Regional and Remote Communities Reliability Fund Microgrid

MyTown Microgrid

Heyfield local energy options: techno-economic analysis

Part 1 Energy options: initial results

Milestone 3.4a – February 2022

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Key support

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Wattwatchers Digital Energy
AusNet Services
Heyfield Community Resource Centre
Latrobe Valley Authority

About the project

MyTown Microