are the most technologically advanced and widely available options, making them ideal for a neighborhood grid.

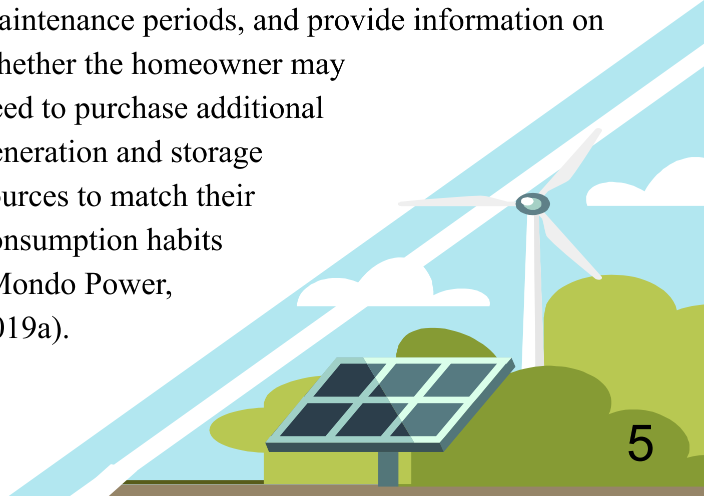
Loads

The third component of a microgrid is the load, entities that draw on the power and use it for their specific needs. Loads can be classified on many levels, but are often residential and commercial buildings themselves. A great variety of applications also exist that are usually within these buildings, and can also be called loads. The loads on Halpin street are residential homes (Mariam, Basu, & Conlon, 2016).

Energy Monitoring Systems

The final component of a microgrid is an energy monitoring and management system. Integrating generation and storage sources is necessary to allow homeowners to share their electricity. In turn, homes require a "smart" metering system to monitor and regulate the flow of electricity. This system monitors the energy consumption and production of homes, provides detailed analytics on energy consumption and savings of homes in the neighborhood, and possibly allows for user input when trading surplus electricity between other households and the main grid (Greensync, 2016a). This section details the features of an energy monitoring system by describing Ubi, a system offered by Mondo Power, an energy and technology company focusing on renewable energy. Additionally, the section briefly describes other variants of energy monitoring systems provided by other technology companies.

According to Mondo Power, Ubi can both monitor electricity throughout a microgrid and possibly allow for energy trading between neighbors through a cloud-based system (Mondo Power, 2019a). Ubi monitors the energy consumption of homes and the available electricity capacity in the respective storage and generation sources of the household. The Mondo Portal (Figure 2) displays all this information (McGowan, 2018), and is accessible through smart devices and laptops. The portal displays the homeowner's amount of surplus energy exportable to the neighborhood, the amount of energy being generated and consumed by the home, and the neighbors' energy usage relative to the home. In addition to Ubi's Portal, the system can directly send notifications and alerts to homeowners regarding high energy usage, recommend maintenance periods, and provide information on whether the homeowner may need to purchase additional generation and storage sources to match their consumption habits (Mondo Power, 2019a).



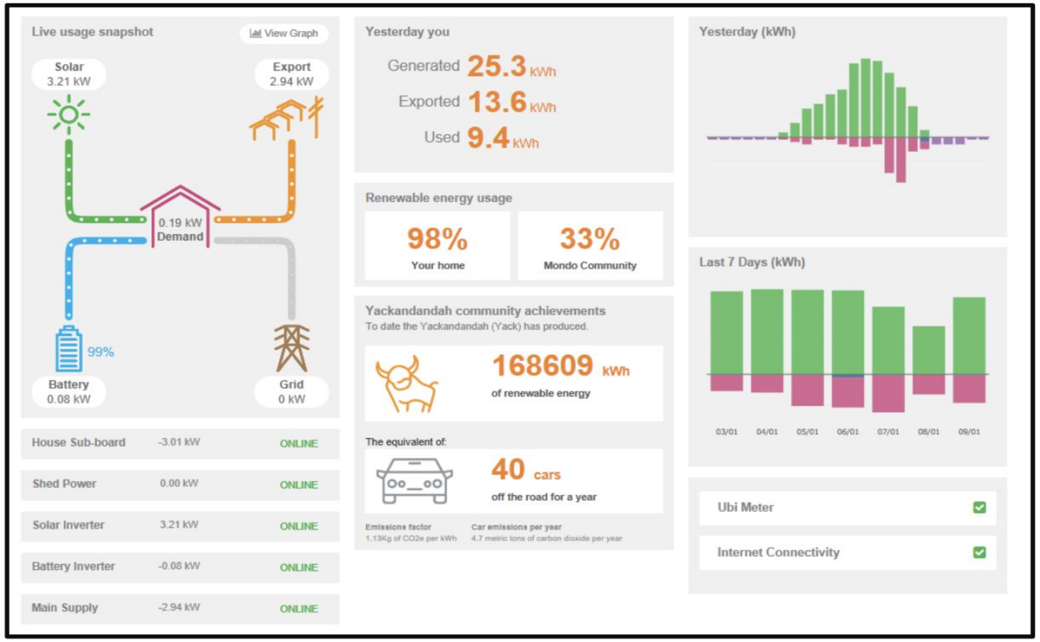


Figure 2: Ubi's Mondo Portal

The Ubi software is also able to control energy consumption and efficiency by directly controlling household appliances and facilitating the trading of surplus energy from generation or storage sources. Appliances such as water heaters and heat pumps can remotely be turned on or off using the Ubi portal to reduce energy consumption and maximize surplus energy for later use (*ibid.*). Ubi devices across all homes in the neighborhood are connected through WiFi to facilitate energy trading with different cost structures. Specific information on user energy trading and automatic energy trading, based on consumption, was not available on Ubi's website. We described the cost of the Ubi Software and included hardware components in an energy monitoring matrix (see SM-E) to further compare it with other systems.

The Ubi energy monitoring system can control energy trading across a neighborhood grid; however, it does not support remote trading between homes not directly connected through the neighborhood grid. Powerledger, another renewable energy technology company, does offer a system called xGrid that allows for remote energy trading. With neighborhoods directly coordinating with their local energy retailer, xGrid offers the capability for each home to trade and sell energy with other homes directly through the main grid (Powerledger, 2019). Homeowners can view detailed billing and transaction records through an online portal and electricity retailer. The main advantage of this system is that it does not require homes to be connected to a neighborhood powerline grid separate from the main grid, which would reduce installation costs and infrastructure in installing the powerline grid. However, compared to traditional residential neighborhood grid monitoring systems, less information is available on how Powerledger controls the pricing of electricity based on demand and how this pricing structure will apply to a neighborhood. Additionally, information on installation costs of the system is not available and it will be obtained through interviews with Powerledger.

The Ubi software can monitor and control energy data for individual homes; however, no information on whether it applies to a central storage source in a microgrid is provided. ABB's Microgrid Plus Software can monitor and control transactions through a central battery storage system called Powerstore. The Microgrid Plus system can automatically control the operating hours of the generation sources, and integrate all generation sources into a controllable network by the user. Unlike Ubi, the Microgrid Plus system is reported to be compatible with several different generation sources that include: wind power, solar cells, and diesel generators (ABB 2019). Additionally, the energy stored in the Powerstore battery system can be monitored through WiFi and sent to areas consuming the most energy within the microgrid (*ibid.*). ABB's system is beneficial because of its automation capabilities, but the incorporation of the system remains focused on single industrial or rural estates. Currently, little information is available on the capabilities of the Microgrid Plus system in controlling energy transactions between homes on a residential neighborhood grid.

Another energy monitoring system, similar to Ubi, with the potential ability to trade and monitor energy consumption, is MicroEM offered by Greensync. The system's features and specific interactions with the generation, storage, and other technical components of microgrids will be further detailed in the Microgrid Pilots section of this chapter. The MicroEM software was discovered to be no longer offered by Greensync. However, the components are still detailed to establish a basic understanding of the features of energy monitoring systems similar to it. Other energy monitoring systems are compiled and evaluated under different categories in the background research based energy monitoring systems matrix (see SM-E).

All the components explained in this and prior sections were carefully considered and evaluated to connect them together effectively (Figure 3). The next section explains two real-world examples of microgrid pilot projects and how the components interact to create a functioning microgrid.

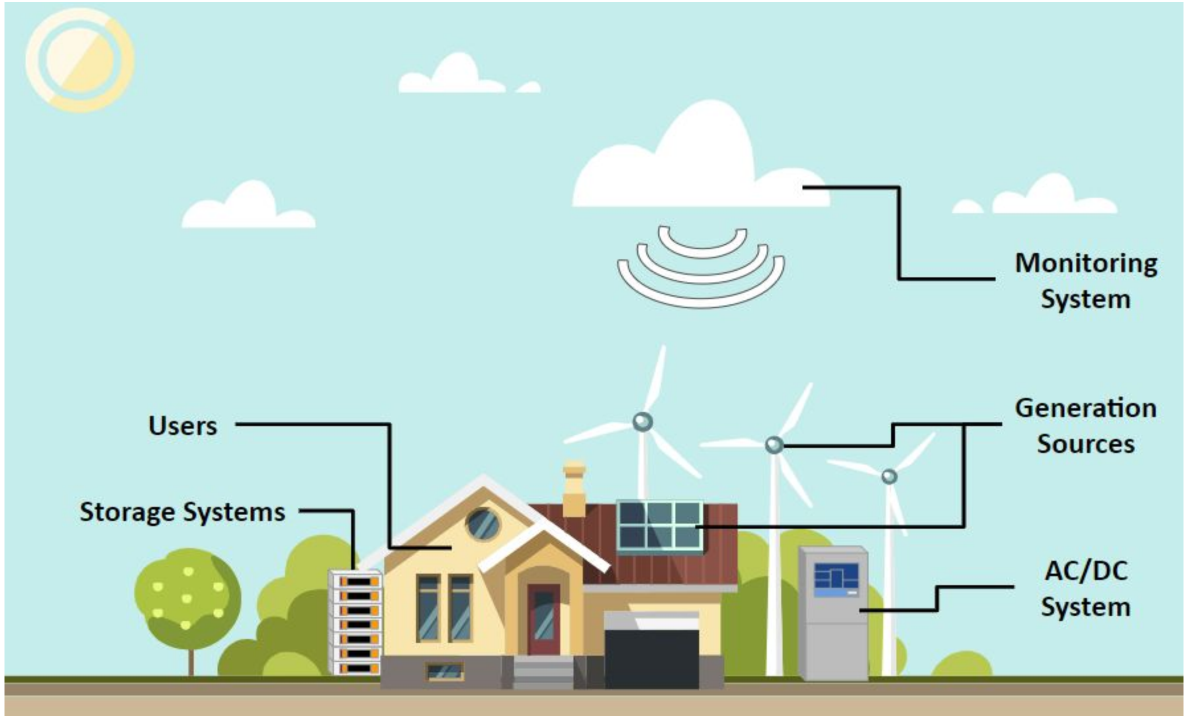


Figure 3: Microgrid with Individual Components

Microgrid Pilots

Examples of microgrids were an essential source of information for identifying applicable microgrid models for the Halpin Street neighborhood. This section will describe the financial and technical aspects of two microgrid pilots: the Yackandandah and Mooroolbark microgrids. The breakdown of the Mooroolbark microgrid will cover technical components and their use of an energy monitoring system from their successful microgrid trials. Discussion of the Yackandandah microgrid will primarily focus on the governing financial model being used for the grid and how that might apply to Halpin Street.

Mooroolbark Microgrid

The Mooroolbark microgrid, located in a suburb of Melbourne, was launched on April 19, 2016, and led primarily by AusNet Services, the electricity network responsible for distributing electricity to the Mooroolbark area, and Greensync, a global energy technology company (Greensync, 2016a).

Ausnet Services equipped 14 homes with solar panels from SunEd (label E in Figure 4) and 10 kWh LG lithium-ion batteries (label C in Figure 4) each, which, when fully charged, were able to support a day's worth of moderate power consumption (Harding, 2017). Additionally, AusNet Services installed a "mini-grid" line branching off from the main grid to connect the houses as a microgrid. The solar panels are producing DC, which then needs to be converted to AC to power household appliances. Due to this, solar inverters made by Fronius, an Australian Energy technology company, were installed in every home to convert the DC to AC for home appliances (label A in Figure 4).

As part of microgrid trials, the battery holding cabinet for each home was equipped with several other control, communication, and safety devices. One of them is a Selectronics inverter (Label D in Figure 4) that converts DC to AC for the battery to allow the home to run on electricity while disconnected from the neighborhood known as an off-grid mode. Additionally, it provides AC to other homes in the neighborhood grid and the main grid. The Selectronic inverter also has the ability to automatically switch homes to an off-grid mode in case of a power outage.

Secondly, the cabinet holds Greensync's Peak Response Unit (label B in Figure 4), which is a hardware device. This device monitors energy consumption, controls energy flow between neighbors, and optimizes solar generation depending on individual usage during peak energy demand times or national grid outages (Greensync, 2016b). Additionally, it is connected to Greensync's MicroEM software that allows the user to provide input for energy storage and generation, and specify amounts of energy to be transacted to neighbors (*ibid.*). This software allows the user to send respective alerts for various situations: such as when energy consumption reaches a maximum set amount or when future weather conditions can affect output from panels.

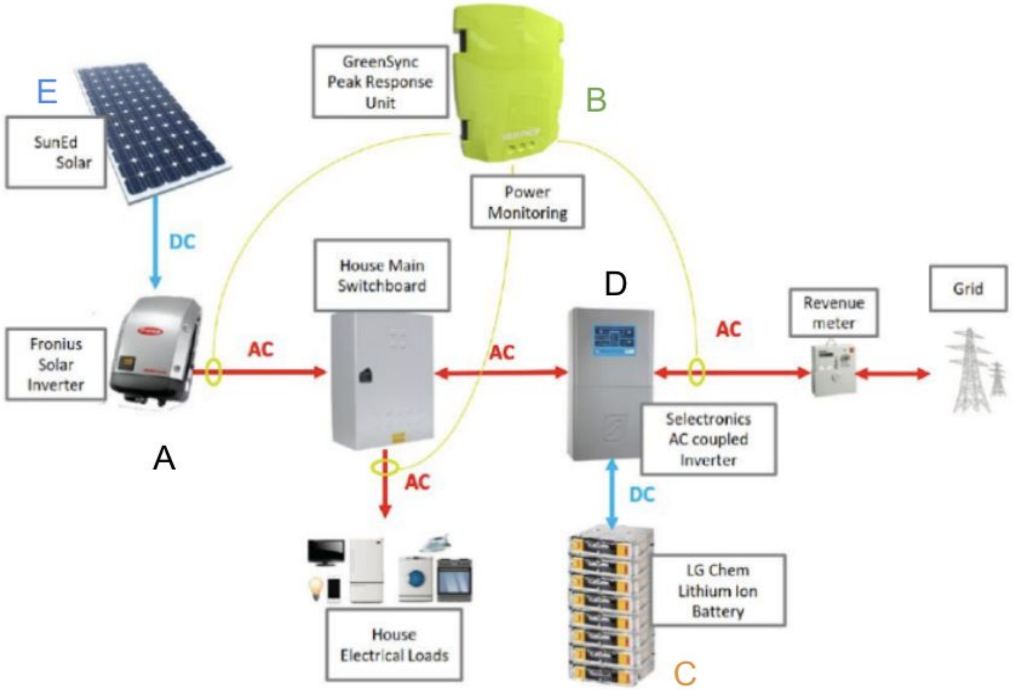


Figure 4: Components Installed in a Mooroolbark Home (Harding, 2017, p.20)

Third, the battery holder also contains a communication module that allows remote operation of the system and importantly connects the MicroEM and the Peak Response Unit of a home to all other homes within the neighborhood (Harding, 2017) through the use of a 3G or 4G communications network (*ibid.*).

With all the components maintained and installed, the neighborhood was successfully able to disconnect itself from the main grid for almost 22 hours during March 2018 as part of its third trial run. Interestingly, 18 homes participated in the trial, and four of these homes did not have solar panels or battery cabinets. Yet, by connecting with the solar inverters of homes with solar panels, they were still able to disconnect from the national grid (Ausnet Services, 2019). Inverter connections, such as in the Mooroolbark grid, allows for homes unable to install solar or battery systems to be part of the neighborhood grid on Halpin Street still.

The plan was to have the microgrid disconnected from the grid for 24 hours. However, a resident came back home from work and switched on their air conditioning unit, which consumed slightly more energy than what was being generated, according to Alistair Parker, director of regulation and network strategy at Ausnet services (Vorrath, 2018). This mishap prompted the neighborhood grid to reconnect itself back to the grid and end the trial. The trial indicates a required amount of involvement from the residents to occasionally check for notifications or alerts from their energy monitoring system and to establish proper means of communication between one another. Even without the goal of disconnecting from the main grid and achieving "island" mode, residents on Halpin Street must still carefully monitor their energy consumption to prevent purchasing too much electricity from the main grid.

Yackandandah Microgrid

The Yackandandah microgrid is located in a suburban setting similar to Halpin Street. Yackandandah is a small town located in Northeast Victoria, Australia. The whole town, with a total population of 950 residents, is planning to run on 100% renewable energy by the year 2022 and is an example of a microgrid on a much larger scale than Halpin Street. Ausnet Services took the lead on this project while partnering with Mondo Power, which is an independent subsidiary of Ausnet Services and several other stakeholders such as the TRY (Total Renewable Yackandandah) organization (Maisch, 2018).

The process of converting the whole town of Yackandandah into a renewable energy microgrid was divided into five major phases (Figure 5), which can be potentially adopted by Halpin Street on a smaller scale (Harding, 2017). The first phase, completed in 2017, involved equipping all homes with solar panels to minimize dependency on the main grid and

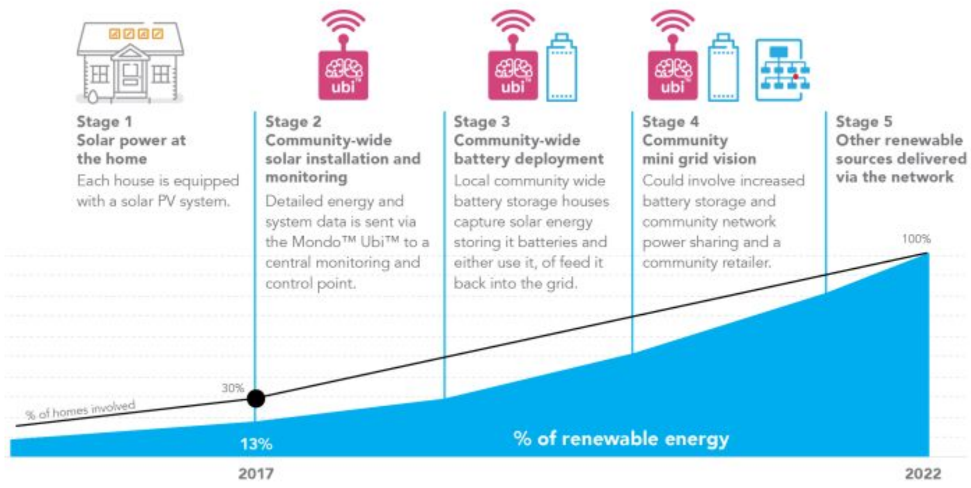


Figure 5: Yackandandah Microgrid Development Phases

allowing for the community microgrid to have the potential to detach from the main grid. Currently, there are 106 homes with an average of about 5 kW of solar capacity per household, which totals to 550 kW of total available capacity (Mondo Power, 2019b). The ongoing second phase involves the installation of Mondo Power's Ubi energy monitoring system for all homes. The third phase, also ongoing, consists of the installation of lithium-ion batteries in all homes, and about 14 homes have batteries currently installed, which totals to 110 kWh of storage capacity in the community (McGowan, 2018). The fourth phase involves potentially increasing battery storage as seen fit from trial runs and implementing a community retailer, who helps in setting trading tariffs within the neighborhood and coordinates energy transactions to the main grid (see SM-F for additional information on community retailers). Finally, the fifth phase plans to install and test out other renewable sources to achieve Yackandandah's 100% renewable energy goal. Dividing Halpin Street's neighborhood grid component installations into similar phases would greatly aid in organizing Halpin Street's development.

Homes can either buy the system outright or pay in monthly installations over the course of five years, depending on the capacity of the system (Figure 6). Additionally, the unsubsidized total cost of the system, which includes Ubi, 6kW solar panels and 10 kWh batteries, is 30,823 AUD per household with an estimated payback of 17.1 years (ISF, 2019). With a subsidized installation, cost is 21,963 AUD with a payback of 12.2 years (*ibid.*). The total cost had been reduced by 8860 AUD from subsidies. This considerable reduction in costs highlights the economic importance of obtaining a grant or rebate scheme for installations of neighborhood grid components on Halpin Street.

Instead of paying upfront or through monthly installments for microgrid components like in the Yackandandah microgrid, an energy company could potentially pay upfront for installation and maintenance costs of solar and battery equipment. The retailer then owns the equipment, but electricity is generated and shared across the neighborhood grid. However, individuals have to pay the retailer for the amount of electricity that is being generated by their solar panels (Mcgowan, 2018). One such electricity technology company that offers this model is Ovida under its Power Purchasing Agreement (PPA). Under a PPA, Ovida is responsible for monitoring, maintaining, and servicing the system in addition to covering installation costs. The main issue models like this have is that homes do not own their solar panels and may have to pay for both the electricity bills from the main grid and the solar panels. Ovida claims that the electricity costs from the solar panels at peak times can be 66% lower (Energy Stuff, 2019) than the electricity cost rate from the main grid. This cost rate is an important factor that residents of Yackandandah commented upon through surveys and meetings. A few homes believed this model would be feasible if the cost rate of electricity generation from solar

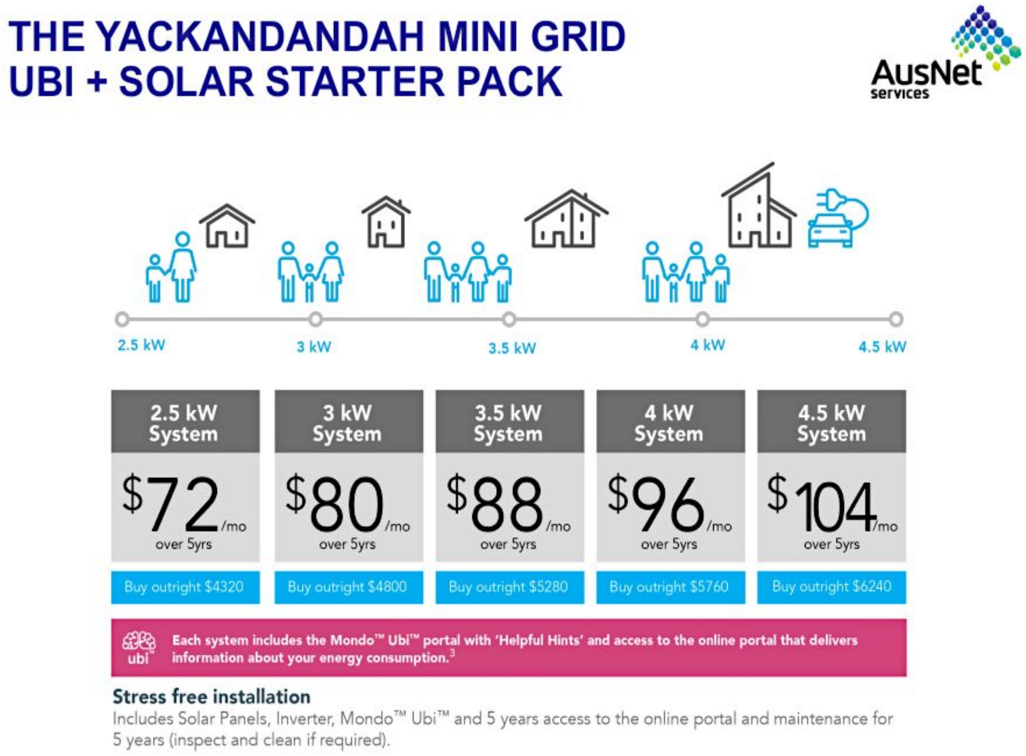


Figure 6: Subsidized Ubi Software and Solar Panel Costs for the Yackandandah Microgrid (Harding, 2017, p.33)

panels is lower than the electricity rate from the main grid (McGowan, 2018). Additionally, PPA providers like Ovida can act as an external regulator that helps manage energy generation and consumption by alerting individual households on their energy use. By helping regulate, it ensures that the neighborhood does not purchase too much electricity from the main grid and would importantly reduce the amount of time the residents spend managing the collective energy usage of the neighborhood. Extending the PPA to include energy monitoring systems could remove upfront installation costs of microgrid components for participating homes, and may make the retailer model a possible option to consider when installing neighborhood grid components on Halpin Street.

Halpin Street Neighborhood Grid Project

From the previous microgrid trials, we can apply parts of their successes into the Halpin Street Neighborhood Grid project. Halpin Street is a forty three-home community in a suburb of Melbourne, Victoria. Roughly 80% of its homes are owner-occupied while the remaining are rentals. Families predominantly occupy these homes. The entire street also falls under a heritage overlay, which creates some issues in the placement of solar panels. Heritage overlay is a zoning law to protect buildings of heritage value. It requires the homeowner to file a planning permit when making any modifications that are visible from a street or a park (Moreland City Council, n.d.). Residents on the south side of the street cannot install solar panels on their north-facing roofs without filing for a planning permit because they would be visible from the road. These residents would need to pay a fee when completing the planning permit to place solar panels on the north face of their roofs, which has led to some push back in installing the panels. The AEF has a program called Positive Charge; if residents install their panels through this program, the planning permit fee can be refunded. Selected solar suppliers are part of this program, and residents can call the program and request a quote from affiliated solar suppliers (EnergyMatters, n.d.a). Many of the homes also have a Spanish style roof with ceramic tiles, which can potentially add complication in installing the solar panels when made of clay. Clay tiles are brittle and can easily break; however, concrete tiles will allow for a much easier installation. The homes are all single story; most of the roofs have a shallow angle and vary significantly in size and shape.

Based on the Nearmap image of Halpin Street (Figure 7), eight homes have installed solar panels, and according to Rob Catchlove, the main resident of contact that proposed the project, none of the homes have batteries installed except for his. Catchlove has 20 panels that total about 6 kW in capacity coupled with a smart inverter from a company called Solaredge. Additionally, he has a 7 kWh battery from LG chem. Initially in 2016, Catchlove projected a final solar panel capacity of 100 kW for Halpin Street based on a rough estimate of home electricity usage. However, upon initial discussions with Catchlove, we determined that this estimation will be developed by mapping Halpin Street's total capacity to house solar panels.

Figure 7: Homes on Halpin Street (Red dots mark homes with solar installed)

To further analyze the energy consumption habits of residents, a system called PowerShare was used to simulate a microgrid for homes on Halpin Street from December 2017 to May 2018. This system worked by metering net energy consumption of six participating homes and using virtual currency to simulate the act of selling energy to neighboring participating homes. The system also included a small electronic display in each home that presented tips, warnings, and insights based on the home's energy usage (Australian Energy Foundation, n.d.). This data was gathered by researchers from the University of Melbourne but is not available to the public.

After Rob Catchlove brought this project to the AEF in 2016, a proposal was sent to the local electricity distributor, Citipower. They pitched the creation of a Halpin neighborhood grid as a way to help Citipower defer a substation capacity upgrade projected to cost $22 million. The AEF originally planned to form a funding and project plan for Halpin's neighborhood grid with Citipower. However, a lack of rebates and grants for the installation of solar panels and batteries caused Citipower to abandon the project. Halpin Street is currently ineligible to receive rebates for installation of batteries, as Brunswick West's postal area code is not included in the Victorian government solar battery rebate scheme. To be an eligible suburb, the area must be a high growth suburb and have high PV penetration or a large amount of installed solar panels (Solar Victoria, 2019a). On the other hand, solar panel rebate schemes are available for homes on Halpin Street and can cut solar costs by $2225 (Solar Victoria, 2019b). To be eligible for these rebates, homes must be valued under 3 million AUD, can not have an existing solar PV system, have a combined taxable income of less than $180,000, and residents must be the owner-occupier of the property (Solar Victoria, 2019b). However, residents have not had the time to apply for rebates, and some are unaware of the availability of them.

Halpin Street initially applied for two grants: the Climate Change Innovation Grant in 2017 and the Community Energy Project Grant from the Bank of Australia in early 2019. Both applications were rejected, and no other grant applications have been submitted. Although many residents of Halpin Street were initially supportive of the project, the absence of a grant to subsidize costs halted progress and caused interest to fall off. Since then, Rob Catchlove has reached out to the Australian Energy Foundation to gain some assistance in the development of this project.

The Australian Energy Foundation and its Goal for a Zero-Carbon Australia

In 2000, the Moreland City Council established the Moreland Energy Foundation Limited (now known as the Australian Energy Foundation), an independent non-profit organization meant to assist local businesses and communities with low-emission and clean energy solutions. Through partnerships with government agencies and private energy suppliers, it supports communities by testing new and innovative energy solutions, advising people and communities in their transition to clean energy, and delivering solutions such as solar panels and draft-proofing to homes and businesses (Australian Energy Foundation, 2019).

The AEF's strategy of bringing together partners in the public and private sectors has seen significant success. They have partnered with Ovida, an Australian energy services company, for its Community Energy Hub Project (*ibid.*). This project, which is currently ongoing, received $980,000 of funding from the Victorian Labor Government's Microgrid Demonstration Initiative. The AEF led the community engagement aspect of the project, acting as an intermediary between the community and the companies who install microgrid components to ensure the needs of the customers are met (*ibid.*).

Australian Energy Foundation

As the AEF has grown, its priorities and purpose have changed. They currently describe their strategic goals in three parts:

1. We create, demonstrate and share clear transition pathways to a zero-carbon society.
2. We increase energy efficiency and investment in renewable energy in Australia.
3. We are a sustainable organization.

Our project in Brunswick West directly aligns with the AEF's goals of creating pathways toward efficient renewable energy in Australia. By trialing a neighborhood grid in a small community with engaged residents, the AEF hopes to demonstrate a renewable energy solution that can be implemented across Australia.

Moreland's Energy Plans

The municipality of Moreland is located in the inner north part of Melbourne, VIC, Australia, and encompasses four suburbs. Moreland is approximately 50 square kilometers and is "one of Melbourne's most populous municipalities with more than 160,000 people" (Moreland City Council, 2019a). One of the suburbs includes Brunswick West, where we will be working with the neighbors of Halpin Street.

The Moreland City Council has been proactively working towards a carbon-neutral community since 2007, but the Council recently created a new strategic plan. In 2017 and 2018, the Moreland City Council partnered with the Moreland Energy Foundation Limited (now known as the Australian Energy Foundation) to develop the *Moreland Zero Carbon-2040 Framework*. The overarching goal of this project is to be "a 'zero carbon' community by 2040" (Moreland City Council, 2019b).

One of its main targets is energy transition - ultimately, the goal is to have the city function efficiently from 100% renewably powered energy. Specifically, the Council plans to increase solar power capacity from 22MW to 44MW and aims to set 80% of the city council's electricity generation to be from renewable energy sources by 2030 through a partnership with the National Renewable Energy Target 'RET' (*ibid.*). The RET scheme is a two-part scale, large and small, meant to provide financial incentives to aid in the "establishment or expansion of renewable energy power stations" (Department of Environment and Energy, 2019). The small-scale renewable energy scheme applies to the development of Halpin Street's neighborhood grid because it will alleviate some of the upfront costs of implementation when the neighbors are ready to install their solar panels.

Additionally, Moreland City Council developed three interconnected goals for themselves at the state, local, and internal level. On the state and federal level, Moreland City Council is "advocating change" geared toward renewable energy (Moreland City Council, 2019b). At the local level, they are advocating for programs, financing incentives, and partnerships with other organizations to assist with the transition to renewable energy. As for the internal level, Moreland City Council is trying to reduce its carbon emissions (*ibid.*). These goals apply to Halpin Street because of the local incentives to engage the community in the renewable energy transition. This includes the financial renewable energy transition scheme as mentioned before and adjusting local regulations that impact the building of neighborhood grids; these will be discussed later under the Regulations section.

With the Moreland City Council interested in transitioning to renewable energy, as seen by its proactiveness and energy transition goal from their 2040 Framework, we believe our project with the Halpin Street neighborhood grid will be a beneficial addition to their efforts.

Regulations Applicable to the Halpin Street Neighborhood Grid

The process of establishing a neighborhood grid on Halpin Street would involve regulations at all levels of government. Though some of these regulations require compliance at the level of installation rather than design, they still had an impact on our planning process.

At the national level, the construction and installation of neighborhood grid infrastructure in the form of neighborhood power lines must comply with a body of codes and standards known collectively as the National Construction Codes or NCC (Australian Building Codes Board, 2019). These standards apply to our project mainly in the form of electrical safety standards, though electrical efficiency and other building standards will also apply (*ibid.*). However, certified builders and contractors would ensure that these requirements are met; they will have little direct effect on the neighborhood's design decisions.

Within Victoria, most electricity infrastructure is managed by private

companies (AEMO, 2019). As a result, state-level regulations for solar panels and other electrical components require the formation of contracts with private energy companies (Victoria DELWP, 2019). If homeowners wish to generate their electricity, they must work with these companies to install two-way metering and enter a feed-in tariff contract to sell surplus energy back to these companies (*ibid.*). Feed-in tariffs are a rate paid for excess electricity sent back to the main grid, and these rates vary for different states in Australia. The feed-in tariff rate varies from 9.9¢ to 29¢ per kWh depending on the electricity retailer (Energy Matters, n.d.b). The tariff rates can also be offered as a single fixed rate or a time-varying rate depending on the retailers, where the feed-in tariff rate during peak hours in the evening is set at 14.6¢ per kWh (Victoria State Government, 2019). Additionally, installing a battery storage system in Victoria will not affect feed-in tariff payments to the user. The Victorian government also requires safety compliance through a regulator called Energy Safe Victoria, which requires all contractors to be registered through them and file certificates of safety for all solar installations (Victoria DELWP, 2019).

The City of Moreland is responsible for enforcement of the National Construction Codes within the city, as well as zoning regulations (Moreland City Council, 2015). Halpin Street is designated as a residential zone with the Heritage overlay zoning restrictions, as explained in the Halpin Street Section (Victoria DELWP, 2019). The City of Moreland also has voluntary building codes that require higher levels of safety and efficiency than the National Construction Codes, intended to "future-proof" projects for future requirements (Moreland City Council, 2015).

Methodology

The goal of this project was to design a neighborhood grid on Halpin Street in Brunswick West, Victoria, Australia, with the capability to be replicable within other neighborhoods. To accomplish this goal, we set three main objectives to aid in the interest, understanding, feasibility, and implementation processes.

Objective 1- Identify the options for and essential components of microgrids

Comparative Analysis of Microgrids

Objective 2- Assess the Halpin Street residents' knowledge about, interest in, and resources for working towards a neighborhood grid

Solar Mapping and Capacity Calculations

Resident Interviews

Energy Management Systems Comparison

Objective 3- Create appropriate materials that will help neighborhoods implement alternative energy generation and monitoring systems- with specific recommendations for Halpin Street

Developing the Materials

Objective 1: Identify the options for and essential components of microgrids

The first step we needed to take to complete this objective was to understand the necessary components of a microgrid, which we did through a literature review. In addition to gathering general information on microgrid components, we reviewed published information on existing microgrid trials. We then used a set of matrices to conduct a comparative analysis of the generation, storage, and energy monitoring options used in the trials (see SM-C, SM-D, SM-E). The Result chapter of this document reports our findings.

The generation matrix was the most important of the three as generation sources must be compatible with storage and energy monitoring systems. We considered several forms of energy generation, including renewable and nonrenewable. Although we aimed to focus on renewable generation, many microgrids have nonrenewable generation sources because of some distinct advantages they have.

The first two matrices give a brief description, advantages, and disadvantages of the technology. The categories listed in our matrices were adapted from Diaz-Gonzalez (2012), Hirsh (2018), and Hossain (2014), and some of these sources also noted similar advantages and disadvantages. Our findings from the analysis were later used to help us determine the most feasible choices for generation and storage at Halpin Street. It was challenging to acquire quantitative data on prices, energy capacity, rates of generation, etc. The reason for this is because variations can arise from several different factors which include:

- the specific size of the microgrid
- surrounding geography
- existing main grid
- yearly weather patterns
- several other unique site-oriented factors

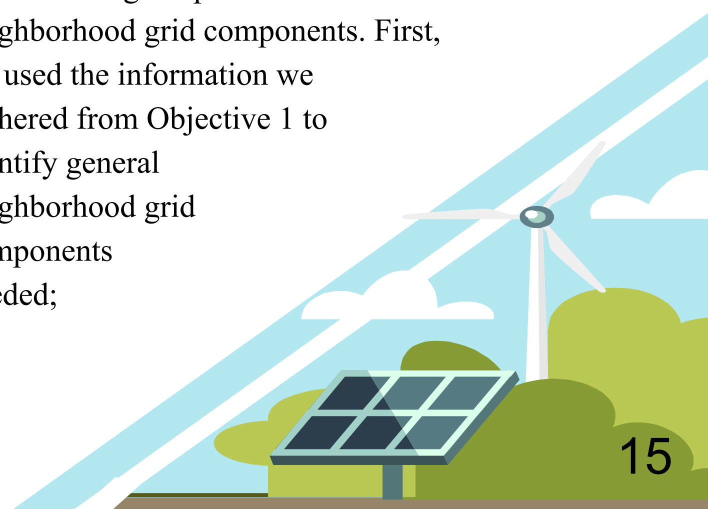
Additionally, costs vary due to fluctuating government subsidies and incentives, manufacturer price, and how the neighborhood organizes the microgrid.

Through literature review on company websites, we created a background research based energy monitoring system evaluation matrix (see SM-E). We collected information on installation and maintenance costs for software and hardware packages included with the systems. Once we arrived in Melbourne, we created a more detailed evaluation table (Table 8), further explained in Objective 2, and directly called company representatives to acquire additional information to fill it

Some of the questions we asked were whether each system could "Monitor energy?" and "Control and Allow for Energy Transactions?". We asked these questions because they were desirable features of an energy monitoring system we had found through the literature review. Additionally, we also noted whether each system was available as a package with other components such as solar panels, batteries, and inverters. It is essential to note the total package costs to determine the convenience of installation and the cost-effectiveness of the systems, as they will bring into consideration additional components that need to be integrated if the monitoring systems are considered to be installed as a package.

Objective 2: Assess the Halpin Street residents' knowledge about and interest in, and resources towards a neighborhood grid

We took a variety of approaches for understanding Halpin Street's resources for neighborhood grid components. First, we used the information we gathered from Objective 1 to identify general neighborhood grid components needed;



then, we obtained further specifics through interviews with local companies. As part of examining available resources, we also determined the solar capacity of homes given their roof size and other factors. Finally, we finalized the goals and interests of the community through resident interviews.

Solar Mapping and Capacity Calculations

To identify Halpin Street's potential for generation through solar, we used a digital mapping tool provided by the AEF called Nearmap. Nearmap allowed us to view satellite images of Halpin Street with a sufficient amount of resolution to make out obstructions on the roofs and the overall shape and orientation of the roofs. We took images from different times of the year and day to study the shaded regions of roofs, which would affect the efficiency of the solar panels. Most importantly, this tool allowed us to drag and drop solar panels with particular capacities onto images of individual roofs, Nearmap would calculate an estimate of what the solar capacity for that home is (Figure 8). Based on an estimation from Daniel Beaton, an AEF member, single-family homes around the size of those in Halpin Street consume about 40 kWh of energy per day on average and should aim to cover roughly 50% of their consumption to minimize energy exported from the main grid. Therefore, each Halpin Street home would need 20 kWh from solar to cover approximately 50% of the energy consumption; this results in 5.4 kW worth of solar panels. About eighteen 300W solar panels are required to get close to this amount. Solar panel installers also do not usually add panels to a house if they generate less than 2kW of power, meaning that the minimum ideal number of 300W panels would be at least seven, which we used as our minimum threshold value. Any homes unable to install seven solar panels could install batteries instead, and the size of the batteries would depend on their annual energy consumption. The recommended maximum number of solar panels to be installed was determined to be about 5kW or 20 solar panels. Inverters can only convert 5kW of power generated from solar panels, which is how we decided this evaluation; any extra energy generated is lost and cannot be recovered or shared.

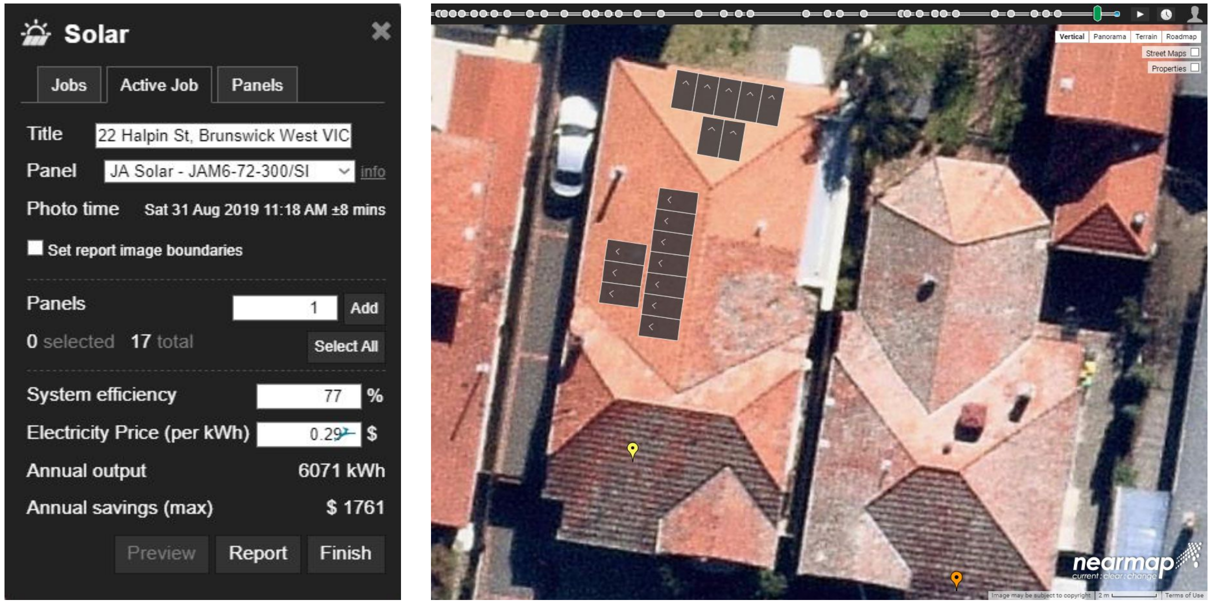


Figure 8: Nearmap Software Interface

We initially used this tool to estimate the maximum number of solar panels installable on each home and determine the potential for battery storage based on the household energy consumption estimates given by the AEF. We then refined the information to a layout for solar panels based on shading, panel size, roof shape, and inverter limitations. Shade was considered by looking at satellite images from different times of the day and seeing what areas on the roofs have shade. We did not place solar panels in the circular area where the shade could potentially appear year-round. Additional limitations to panel placement included panel size and roof shape.

String inverters, which are commonly used inverters, cannot support many arrays of consecutively connected panels, meaning that we had to balance the number of panels on different sides of the roof to not have more than two rows or array of panels per side. This data was shared with the residents and compared with their energy consumption amounts.

To effectively gather data, we have created a table with nine main categories for each home (Table 1). The categories were :

1. Panels on North Facing Roofs
2. Panels on West Facing Roofs
3. Panels on East Facing Roofs
4. Total Solar Capacity (kW)
5. Total Number of Panels
6. Annual Output (kWh)
7. Maximum Annual Savings (AUD)
8. Total Cost (AUD)
9. Payback Time (Years)

The total cost of solar panels was determined based on an estimate provided by the AEF that a kW costs about 1500 AUD. Based on this amount and the maximum annual savings, the minimum payback time can be determined. We summarized this information and the aerial satellite Nearmap image of their home with panels in a visual pamphlet for all homes on Halpin Street. Different efficiency values were used for panels on different sides of the roofs based on Australia's geographical location to calculate the annual output and savings.

North facing roofs are considered as the primary area to install solar panels since Australia is in the southern hemisphere, and receives higher and more consistent solar yield from the north. West-facing solar panels are considered second in priority after north-facing roofs since they result in higher return when the sun is setting. This period when the sun sets generally coincides with the time when electricity retailers charge homes peak usage rates as homes consume more electricity during the evening into the night. The east-facing solar panels are considered third in priority since they receive more sunlight during sunrise; however, electricity costs are not as high as the evenings. The south-facing roof is also not considered as it faces in the opposite direction from direct sunlight and receives the lowest solar yield throughout the day in Australia.

Values obtained for annual energy output and savings, as indicated in the black box (Figure 8), were later used to recommend the number of solar panels that residents can install. Additionally, the black box also contains sliders that allow the user to control the tilt angle of panels relative to the roof, the electricity price (per kWh), and the system efficiency. The tilt of the solar panels was always recommended to be set to 22.5 degrees by the AEF. According to Daniel Beaton, the electrical cost is based on the Victorian price set at 0.25 dollars per kWh. The system efficiency considers energy losses from shading and dust on the panels, battery conversion efficiency, manufacturer tolerances, etc. (Nearmap, n.d.). The AEF recommended that the solar panels be set to 100% for north-facing panels, and 80% for east and west-facing panels for maximum system efficiency. These three factors affect the annual energy output and savings determined for each home.

Resident Interviews

To familiarize ourselves with the interests of the residents of Halpin Street, we went to a Halloween gathering event on the street to informally introduce ourselves and the project description. We handed out pamphlets that succinctly explained the benefits and goals of our project, as well. Additionally, at a street-wide BBQ event, we conducted our semi-structured interviews with the residents in attendance. We also presented a sample Nearmap pamphlet for a home on the street to the residents.

The interview questions (Figure 9) provided us with information on technical features of homes with installed solar panels, the possible interest of all residents in participating in a neighborhood grid, and the annual energy consumption of residents. Before each interview, the respondent listened to our consent preamble (see SM-G) and project summary (see SM-H), then we required they gave their consent to the process.

The first part of our interview asked the residents about general information on their homes. Next, the interview asked those with already installed solar panels about their energy usage and the brand and costs of their inverters. Additionally, the interview asked whether the solar owners have an energy monitoring system, and if not, whether they were aware of the benefits of such a system or not. The final portion of the interview asked about the amount of energy being consumed annually by the residents and if they knew of potential savings by installing panels. This information allowed us to alter our initial map of homes with solar panels using Nearmap; we added or removed solar panels depending on their annual consumption amount. The responses also were used to segment the residents into different community interest categories, and we would provide them with links to specific pages on our how-to website, depending on that segmentation. The three community interest categories were:

- 'Interested in Participating and in learning about technical details'
- 'Interested to Participate but not in learning technical details'
- 'Not interested in participating and learning'

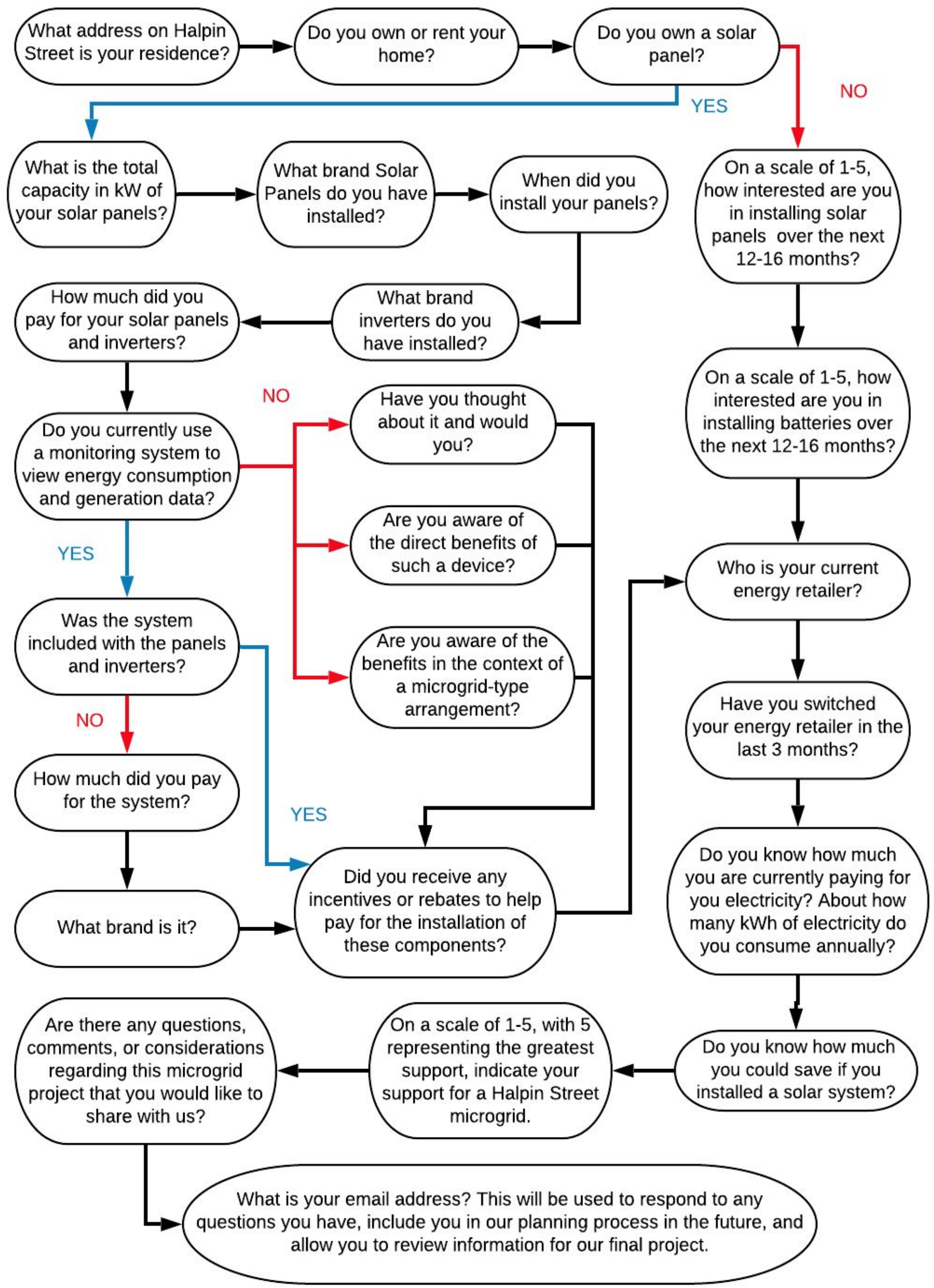


Figure 9: Resident Interview Questions Flowchart

Energy Monitoring Systems Comparison

Our sponsor and Rob Catchlove developed additional categories to supplement the comparative analysis of energy systems we had done in the prep term (see SM-E), and they provided us with other companies' software to observe once on site. The categories were:

- "Can it monitor production, consumption, and storage data for both batteries and panels?"
- "Does it require panel and batteries for installation? Any Non-compatible battery brands?"
- "Can you install a monitoring system for already installed solar or batteries?"
- "Can it control home appliances?"
- "What are the installation and subscription costs?"
- "Is data user-friendly/accessible?"
- "Ability to view fleet data?"
- "Any Hardware Packages required to be installed with the system?"

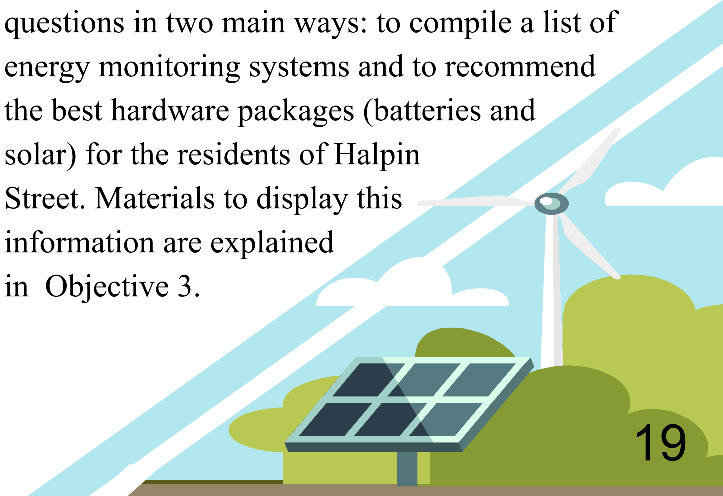
The ability for the system to trade was not considered as a category for this table because, according to our sponsor, it is currently not feasible to allow for home-based neighborhood trading based on Victorian regulations. He instead told us to focus on monitoring systems that can be installed to follow current regulations. Once regulations have been reduced and lifted, the possibility of trading will be more likely. Some energy monitoring systems only allow certain branded batteries with the installation of their monitoring system, and the systems may not be compatible with certain brands of batteries. The ability of the energy monitoring system to control home appliances was determined to be an essential factor by our sponsor since it can aid in reducing the energy consumption of the household to lower electricity load from the main grid. The "ability to view fleet data" allowed neighbors to monitor one another's energy usage collaboratively. Additionally, they could provide advice to households who needed to reduce their energy consumption more so. Finally, "Is data user-friendly/accessible?" was added to make sure users could conveniently check their energy data through an application or web portal on their smart devices.

Additional literature review through company websites was done to fill out some of the categories for the newly added monitoring systems. However, information regarding installation costs and hardware packages for these systems was not available online, so instead, it was filled out with help from the AEF from data they had based on past experiences with the systems. The company questions, explained below, for the newly added companies were sent out, and the companies were also directly contacted through the phone a few days after the questions were sent out. The completed table (Table 9) is in Results.

We contacted Australian energy companies (see SM-I) to acquire additional financial details on their energy monitoring systems and other hardware components (storage and generation types). Initially, we considered five companies: Ovida, Mondo Power, Greensync, and ABB. However, upon discussions with our sponsor and Rob Catchlove, we sent out questions to additional companies, which were Solar Analytics, SolarEdge, Reposit, Evergen, Simble, SwitchDin, and Edge Electrons. These companies focus on providing energy monitoring systems that can monitor energy usage and possibly turn home appliances on and off, depending on the homeowner's energy consumption.

For all companies, except for Ovida, the questions were based on missing or incomplete information for the categories in the background research based energy monitoring evaluation table (see SM-E). While for Ovida, the questions focused on the capital and installation costs of the solar system through a PPA (Power Purchasing Agreement).

We used the data obtained from the questions in two main ways: to compile a list of energy monitoring systems and to recommend the best hardware packages (batteries and solar) for the residents of Halpin Street. Materials to display this information are explained in Objective 3.



Objective 3: Create appropriate materials that will help neighborhoods implement alternative energy generation and management system - with specific recommendations for Halpin Street.

For our final deliverables, we used the research mentioned above to create three levels of information on neighborhood grid development. The first was a set of graphics outlining the four-step journey of creating a neighborhood grid from start to finish. These materials were elaborated further on a website for those who seek a better understanding of the technicalities and options available. The site is meant to be both broader and more in-depth in other areas to cater to a more general audience. The third deliverable was an event designed to deliver more customized options and analyses to residents of Halpin Street. The event included informative posters, a customized pamphlet for each homeowner, which included individual solar estimates, personalized information based on their interest, and energy saving tips and activities in which neighbors might assess their preferences for enacting particular options.

Developing the Materials

Because a large part of our final deliverables was to translate technical information into clear and persuasive materials for residents with different levels of interest, we first needed to understand some basics of how to deliver this complex information effectively. In guiding readers through the task, it helps first to analyze the task in detail and how people complete it. "Task analysis is the process of learning about ordinary users by observing them in action to understand in detail how they perform their tasks and achieve their intended goals" (Usability, 2019). The importance of developing this before the how-to material was to understand who the user is. Having a better understanding of the end-user allowed us to tailor the needed information within the documentation. Our user and task analysis for the residents of Halpin Street was based on the interest segmentation process, providing more information to those who wanted it. In *User and Task Analysis for Interface Design*, JoAnn Hackos and Janice Redish (1998) explain the reasoning of how a task analysis helps with understanding. For ourselves to have a better understanding of what the residents of Halpin Street need to know for the journey of neighborhood grid implementation, we needed to develop this user and task analysis to understand what the residents want and to put ourselves into their shoes.

Because some of our materials (the four steps of creating a neighborhood grid) fall into the "how-to guide" genre of writing, we reviewed the best practices used in that kind of writing. First, writers should break their procedures into numbered steps, using active voice and action-oriented tasks to aid the reader's ability to process the information. They can even provide workflow overviews - a graphic depicting a series of events in a sequential order to accomplish a more substantial, broader goal. Second, in explaining background concepts (for example, what a grid is), the writer needs to define its components.

In designing our website structure, we used an "Every Page Is Page One" style of writing. This concept stems from the idea that readers rarely start from the beginning and read through a how-to document (from start to finish) like a book, so writers need to present topics that function alone, without dependencies on a hierarchical structure (Baker, 2013). We used the writing conventions detailed in SM-J to draft each section of the website. We applied this to all our handouts because we will have residents with different levels of knowledge, starting from different stages within the process of neighborhood grid development.

Results

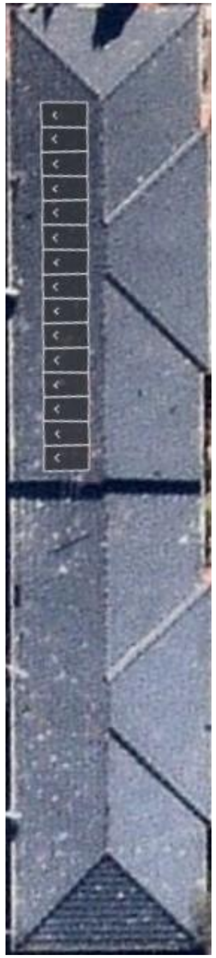
In this section, we report and highlight the key implications of our initial literature review on microgrid components, our solar mapping of the homes on Halpin Street, resident surveys, evaluation of different monitoring systems, and final deliverables.

Microgrid Components for Halpin Street

Our Background summarizes information from our literature review, which identified vital components of a microgrid. This information guided our decision on which components would be most useful for Halpin Street. The most accessible generation and storage systems appeared to be solar panels and batteries, respectively. Solar has shown a steady decline in price while remaining an excellent renewable energy generator for residents. Moreover, some residents had already implemented solar panels, providing initial evidence towards Halpin Street's interest in renewable energy. We also found there was already proof of solar panels and batteries successfully working together in a microgrid pilot in Mooroolbark, VIC. However, our literature review did not provide evidence for a clear decision on which monitoring system would be best for Halpin Street. Still, we learned more on-site about the options and their feasibility as we worked towards Objective 2, which we reported later in this chapter.

Solar Mapping and Capacity Calculations

Using Nearmap, a mapping software for solar panel placement, we were able to compile a table specifying for each roof on Halpin Street the solar panel capacity, their energy generation potential, cost, and minimum payback period (Table 1). This information varies depending on roof size, the orientation of the house, and other factors, and it suggests which homes may be optimal candidates for installing solar panels. Houses 10 and 11, for example (Figure 10), have the same solar capacity of 4.5 kW of panels and an installation cost of 6,750 AUD. House 10 will have a higher annual energy output and more savings along with a lower minimum payback time since some of the panels are north-facing. Based on criteria from Daniel Beaton and the AEF, we created a designation for whether the residents should install solar panels or not (Figure 11). If they were able to generate 5.4 kW or more, they were considered optimal for installing "Solar." If they were only able to generate 2 kW or less, then they were more suitable to install a "Battery." The homes that could generate between 2 kW-5.4 kW were segmented into the "Either" category because they have the potential for both solar and battery storage. Figure 11 reflects the designations of all 43 homes, including the nine who already have solar panels.



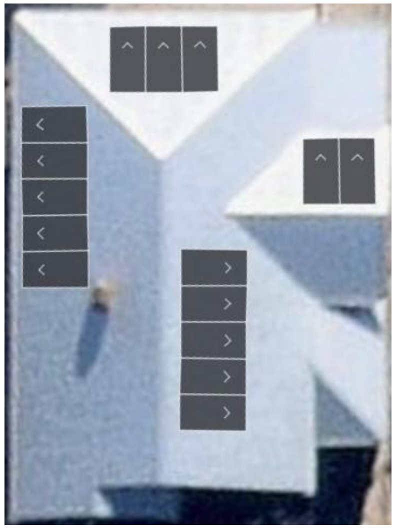


Figure 10: Solar Panel Layout for Houses 10 (left) & 11 (above)

Table 1: Nearmap Data for Halpin Street

House Number	North facing panels	West facing panels	East facing panels	Number of Panels	Total Solar Capacity (kW)	Solar Installation Designation	Annual Output (kWh)	Maximum Annual Savings	Total Cost	Minimum Payback (in Years)
1	7	12	0	19	5.7	Solar	7,653	$1,913	$8,550	4.5
2	0	10	6	16	4.8	Either	5,597	$1,399	$7,200	5.1
3	6	0	5	11	3.3	Either	4,542	$1,136	$4,950	4.4
4	4	8	0	12	3.6	Either	4,262	$1,224	$5,400	4.4
5	5	4	6	15	4.5	Either	5,842	$1,460	$6,750	4.6
6	8	2	0	10	3	Either	4,587	$1,147	$4,500	3.9
7	0	10	7	17	5.1	Either	5,922	$1,480	$7,650	5.2
9	18	0	0	18	5.4	Solar	9,018	$2,255	$8,100	3.6
10	5	5	5	15	4.5	Either	5,871	$1,468	$6,750	4.6
11	0	15	0	15	4.5	Either	5,399	$1,350	$6,750	5
13	2	6	0	8	2.4	Either	3,073	$768	$3,600	4.7
14	0	6	6	12	3.6	Either	4,676	$1,169	$5,400	4.6
15	7	10	0	17	5.1	Either	6,943	$1,736	$7,650	4.4
16	0	6	5	11	3.3	Either	3,823	$956	$4,950	5.2
17	6	0	7	13	3.9	Either	5,178	$1,294	$5,850	4.5
18	0	10	10	20	6	Solar	6,927	$1,732	$9,000	5.2
19	0	8	10	18	5.4	Solar	6,200	$1,550	$8,100	5.2
20	0	8	8	16	4.8	Either	5,542	$1,385	$7,200	5.2
22	7	10	0	17	5.1	Either	6,938	$1,735	$7,650	4.4
24	0	10	10	20	6	Solar	6,927	$1,732	$9,000	5.2
26	0	10	10	20	6	Solar	6,927	$1,732	$9,000	5.2
27	6	0	4	10	3	Either	4,204	$1,051	$4,500	4.3
28	8	3	7	18	5.4	Solar	7,247	$1,812	$8,100	4.5
30	0	5	5	10	3	Either	3,464	$866	$4,500	5.2
31	0	5	10	15	4.5	Either	5,121	$1,280	$6,750	5.3
32	6	2	0	8	2.4	Either	3,618	$904	$3,600	4
33	0	8	12	20	6	Solar	6,874	$1,719	$9,000	5.2
35	0	10	10	20	6	Solar	6,927	$1,732	$9,000	5.2
36	8	7	5	20	6	Solar	8,012	$2,003	$9,000	4.5
37	13	0	0	13	3.9	Either	6,304	$1,576	$5,850	3.7
38	0	11	9	20	6	Solar	6,953	$1,738	$9,000	5.2
39	0	6	4	10	3	Either	3,488	$872	$4,500	5.2
40	20	0	0	20	6	Solar	9,692	$2,423	$9,000	3.7
41	14	0	0	14	4.2	Either	6,792	$1,698	$6,300	3.7
8	8	0	0	8	1.08	Battery	1,740	$435	$1,620	3.7
12	8	8	0	16	4.8	Either	N/A	N/A	$7,200	N/A
21	0	6	6	12	3.48	Either	4,033	$1,008	$5,220	5.2
23	0	14	8	22	5.94	Solar	6,929	$1,732	$8,910	5.1
25	10	10	0	20	4	Either	5,606	$1,401	$6,000	4.3
29	0	12	0	12	3	Either	3,603	$901	$4,500	5
34	7	5	0	12	3.48	Either	5,036	$1,259	$5,220	4.1
42	6	0	0	6	1.8	Battery	N/A	N/A	$2,700	N/A
44	0	8	0	8	2	Battery	2,397	$599	$3,000	5
				Sum	**184.98**		**229,887**	**57,630**	**277,470**	**191.2**
				Average	**4.3**		**5,607**	**1,406**	**6,453**	**4.7**

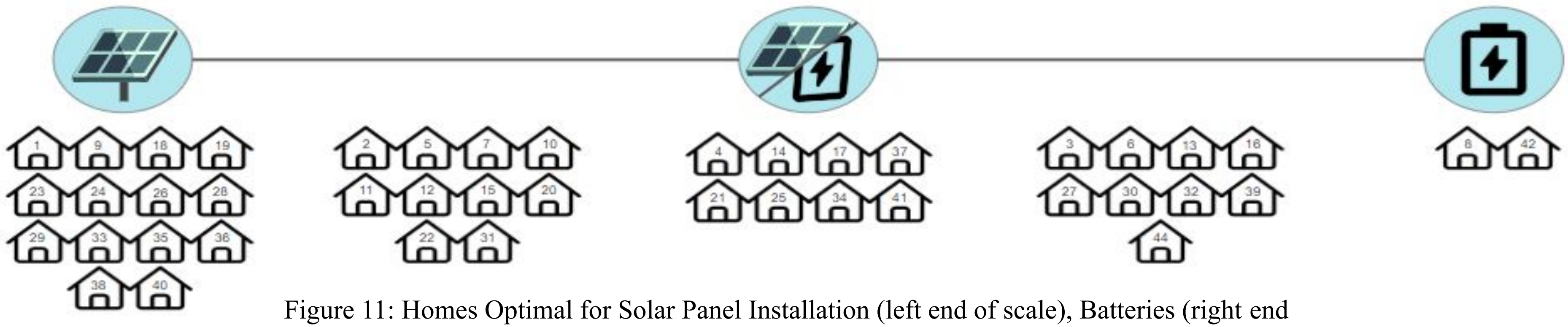
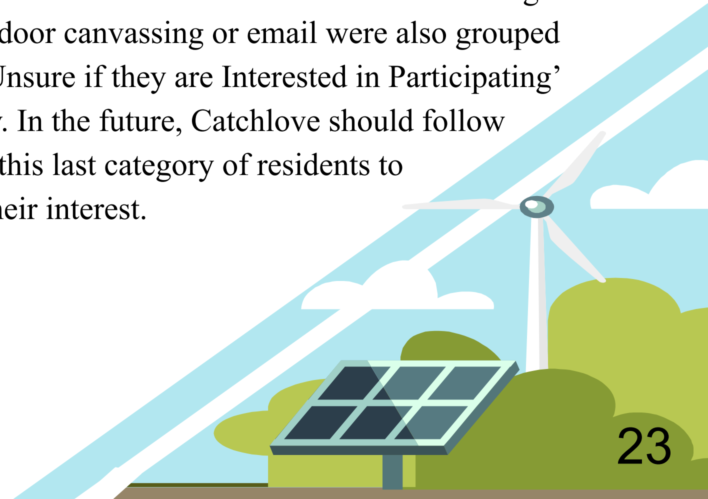


Figure 11: Homes Optimal for Solar Panel Installation (left end of scale), Batteries (right end of scale), and either Solar Panels or Batteries (middle of scale)

Using this data, we calculated averages for purchase and installation costs, savings, and minimum payback for the entire street. The average cost for the panels was 6,453 AUD, and this was strictly based on a relationship with the amount of energy generated. The average maximum savings were 1,406 AUD per year, and the average minimum payback time is 4.7 years. Homes with more than half of their panels facing north have an average minimum payback time of 3.9 years, while the rest of the homes have an average of 4.9 years. These figures illustrate that some homes are better off having more solar panels and then sharing power with the rest of the community, while some households may be better invested in energy-storing batteries that the homes can draw on.

Residents' Interest and Knowledge of a Microgrid

There are 43 homes on Halpin Street. Through the BBQ event, an email survey of homes for which we had email addresses, and through door-to-door interviews, we received a total of 20 responses (See Halpin Street Resident Interview Responses for all response data).[2] Five were from interviews during the BBQ event, eight were from the door-to-door interviews, and seven were from the email survey. Of these 20 homes, one (#33) was a rental, and the residents were moving out, so we omitted that home from our data set. This left us with 19 total responses. Of the 19 respondents, three were not interested in conducting the interview, and another four were unable to speak English, so we could not gather data from them. We categorized respondents into four categories based on their interest in supporting and participating in the neighborhood grid, which we determined from their responses to a question asking them to rate their 'Support for Halpin Street's Neighborhood Grid' based on a scale of 1 to 5, with 1 corresponding to not interested, 2-3 as somewhat interested, and 4-5 as interested (Table 2). Eleven respondents were 'Interested in Participating,' and one was 'Somewhat Interested in Participating.' Residents who told us they were not interested in answering our questions were grouped into the 'Not interested in Participating' category. The four residents who could not speak English were grouped into an 'Unsure if they are Interested in Participating' category. Residents that we could not reach through door-to-door canvassing or email were also grouped in the 'Unsure if they are Interested in Participating' category. In the future, Catchlove should follow up with this last category of residents to assess their interest.



[2] Halpin Street Resident Interview Responses may be found at wp.wpi.edu/melbourne/projects/, using the search bar to locate the project report materials

We also asked the twelve residents who were willing and able to complete our survey to rate their interest in installing panels and batteries over the next 12-16 months (Table 3). The average interest rating for installing solar panels was 3.8, and for batteries, it was 3.2. Homes are more reluctant to install batteries compared to panels; this could potentially stem from the higher average costs of batteries compared to panels. We found an overall interest level to be quite promising at 4.4; however, it was higher than the interest levels for installing solar panels and batteries. This suggests residents may not fully understand the importance of solar panel and battery installation in developing a neighborhood grid. It may also indicate the residents are unsure about the technical features of such systems and whether their homes may have the appropriate infrastructure to support them.

There were only five residents who rated a 5 for supporting a neighborhood grid. Of homes with solar panels, only a single home rated a 5 for supporting a neighborhood grid, and for homes with panels, the average overall support for the neighborhood grid was only at a 4. While for homes without solar, the average overall support for the neighborhood grid was at 4.8. This discrepancy could stem from the belief that supporting the neighborhood grid may require homes with installed panels to spend more money, in addition to what they have already spent

Table 2: Segmentation of Homes on Halpin Street - based on interest of participating in the Neighborhood Grid

Categories	House Numbers
Interested in Participating	21, 22, 25, 27, 29, 30, 34, 39, 41, 42, 44
Somewhat Interested in Participating	8
Not interested in Participating	4, 31, 38
Unsure if they are Interested in Participating	1, 2, 3, 5, 6, 7, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 23, 24, 26, 28, 32, 33, 35, 36, 37, 40

Table 3: Interest in Installing Batteries and Solar Panels in versus Interest in Supporting a Neighborhood Grid

House Number	Panels Already Installed	Interest in installing solar panels over the next 12-16 months	Interest in installing batteries over the next 12-16 months	Support for Halpin Street's neighborhood grid
8	Yes	-	-	3
21	Yes	-	-	4
22	No	4	5	4
25	Yes	-	-	4
27	No	5	1	5
29	Yes	-	-	4
30	No	3	3	5
34	Yes	-	-	4
39	No	3	3	5
41	No	4	4	5
42	Yes	-	-	5
44	Yes	-	-	4
Average		**3.8**	**3.2**	**4.4**

Table 4: Solar Panel and Inverter Brands

House #	What brand were the solar panels?	What brand were the inverters?
8	Sony	Fronius
21	JAM290-SLV (MC4)	Ingeteam Sun 3.3 TL M
25	Renesola	Sunny Boy 4000TL
29	Topsolar	Growatt 3000
34	Chinese Brand	Fronius
44	SunEdison	Sungrow

Table 5: Solar Panel Capacity, Pricing, and Age data for Homes with Panels

House #	Total Capacity of Panels in kW	Amount paid for panels and inverters (AUD)	When did you install your panels?	Did you receive any incentives or rebates to help pay for the installation of these components?
8	1.1	$8,000	~10 years ago	Yes, paid for half of the cost of installation
21	3.5	$6,447	~2 years ago	Rebate for some of the price
25	4	$8,500	7 years ago	Yes, they do, pays for about a third of the usage
29	3	$6,260	~5 years ago	Small scale technology certificate ($1855)
34	3.5	~$5,000 (unsure)	~6 years ago	I actually can't recall. I don't think so no.
42	Unsure	~$2,500	~3 years ago	No
44	2	$3,000	~4 years ago	Yes
Average	**2.8**	**~$5,672**	**~5.3 year ago**	**N/A**

on panels, to install additional components such as monitoring systems and batteries. This belief is shown by house 25, as they had a concern about not wanting to contribute more financially to the project based on their open-ended response and answered a 4 for overall support for the neighborhood grid.

Out of the twelve respondents who were interested and agreed to answer questions, seven already had solar panels installed. Six of these were able to provide the brand names of their panels and inverters (Table 4), and these varied quite a bit. Two of the inverter brands were from Fronius, which is a renowned brand that is on the higher end of the inverter brand spectrum in terms of quality and reliability (Svarc, 2019). It was interesting to note the inverter and panel brands were from different companies for all homes. This suggests that residents may have greater flexibility in selecting separate panel and inverter brands of their choice as a package through a solar provider.

Residents wanting to install solar panels may need to do individual research to determine which distributor/installer will provide the best panels for them and which providers are eligible to receive loans or rebates from the Victoria Government. These results align with Rob Catchlove and Sebastian Klein's expectation of having Halpin Street be more independent with their electricity use and allowing them to choose the products themselves.

Although this data set is quite small, the data on the price per kW for solar panels aligns with the general trend: solar panels are becoming less expensive. House 8 paid 7,272 AUD per kW ten years ago, while the most recent home that purchased panels, house 21, only paid 1,852 AUD per kW (Table 5). Additionally, the panels cost an average of 2,026 AUD per kW and were installed on

Table 6: Summarized Information about Monitoring Systems on Halpin Street

House #	Currently Uses a Monitoring System?	Was the System Included with Panels or Batteries?	Thought about Using a System and Would they?	Aware of the Direct Benefits of a System
8	No	No	Thought about it, but don't really need it due to habits	Not really
21	No	No	Yes and yes	Yes
25	No	No	Interesting, probably wouldn't change much	Yes, in terms of appliances, but issues with complying with advice
34	Yes	Yes	N/A	N/A
42	No	No	No	No
44	No	No	Probably would do it, isn't a priority	Yes, use power during peak demand, pressure off grid and bill

average 5.3 years ago. This cost estimate is higher than the average estimate given by the AEF to be at 1500 AUD per kW based on costs in 2019. Based on the averages taken relative to the estimate given by AEF, the data indicates a 500 AUD reduction in the cost of panels over the past five years, which confirms the trend that solar panels are getting cheaper. The decrease in price could sway homeowners previously unable to afford panels.

Five out of the seven homes we interviewed with solar received rebates or incentives. House 8 received the most significant rebate at about 8,000 AUD. Respondents from houses 21 and 44 did not provide an amount. A large variety of rebate schemes seem to exist based on these responses; home 25 currently receives a rebate that pays for a third of their energy usage. House 29 received a rebate known as a ‘Small scale technology certificate’ that covered 23% of its total cost. The majority of the households purchased panels through a rebate scheme, another persuasive point for those worried about cost.

Rebates come and go, however, so the community will need to identify those in play at the time of purchase.

Out of the seven homes with solar panels, six answered questions about monitoring systems (Table 6). Only one had a monitoring system in place. They indicated that their monitoring system was included with their panel and inverters. Out of the five homes without monitoring systems, only two homes expressed interest in installing a monitoring system. One respondent not interested explained that they "Thought about it, but do not need it due to habits." Another noted that it was 'Interesting, probably would not change much.' The lack of installed monitoring systems means that there might be some pushback to installing a community-wide monitoring system as some residents believe that they already have the right habits to reduce energy consumption. It is important to note that monitoring systems will not only be used to educate individuals about energy usage but may be necessary to understand the collective energy usage of the street.

We initially planned to utilize the energy consumption data for each home to come up with a more precise estimate of the number of panels that would be needed to power the entire neighborhood. However, some respondents did not know or could not provide complete data in a consistent way (Table 7). This made it clear that a monitoring system should be installed as the first stage of grid development, to collect accurate consumption data *before* further planning solar panel installation.

A few of the homes had the same energy retailers. Yet, seven different retailers were noted, indicating a future complication when trading energy between homes, as various retailers may have different taxing structures for energy sent between homes and for energy exported back to the main grid.

Table 7: Energy Consumption and Retailer Data for Homes on Halpin

House #	Who is your current energy retailer?	Have you switched your energy retailer in the last 3 months?	Do you know how much you are currently paying for your electricity (AUD)?	About how many kWh of electricity do you consume annually?	Do you know how much you could save if you installed a solar system?
8	Origin	No	For Winter Quarter: $219 Summer: $140	Winter: 9 kWh per day Summer: 7.3 kWh per day	N/A
21	Origin	No	Spring: $78; Winter: $263 Summer: $71; Fall: $143	Spring: 5.39 kWh per day Winter: 8.17 kWh per day	N/A
22	Red Energy	No	$1,300 annually	N/A	N/A
25	Origin	No	$1,100 annually with rebate and $1,400 without rebate	Summer: 7 kWh per day; Winter: 12 kWh per day	About a third of energy usage
27	N/A	No	N/A	N/A	Yes, has looked into it
29	AlintaEnergy	No	Spring: $176; Winter: $206 Fall: $128	Spring: 9.79 kWh per day; Winter: 12.66 kWh per day	N/A
30	Powershop	No	For 2019, paid an average of $158 per month	Over 2018, consumed an average of 13.5 kWh per day.	No
34	AGL Energy	No	N/A	N/A	N/A
39	Simply Energy	No	Dec-Jan: $121; Jan-Feb: $74 March-April: $209; April-June: $203; June-July: $126; July-Aug: $130; Aug-Sep: $125	Dec-Jan: 352 kWh; Jan-Feb: 193 kWh; March-April: 338 kWh; April-June: 574 kWh; June-July: 363 kWh; July-Aug: 374 kWh; Aug-Sep: 357 kWh	N/A
41	Powershop	No	$950-1000 annually	Approx 5 kWh/Day on average	Not really, most of energy use is during the daytime
42	Simply Energy	No	$60 including service chargers and pension discount	800 kW	N/A
44	Red Energy	No	$68	7.76 kWh per day on average	N/A

The responses received from the query asking about any questions, comments, and considerations on this project and any other open-ended responses were analyzed for common themes. Five emerged: Technical Features, Installation Infrastructure, Social Communication, Financing, and Other (Resident Interview Responses).

The Technical Features category involved questions and concerns about the individual components of a neighborhood grid. There were questions about the lifespan of panels and batteries and about the scale of the neighborhood grid. One homeowner did not wish to look too much into the technical details of solar panels.

To address concerns about battery and panel lifespan, quality, and mechanics, we prepared a general list of battery and panel prices depending on quality categories such as premium, standard, and non-premium products that we integrated into our final community event.

The Installation Infrastructure category included concerns about existing or future infrastructure that may need to be modified or added to house solar panels and batteries, and to facilitate energy trading between homes. One respondent was concerned about the ability of the current electricity infrastructure on the street to support energy trading in its current state. He explicitly stated, "Need to look at whether existing infrastructure is the only way to transfer electricity" and questioned, "What's the chance to use the existing infrastructure for energy trading?" We were unable to answer the question during the interview, as various energy retailers may offer different energy trading schemes, and it remains unclear whether they can use the existing powerline on Halpin street or not for this purpose. Investigating this further with energy retailers is an important next step. Additionally, he was concerned about existing roofing space on the North facing roofs and considered moving his solar water heater system to make room for North facing solar panels. It would be interesting to know if other homes have solar water heater systems and whether it is intrusive to panel installations on the North, West, or East facing roofs.

The Social Communication category had questions about how the rest of the community would get involved in a neighborhood grid. One person advised, "the easier it is for people to participate, the better," showing concern for the potential difficulty in collaborating to create the neighborhood grid. Another talked about the "Need to establish as many compelling benefits for the residents as possible." We addressed this by presenting a poster outlining several benefits of the project during the final community event, but continued advocacy for the project and communication about its value is critical.

The Financing category included comments about the costs involved for the individual homes in a neighborhood grid. One person had concerns about contributing to the neighborhood grid since he had already installed his solar panels. He found this concerning because he may or may not feel comfortable about another resident utilizing his energy from his solar panels without contributing anything to the neighborhood otherwise. We had prepared to follow-up with the resident during the final community event to discuss his concerns. We were able to explain that since he already has panels installed, then the cost for him to participate in the neighborhood grid is significantly lower than actually installing the panels, as they only would need to install a monitoring system. Additionally, the residents who are unable to purchase their panels would still be paying for the electricity which they utilize from the collective neighborhood energy produced. One resident had concerns about evaluating panel and battery options available, and believed that "it is time for some costed options to be canvassed." As noted, we repeated some data on cost ranges that we could share at the final community event.

We noted other comments that fit into an "Other" category. One homeowner was greatly interested in the neighborhood grid's impact at a national level, and another resident also wished to know if a neighborhood type project has been done elsewhere.

How can Halpin Street Meet its Goals

Combining results from interviews, surveys, and the layout data from Nearmap, we calculated that the total maximum solar capacity of Halpin Street is 185 kW. We calculated this number based on the current layout of the nine homes that already had solar panels and the theoretical layouts for the remaining 34 homes from Nearmap. We created a graph (Figure 12) representing the number of homes that will need to commit to solar and/or batteries to help Halpin Street reach its needed solar capacity. The solid blue line represents the homes that currently have solar panels installed. The dotted blue line represents the homes that are interested in installing solar panels. And the green line represents the homes that have not yet expressed interest because we have not been able to ask them. We were unable to determine an optimal target for the street, however, we established that there are savings for the residents no matter the current capacity of the street. We graphed this as if those who were to commit to participating and are able to achieve the average solar capacity we calculated from Nearmap used the average capacity from the layouts on Nearmap. A majority of the capacity comes from homes that we

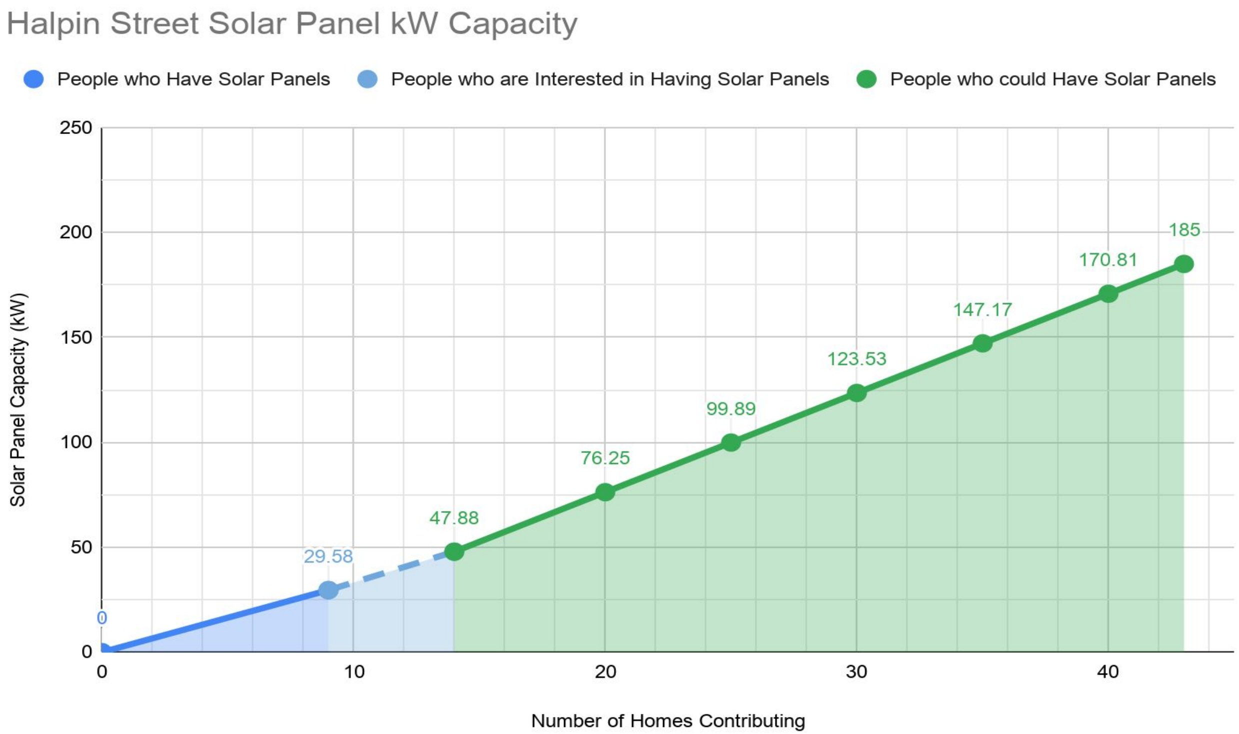


Figure 12: Current and Potential Solar Panel Capacity based on number of participating homes on Halpin Street

have not been able to interview, making it imperative that communication is established with them to determine if they are interested in participating in the project.

While we wanted there to be a threshold for the optimal capacity, we realized that it is statistically impossible to find that value because of the number of unknown variables. While it is possible to find the minimum recommended requirement for all homes, we have analyzed from our interview responses that not all homes are interested and potentially more may not be interested as well. Additionally, that value depends on which household installs the panels as we found some homes are better suited for solar than others. Even when considering the average capacity of all homes, we did not have a precise value to use since different sources gave us different kW value targets per household. We also do not have exact consumption data from the homes on Halpin Street, since there is not a monitoring system in place for the street. As such, we had to use the average home energy consumption amount from a regional sample size, such as Moreland or the state of Victoria, which can be inaccurate for Halpin Street.

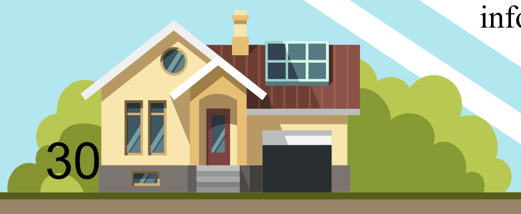
Energy Monitoring System Options for Halpin

We had initially done some background research (see SM-E) for systems offered by six companies during the prep term, which were Greensync, Reposit, ABB, Power Ledger, Mondo Power, and Ovida. However, we did not have enough specific information on pricing and technical features, such as compatibility with certain solar or battery brands. As such, we attempted to contact these companies through email and phone calls. After initial discussions with our sponsor and further research upon arrival, we conducted background research on six new companies. We attempted to directly contact them to acquire additional information about their features (Table 8). Out of the total of twelve companies contacted, we received seven responses through emails and phone calls from EdgeElectrons, Reposit, Solar Analytics, SolarEdge, Greensync, Evergen, and SwitchDin. Our sponsor also had valuable information on Powerledger's Xgrid system to add on to the background research we had completed. However, Evergen only provided information on the financial packages of their system and not on specific technical features such as the system's ability to view data of neighboring units. Overall, we were able to obtain complete data on seven companies, as displayed in Table 8. We recommend Halpin Street to pursue follow up talks with the five companies we were unable to receive complete responses from, which were Ovida, ABB, Mondo Power, Simble, and Evergen. Ovida, ABB, and Simble were omitted from the table as there is insufficient information on their systems. To determine the feasibility of each of the systems for Halpin, we assessed them based on eight different criteria. Systems were deemed to be infeasible when they were not able to meet these two criteria: 'Monitor Consumption, Production, and Storage Data for Panels and Batteries' and 'Data Accessible through Smart Devices.' Two systems were not included in the Monitoring System Evaluation Table (Table 8) as they were determined to be infeasible; these were Powerledger's Xgrid and Greensync's MicroEM.

Systems were determined to be 'somewhat feasible' if they fulfilled the two criteria mentioned above and additional criteria of 'Ability to View Neighbors' Data.' The above criterion is essential in allowing homes to view the collective energy data of the street and their neighbors to finalize the assessments of how many panels or batteries may be needed. Additionally, it increases collaboration in the street by allowing homes to provide tips to neighbors in reducing their energy usage. Systems determined to be 'somewhat feasible' were Reposit, SolarEdge, and Solar Analytics. Evergen may be part of this category if the system can be determined to allow residents to access neighboring fleet data in the future. These systems show significant variance in their ability to control home appliances. However, this criterion was not used to create another level of feasibility above the 'somewhat feasible' category. Residents are still able to develop energy-saving habits by observing monitoring systems, and their homes can become more energy efficient through home modifications such as increased window insulation. As such, homes do not require appliance controlling features and is treated as a convenient add on instead. The feature will be used to designate systems within the 'feasible' category instead.

SolarAnalytics from the 'somewhat feasible' category uses a circuit controlling unit called Wattwatchers. It has the potential to turn on or off smart home appliances automatically. Additionally, these units can monitor energy usage data for six home appliances. However, SolarAnalytic's monitoring system is not able to fully control the hardware capabilities of the Wattwatchers unit and does not have the option to turn on or off household appliances. It can only control pool pumps and hot water services.

We received interesting additional



information on Reposit’s compatibility with different energy retailers. Reposit’s system is only compatible with two main electricity retailers: Powershop and Diamond Energy. These two retailers work with the Reposit unit to allow the homeowner to make money by feeding excess electricity generated from solar panels or stored in batteries back to the main grid. Their representative said that they were willing to work with other electricity retailers on a case by case basis.

Systems determined to be feasible had to fulfill three criteria for ‘somewhat feasible’ systems (Table 8) and two additional criteria: the system must be able to be installed as an add-on to solar or battery systems and must be compatible with most battery or panel brands. These criteria ensure that the residents will not need to purchase solar or battery packaged components that they do not need for their home. Additionally, if the systems can be installed as add-ons to homes with and without panels, then it will ensure that as many residents as possible can purchase the units in bulk for a lower unit price. The systems determined to be feasible were SwitchDin and EdgeElectrons’ Edge ConX. A single most feasible system was not chosen to allow the residents to have more freedom in selecting what they believe to be the most viable system based on ‘Installation and Subscription costs’ and the system’s ability to control home appliances.

SwitchDin’s system utilizes hardware units called Droplets that have direct connections to the home appliances. An online platform called Stormcloud connects with Droplet units to allow the user to view generation and storage data from panels and batteries. The Droplet units can control home appliances by variably controlling the voltage sent to the devices and lower the power setting of an appliance, instead of simply turning it off to save energy.

EdgeElectrons’ representative was interested in the project on Halpin Street and offered to give a demonstration of its EdgeConX monitoring system. It is the only system that has full hardware control of the Wattwatchers unit and can turn on or off smart household appliances through the additional purchase of “smart plug” units. Smart plugs are adapters that fit between the power socket and the appliance being monitored, and the EdgeConX system can work with any generic smart plug on the market. The EdgeConX is more favorable if residents want to save on cost, while SwitchDin has extra capabilities in terms of variably controlling home appliances.

“The EdgeConX is more favorable if residents want to save on cost, while SwitchDin has extra capabilities in terms of variably controlling home appliances.”

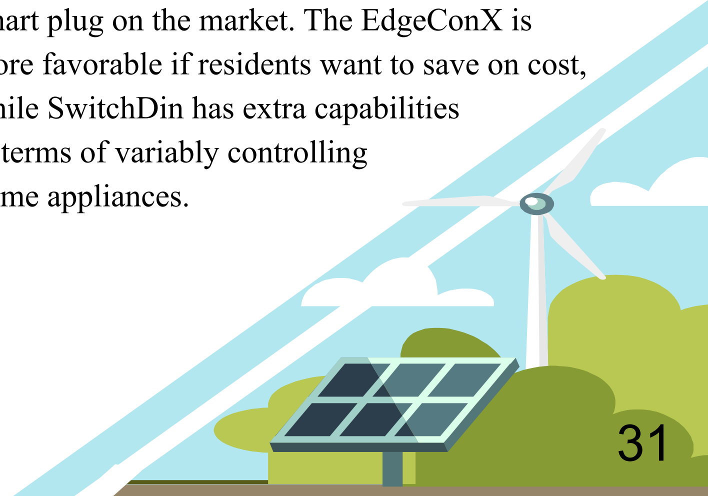


Table 8: Energy Monitoring Systems: Comparison of Key Features and Feasibility for Halpin Street

	Monitor Consumption, Production, Storage for Panels and Batteries	Battery or Panel Brand Requirements	Ability to Add onto Existing Panels/Batteries	Home Appliance Control	Installation and Subscription Costs (AUD)	Data Accessible through Smart Devices	Ability to View Neighbors' Data	Required Hardware Packages	Feasible?
SwitchDin	Yes	None, compatible with all brands of batteries and panels. Does not require homes to have panels and batteries.	Yes	Yes, can provide variable load control instead of simple on or off states as with Wattwatchers.	$330 for unit cost (inclusive of installation cost) with $60 annual subscription cost.	Yes	Yes	None	**Yes**
Edge Electrons' Edge ConX	Yes, can monitor six main home appliances through Wattwatchers unit (See additional notes SM-L).	No, doesn't require panels and batteries for installation.	Yes	Yes, but need to additionally install 'smart plugs' that plug into appliance to be controlled. Has full hardware control of Wattwatchers unit.	Individual cost is at $360, while bulk purchase for a minimum of 12 units is at $209. Additional Smart Plug units cost $50 each.	Yes	Yes	None, can be purchased with their voltage monitoring and regulating system.	**Yes**
Solaredge	Yes	Requires SolarEdge panels. Batteries are not required to be installed beforehand.	Yes	No	Depends on quotes from solar installers/providers.	Yes	Potentially, all homes would need to send data from solaredge inverters to the same database.	Yes, a package from a third party supplier including inverters, monitoring system, panels, batteries.	Somewhat
Reposit	Yes	Yes, not compatible with Sonnen and Tesla batteries. Batteries are not required for installation.	Yes, suppliers supported by Reposit. List is not public, need to directly contact Reposit.	Potentially, if integrated with platform from a third party solar provider.	Total cost of 329 AUD (No subscription fee)	Yes	Yes	Yes, packages depend on solar installer/providers compatibility with Reposit.	Somewhat
Solar Analytics	Yes, monitor up to six main appliances through WattWatchers unit.	Does not require batteries for installation, does require solar installation from provider. Compatible with AC batteries.	Yes, panels and batteries need to be from a list of suppliers	Somewhat, can only turn pool pump, heat pipes, hot water service on or off.	Starts at 239 AUD for hardware unit cost + $50-100 labour install + subscription costs (See additional notes SM-L).	Yes	Yes, need to install a separate portal called the custom display that costs $750, separate login for each individual and everyone can share this cost.	Locked into Solar Analytics subscription with varying solar and battery packages compatible with certain installers/providers.	Somewhat
Evergen	Yes, monitor up to six main appliances through WattWatchers unit.	Yes, need to install as part of package based on list of panel and battery companies partnering with Evergen.	No	Unclear	Varies from $13,799 to $18,999 depending on panel size. (See additional notes SM-L). Offer loan terms from 3 to 7 years.	Yes	Unclear	Yes, Evergen directly manages and installs their packages. Monitoring system needs to be installed with batteries alone or with both panels and batteries.	Unclear, cannot be feasible could be somewhat feasible
Mondo's Ubi	Yes	No	Unclear	Yes, need more info to what degree of control.	Unit cost is $500.	Yes	Yes	Unclear	Unclear

Materials to Guide Halpin Street and Other Communities in Future Neighborhood Grid Planning

Based on the above research, we designed a series of materials for a neighborhood event where we presented our recommendations. We created a set of larger posters, customized pamphlets for each household, and an informational website. The purpose of these is to later aid in the replicability of the neighborhood grid and assist Halpin Street through the pilot process by assessing their homes for them - presented in an easy to understand media.

Posters

We developed 14 posters, which were displayed at a final interactive community event on the 10th of December, 2019. We invited residents from Halpin Street, members of the AEF, and members from the Moreland City Council to listen to our recommendations and ask questions. Our posters were hung around the room in a clockwise manner, in the same order as the following figures. The posters helped educate attendees about the project and recommended future steps that Halpin Street may take to finish implementing their neighborhood grid.

Our first poster, depicted in Figure 13, is a roadmap showing the four stages of the neighborhood grid development journey. We have broken down the process into four steps: gauge interest, understand grids, assess feasibility, and implement yours. Following this poster, we included four more informative posters detailing each of the stages (Figure 14), "Gauge interest," details three steps communities can take to learn about their neighbors' level of interest in participating in a grid, as we did through our interviews. The second stage, "Understand grids," defined the components of a grid, including options for energy generation, storage, and monitoring. Communities need to research the best components given their context. The third stage, "Assess feasibility,' has three steps - energy usage, behavior changing and energy efficiency installations, and solar batteries and solar devices. Each step within the list describes an aspect in which homeowners need to evaluate their home based on their day to day energy usage and solar capabilities based on roof orientation for immediate savings and an increase in energy efficiency. The fourth stage is to "Implement yours," detailing the five steps that residents can take to set up a neighborhood grid in their community.

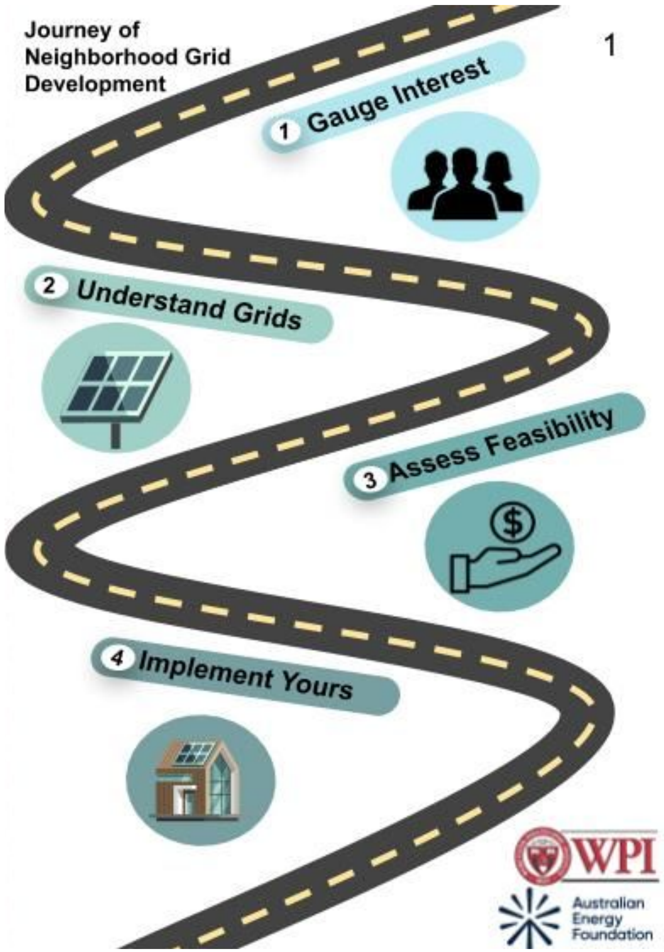


Figure 13: The Journey for Neighborhood Grid Development Roadmap

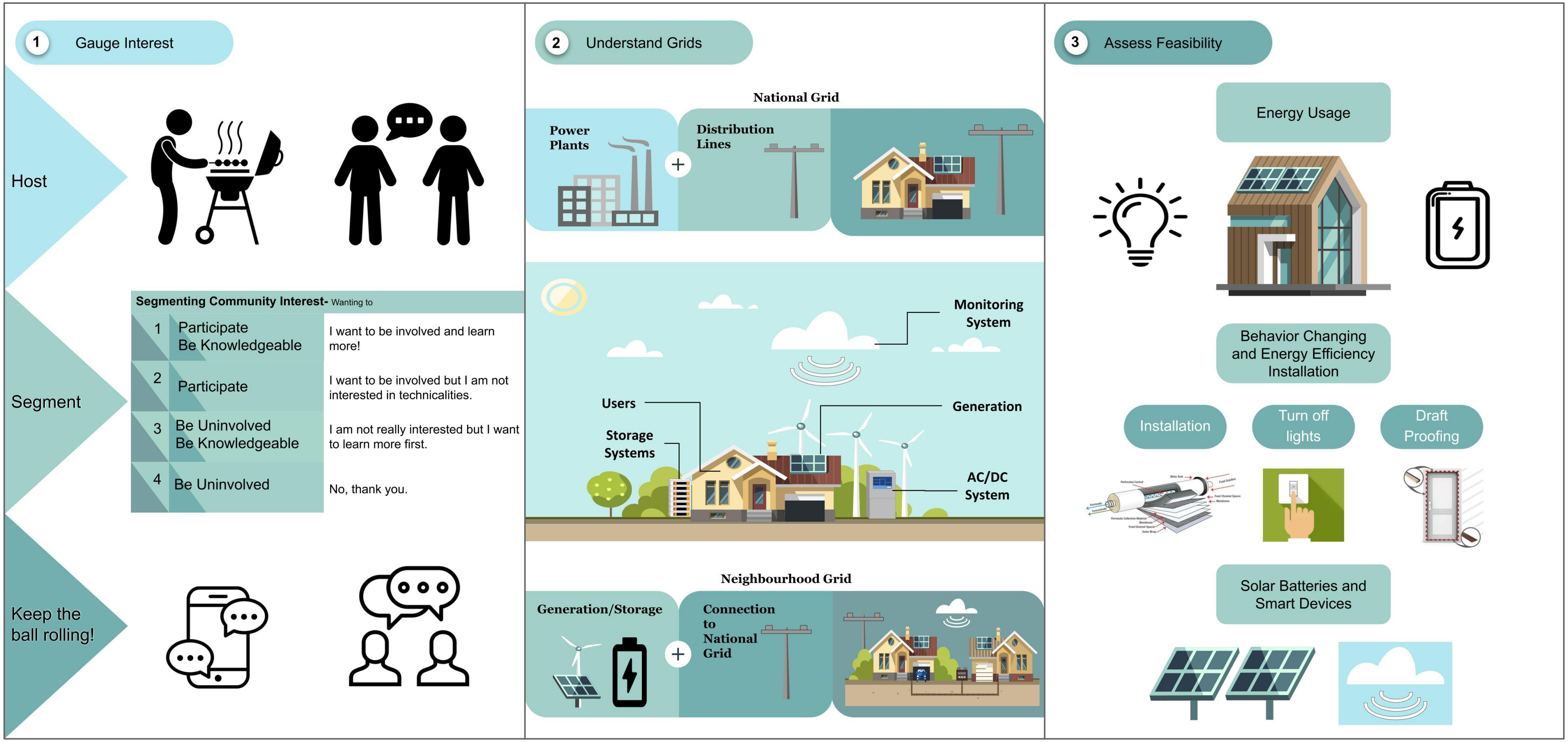


Figure 14: The Four Neighborhood Grid Development Stages

Figure 14: The Four Neighborhood Grid Development Stages (cont.)

A sizeable interactive poster with an aerial image of each home was displayed on one part of the wall (see SM-K). We asked residents to consider the options they might want to pursue for their home, including

- 'Installing a Monitoring System'
- 'Installing Solar Panels on your Home'
- 'Neighborhood Battery'
- 'Community Electric Car'

Each resident was then asked to place a colored sticker, each color representing one of the four interests mentioned above, onto their home on the interactive poster. We developed this interactive poster to collect more information on community interest as a whole and to provide the community with guidance on the next steps which they should be taking to keep the project in motion and ultimately be successful. They were also asked to sign up on a sheet for an email and house number to stay in contact. These instructions were given verbally at the beginning of the event, noted in another poster, "What options do YOU want to pursue" (Figure 15) and further explained in pamphlets.

We made additional posters on each of these four options, tailored to the specifics of the residents of Halpin Street. Individual recommendations were given in three posters. On the first poster, we detailed steps to 'Installing a Monitoring System' for the whole street (Figure 16). This was to gather more accurate energy usage data to finalize the planning of solar and battery components required for the neighborhood grid. On the large poster, we detailed the steps for 'Installing Solar Panels on your Home' and a 'Neighborhood Battery' (Figure 16). These steps were combined with a collective summary of the Nearmap data in each pamphlet. Homes that were optimal for solar, battery, or either were displayed on the spectrum to give the residents a collective estimate of how many homes would be suitable for panels, batteries, or both. On the final poster, we detailed future plans for a 'Community Electric Car' that the residents could share (Figure 16). It is a more idealistic goal, but gives the community a goal to reach for and to see tangible evidence that the neighborhood grid works. To complement these goals, we placed a poster outlining the benefits of switching to renewable energy usage (Figure 15) through a neighborhood grid beside the three of the goals.

YOUR FUTURE with a neighborhood grid

Figure 15: Your Future Goals - Choosing what you are going to do

Which options do YOU want to pursue?

You have been given 4 colored stickers in your pamphlet, each corresponding to the options below. Please indicate which options you are interested in pursuing by placing the appropriate colored stickers on your home, which you can locate on the large Halpin Street map. These stickers will help us identify which neighbors might want to work together to pursue a neighborhood grid. The more neighbors, the greater the savings. If you have questions about these options, see the information posters or talk to the students.

Installing a Monitoring System

Installing a monitoring system will help you keep track of your energy usage and know the best times to use your appliances. This will save energy and lower costs.

Installing Solar Panels on Your Home

The pamphlet you have been given identifies your home's solar profile and whether it is feasible and beneficial for you to install solar panels. You can use this profile and the information posters to decide if you want to pursue solar panel installation.

Neighbourhood Battery

Purchasing a community battery allows those generating energy from solar to store excess energy, use it as needed, and even share it with neighbors, resulting in significant savings.

Community Electric Car

Purchasing a shared electric vehicle, powered by solar, can be cost-effective and good for the environment

Figure 16: How to Take Action and Accomplish the Future Goals

Installing Monitoring System

Definition: An energy monitoring system monitors your energy consumption, generation, and storage that could send you alerts and control your appliances to increase your energy savings.

For Halpin neighbors, we recommend:

switchDin EDGE ELECTRONS™

Why SwitchDin or EdgeElectrons?

- You can install them as an add on to any solar or battery system, and even a home without solar or battery.
- You can control your smart home appliances for extra savings.
- You have the ability to view communal for neighboring units.
- EdgeElectrons is cheaper, SwitchDin provides greater home appliance control.

What to do next:

Step 1	Step 2	Step 3
All homes interested in installing monitoring systems should come together in a community meeting.	Decide on the model you want and the number of units you will need.	Contact the company and inquire about bulk purchasing schemes.

Community Electric Car

Why buy more cars than necessary?
Collectively owning an electric car with neighbors allows you to split costs and use the vehicle as you need it. The community can use the solar power it generates to charge the car, saving on gas and benefiting the environment.

- Why do you need a community electric car? Find others interested too!
- Are you a member of a car sharing service like Flexicar?
- How many people are willing to use and pay for the car through a car sharing service?
- Where will the car be parked and charged when not in use?
- What system will neighbors use to reserve the car on specific days?
- Which type of car is best for the community? Sedan, minivan, SUV?

Installing Solar Panels on Your Home

The pamphlet you have been given identifies your home's solar profile and whether it is feasible and beneficial for you to install solar panels. You can use this profile and the information posters to decide if you want to pursue solar panel installation.

Average total solar capacity for Halpin Street
4.3 kW

Below is your categorization of where we think you home best fits based on the NearMap software findings. More details can be found in your pamphlet.

Neighbourhood Battery

Definition: A shared electrical storage device that the whole community can use.

Advantages: Collaboration, saving money, freedom from electrical companies

Disadvantages:Requires a level of commitment and cooperation from the whole community

Questions to ask	and how to answer them
How large is the capacity? How much is the electrical draw? How much excess energy is generated?	Depends on how many people are committed. Determine where the battery would be located.

What is your home optimal for?

We made two additional posters. One was of Figure 12, an enlarged version of the solar capacity of Halpin Street data. The other depicts the different pricing models to purchase solar panels to provide more general financing options to the residents (Figure 17). We believed this poster was necessary because of the consistent responses and questions about financing options from the residents. The incentives or payment models will help guide the residents in selecting a solar provider of choice.

Pamphlets

We also created eight-page individual pamphlets customized for each home in the neighborhood. These pamphlets described: the four steps of a neighborhood grid journey (see SM-L), what the Halpin project is (Figure 18), the benefits of the project, the solar capacity of each home using the Nearmap data (Figure 19), the different interest categories (see SM-L), and finally the AEF energy savings tips (Figure 18). The benefits page in the pamphlet (see SM-L) differed depending on each Resident's Interest, based on their interview responses. As shown in Figure 19, each home assessment showed how many panels would fit on the resident's roof and estimated cost, payback time, total solar capacity, and potential annual savings. Four additional pages of the pamphlet are in SM-L since they are similar in content to the posters displayed previously.

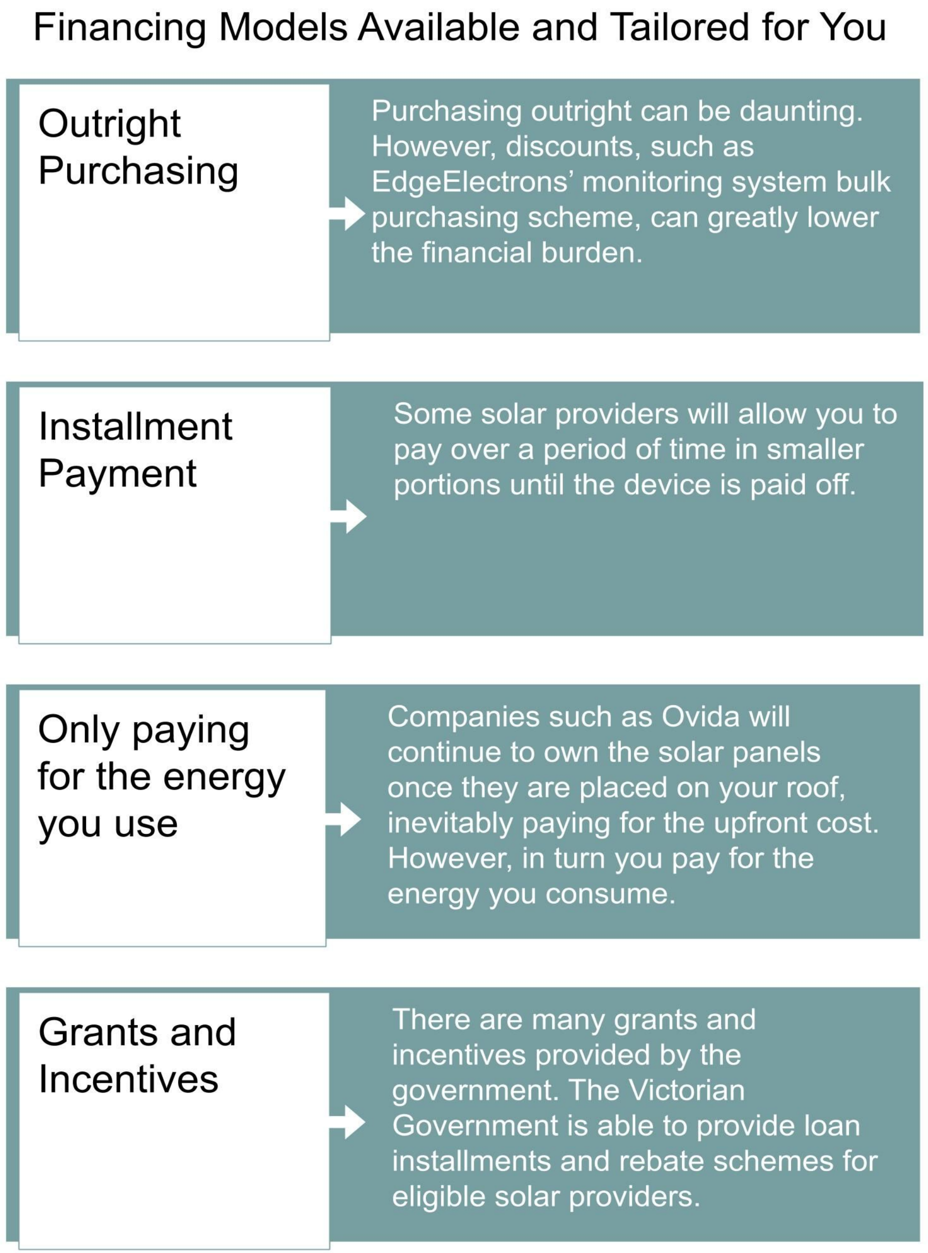


Figure 17: Financing Models Available and Tailored for You

Who we are:

Worcester Polytechnic Institute (WPI) students from Massachusetts, USA.

Taking the Power Back: Designing a Replicable Neighborhood Grid for Halpin St

What we have done:

- Independent the options for and essential components of microgrids.
- Assessed resources for your street.
- Created appropriate materials that will help your neighborhood implement an alternative energy generation and monitoring systems.

Tips to be energy smart now!

- **Turn off appliances at the plug** when not using them, especially entertainment systems. Standby power can account for more than 3% of your energy bill.
- **Take shorter showers**, ideally 4 minutes or less. Use a shower timer as a reminder.
- **Set the thermostat of your fridge to the most efficient setting**; your fridge should be set at 3° to 5° and your freezer at -15° to -18°.
- **Use cold water** when washing your hands or cleaning your teeth.
- **Dress for the weather** – before turning on the heating or cooling adjust your clothing to suit the temperature.

For more tips, please visit: https://aef.com.au/resources/energy-for-everyday-people/energy-efficiency/

Figure 18: Project Description and the AEF Energy Smart Tips in the Pamphlet

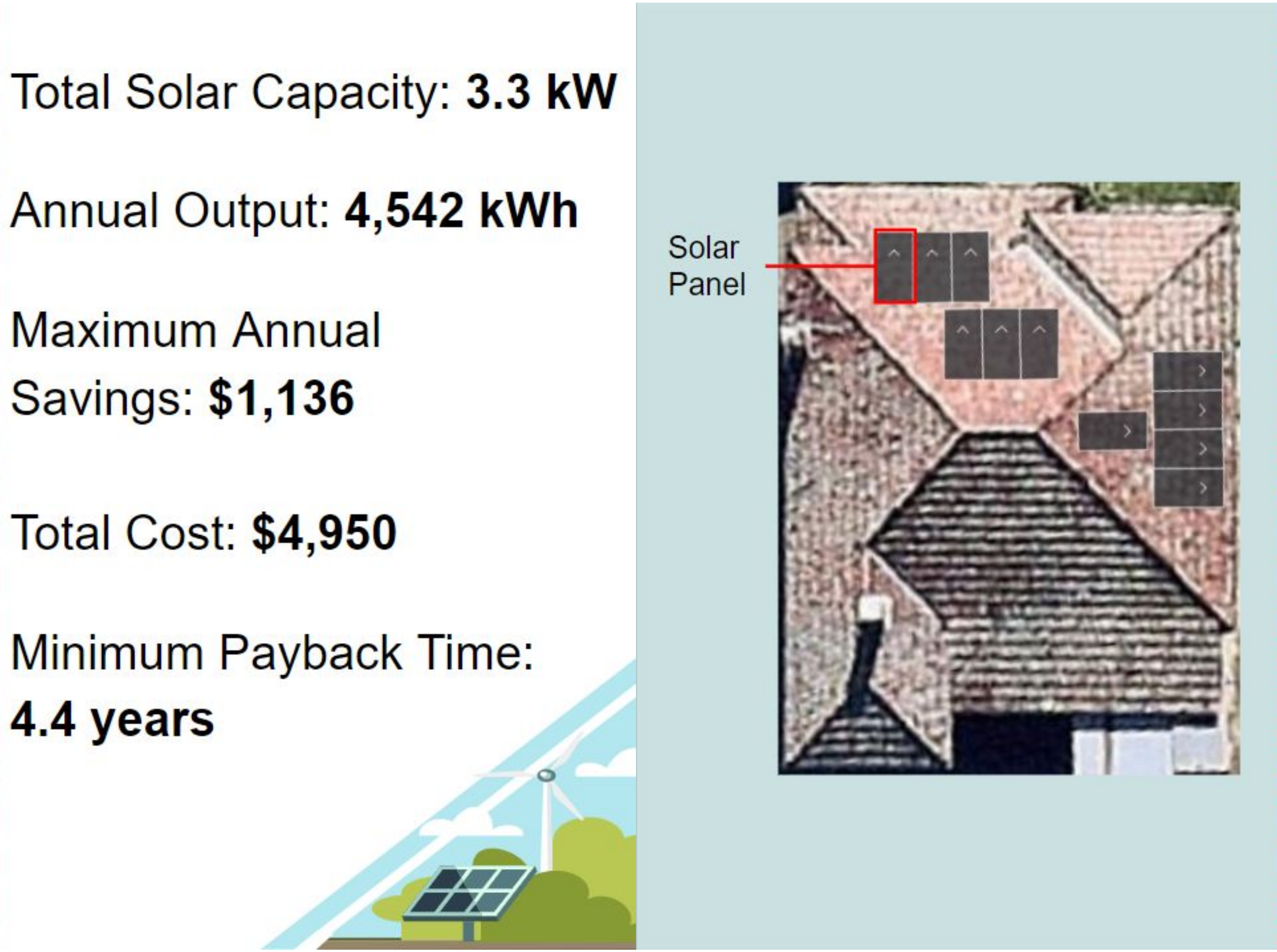


Figure 19: Example of a Home's Nearmap Solar Capacity Data in the Pamphlet

Final Event Agenda

What: Halpin Street Neighborhood Recommendations
When: Dec 10, 2019 at 7pm
Where: St. Ambrose Church - 287 Sydney Rd, Brunswick VIC 3056

Details:
Name Tags
Rishi “Ask me about neighborhood grids”
Anavat “Ask me about monitoring systems”
Deanna “Ask me about your next steps”
Agenda:
6:30 PM - SET-UP
7:00 PM - ARRIVAL
7:10 PM - INTRODUCTION
7:30 PM - OPEN HOUSE
8:30 PM - WRAP-UP

Figure 20: Agenda Overview for the Final Community Event

Commentary:

7:00PM- ARRIVAL

- Residents make a name tag with their name and house number
    - Deanna waits by the door to greet people and guide them to make a name tag

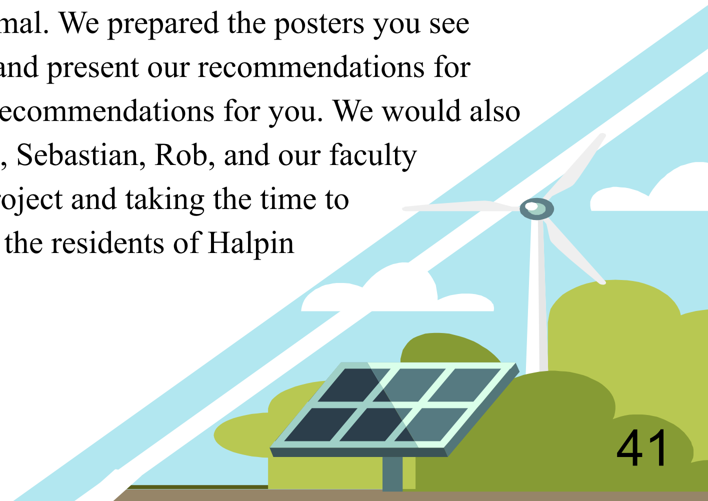
7:10PM- INTRODUCTION

- Rob Catchlove - Community member from Halpin Street introduction
- Sebastian Klein - AEF member/our sponsor introduction

Acknowledgement of Country “We acknowledge the Traditional Owners of country throughout Australia and recognise their continuing connection to land, water and culture. We pay our respects to their Elders past, present and emerging.”

Our Introduction

- We introduce our names “Hello, I’m Deanna, I’m a double major in robotics engineering and professional writing” “I’m Anavat, double major in robotics and mechanical engineering” “and I’m Rishi, majoring in mechanical engineering”
- Rishi - “As mentioned we are students from Worcester Polytechnic Institute from Massachusetts. We have been working on our 3rd year project for the last 15 weeks and gives us the opportunity to work on a project that interests us that we might not have necessarily had the opportunity to participate in on campus. As mentioned before, our project is ‘Taking the Power Back: Designing a Replicable Neighborhood Grid for the Residents of Halpin Street’ with the goal of determining the journey of implementing a neighborhood grid. We began with a literature review of microgrids - to learn about the key components and research options for this neighborhood. We then evaluated each home’s solar capacity with a solar mapping software called Nearmap to determine which homes are optimal for solar panels and which might participate through supporting an energy storing battery. We also conducted interviews with local energy companies and residents to determine their interests and the best options for the neighborhood.”
- Anavat - “We were able to identify the best option for energy generation (solar panels), storage (batteries), and the ideal number and placement for the panels. We also determined which monitoring systems are optimal. We prepared the posters you see around the room in order to share our journey and present our recommendations for Halpin Residents. We would like to share our recommendations for you. We would also like to thank the Australian Energy Foundation, Sebastian, Rob, and our faculty advisors for helping to guide us through this project and taking the time to work with us as we helped find what best suits the residents of Halpin Street.”



- Deanna - “Around the room we have a series of posters beginning with an overview of the 4 main steps communities must take to plan a neighborhood grid. The remaining posters contain information on solar panel and battery installation, monitoring systems, and the benefits of each. We would like you to read these and find what interests you and encourage you to ask us questions. We have actually made a pamphlet for residents that not only contains your solar home assessment but also some financial estimates. We also included a set of four color stickers that correspond to specific actions you might want to take. This is explained both in your pamphlet and on the poster in the back in more detail, but we ask all the residents who are here to place the appropriate colored stickers onto your home (each house is numbered so you can find yours). The red stickers means you are interested in installing a monitoring system. The yellow is installing solar panels on your home and green denotes neighborhood battery interest. Finally, the blue is interested in learning more about a community electric car share program. Although this does not commit you to any decisive action, it will give us a picture of neighborhood interest and preferences as a whole, which will help the community calculate what it can save in energy costs if everyone works together. If you are a resident, we ask you to go to the table (gesture towards table) you can pick up your customized pamphlet based on your address and please ask one of us if you have any questions.”

7:30PM - OPEN HOUSE

We disperse into the room, Rishi walking towards the grid data, Anavat to monitoring system implementation, and Deanna to the interactive home map poster (the stickers). Each of us will ask residents if they have been interviewed already. If yes, move on with small conversation to lead into the poster they approached. If no, direct towards Rishi who will have the interviews set up on a laptop nearby at a table to answer the questions.

- Anavat will answer technical questions to those who want to know more details of monitoring systems and technicalities of neighborhood grids and how they function.
- Deanna will be directing people to the map in the back and encouraging people to take action to implement their interest, the benefits of it, and what the next steps are.

8:20PM - WRAP-UP

- Deanna (walks up to front/place of intro again) “Hello everyone again. It is now 8:20 and our event is wrapping up. We would like to thank you all again for attending and participating in our final event and for your support. We will be here a little longer to clean up and answer any more of your questions.”

Website

Our final deliverable was an in-depth how-to website overviewing the neighborhood grid journey and providing links to more information. We drew on the writing conventions detailed in SM-J to draft each section of the website (see Figure 21 for the home page and main tabs). The purpose of this website is to provide the type of information on energy generation, storage, and monitoring that we depicted on our posters and in our Background chapter and to guide interested neighborhoods through the four steps we described above in our posters. The AEF plans to use this website as a place to guide other communities interested in developing their neighborhood grid as they would not always have the posters or pamphlets for guidance and could, therefore, rely on the website. As the website currently stands, the AEF plans to take ownership of the site to adjust the colors and add their images to the already provided textual documentation.

Figure 21: Website Home Page

Conclusion and Recommendations

Here we provide general recommendations and conclusions that might be useful for the residents of Halpin Street and other groups who might work on similar projects.

Takeaways from Our Solar Mapping Process

Nearmap was useful in mapping the number and placement of solar panels on specific homes and in generating data on each home's maximum solar capacity. However, there were no features in the software that calculated how shade from trees and other obstructions might reduce maximum output. We had to manually place panels on unshaded parts of the roof. We additionally had to estimate full installation and unit costs of a kW of panels as the brand and specific price of panels can vary between different distributors. We could have contacted one of the solar providers to ask about their unit costs, but we did not have time to do so.

Takeaways from Interviewing Residents and Contacting Companies

The interviews and surveys that we conducted were some of the most challenging tasks we had for this project. Initially, we thought this would be quite simple; however, we had limited email contact information to conduct an online survey and had difficulties in getting residents to answer the door. Sometimes, there were language barriers, and other times they kindly told us they were not interested. If we had started knocking on doors earlier, we might have collected more data. We drafted the questions early but had to go through several revisions based on feedback from our professors and sponsor before finalizing the question set. Email responses were also slow to come in and were not as detailed as we first thought they might be. We suggest future teams finalize and begin sending their survey questions at the end of the prep term or the beginning of the IQP term, if possible.

Receiving email responses from the energy companies was also quite slow. The AEF requested their employees, who already had professional relations with the companies, call to introduce the project and send our questions for business relations. However, responses from the companies came in slowly. In week four, we were able to contact the companies directly by phone responses. Looking back, making these direct phone calls ourselves from the second week may have speeded up the process and allowed us more time to follow up with other companies.

Our Recommendations for the Monitoring System

Having a monitoring system is essential for the residents of Halpin Street because knowing the energy produced and used will enable energy sharing between the residents. The most feasible systems for homes on Halpin Street are SwitchDin and EdgeElectrons. SwitchDin has a higher unit and installation cost at 330 AUD, with an annual subscription cost of 60 AUD compared to EdgeElectrons' bulk purchase cost of 209 AUD. However, the EdgeElectrons monitoring unit needs to be purchased with smart plugs if the residents want to control up to six home appliances at a time, which adds an extra cost of 50 AUD. Even with this added cost, their monitoring unit should cost less than the SwitchDin unit if purchased in bulk. As such, we recommend interested residents of Halpin Street to collectively decide on and purchase EdgeElectrons units to reduce financial burden.

We recommend interested residents purchase SwitchDin monitoring units if they want more control over their appliances, however. In terms of features, SwitchDin is slightly better suited than EdgeElectron in controlling household appliances since the SwitchDin units can variably manage the power settings of an appliance instead of merely turning it on or off as Edge Electrons' smart plugs allow. We suggest residents wait for the AEF and Rob Catchlove to contact ABB, Mondo, Simble, and Ovida about their monitoring systems before finalizing orders with the brand of choice.

Recommendations from the Interview and Survey Responses

Based on the interview and survey responses to date, 12 of the 20 responses we received were interested in participating in the neighborhood grid; however, some residents wanted to know more about the features and options for different microgrid components because they were unsure of what they entailed precisely. For this reason, we recommend that Catchlove and other organizers continue to inform residents of options. Residents did show interest in installing solar panels, but some were hesitant in installing from lack of knowledge about its lifespan and quality options. We gave a general overview of varying panel prices and quality levels available in the market at our event. Still, final costing is reliant on the company, bulk buy, and rebates. Similarly, we gave a general overview of different battery features and prices for residents unsure about investing in batteries. Additionally, we highlighted the importance of the monitoring system because it is the first step needed to acquire cooperative energy data to help improve household habits and helps provide evidence for each home's energy usage. This data will later help finalize the number of solar panels and batteries that the residents need to follow through with the neighborhood grid.

We have suggested Sebastian Klein, Rob Catchlove, and the AEF continue to conduct interviews and reach out to homes that we could not reach. A table in the Results chapter (Table 2) lists homes we were unsure about, that were not interested, and that were interested. We suggest reaching out to the homes that we were unsure about, since we were unable to get in contact with most of them.

Since face-to-face interviews is the only method of contacting homes for which we lack email addresses, several door-to-door survey attempts will be needed to determine whether those residents are willing to participate.

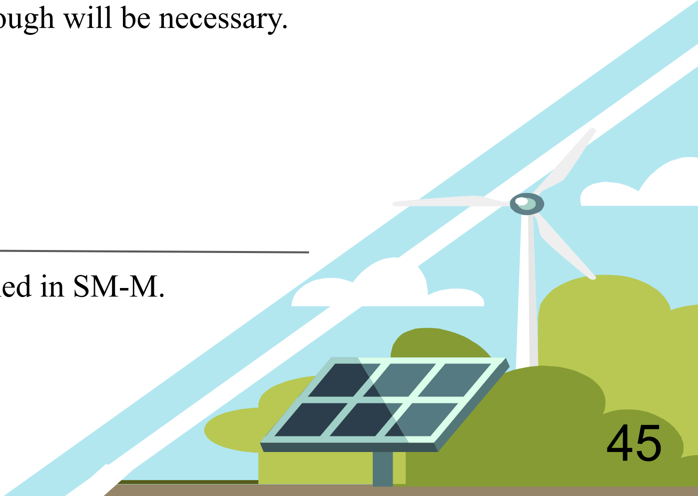
Setting Concrete Future Goals for Implementing the Grid

The Halpin Street neighborhood grid was a pilot project to test the journey of neighborhood grid development's feasibility, the four steps are outlined in the Results chapter. We began the process of the first three stages of: "Gauging Interest," "Understanding Grids," and "Assessing Feasibility." We found of those we were able to contact had a positive interest, had a basic understanding of electrical grids, and we were able to assess the street's feasibility for solar through our mapping software and interviews. Our next step is for the neighborhood to implement the components of a neighborhood grid that interests them. We detailed several steps that we recommend the community take to create a neighborhood grid:

1. Installing a monitoring system to monitor and track the energy usage of each resident's home to get a basic understanding of each home's energy situation. The residents interested in installing a monitoring system should come together in a community meeting and approach either SwitchDin or EdgeElectrons to purchase the units through a cheaper bulk-purchasing scheme.
2. Evaluating their energy consumption behaviors and altering some of their habits based on the advice provided in the booklet and on the AEF's site. Additionally, they can take a look at the AEF's recommendations to create an energy-efficient home.
3. Planning the number of solar panels and batteries for each home based on each home's energy consumption data from the monitoring system.
4. Collaborating to decide how many panels and batteries need to be purchased communally to secure a competitive unit price through bulk purchase.
5. Taking action for future additions and improvements to the neighborhood grid, such as a communal battery, a community solar farm, and/or energy trading services between homes. This information was expanded upon at the final event as well as on the website.
6. Setting up community meetings, similar to our BBQ event, prior to completing each of the steps, with additional suggestions and guidance found on our how-to website.

In sum, this project investigated a rapidly developing and evolving energy system that has the potential to transform how we view and act on our energy needs. Neighborhood grids have the potential to ease pressure on the national grid, delay costly substation upgrades, provide a secure electrical network, and, most importantly, be a sustainable solution. A microgrid allows people to become self-reliant and independent from electrical companies, and Halpin Street has shown a willingness to participate in implementing a neighborhood grid. We have been able to demonstrate the financial and environmental viability of neighborhood grids, but for any of this to be successful, it needs the community's commitment, and follow-through will be necessary.

Author contributions to this project are outlined in SM-M.



Acknowledgements

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- Our Sponsor, Sebastian Klein and the AEF: Thank you for always being supportive and willing to help us with any issues we encountered.
- Halpin Street Resident, Rob Catchlove: Thank you for providing us with this exciting opportunity to work on a very impactful project on your street. We appreciate the guidance you have always strived to give us despite your busy schedule.
- Halpin Street Residents: Thank you for being supportive of our project and actively participating in the events we have organized. We wish you all the very best and hope the street will be a well functioning neighborhood grid in the near future!

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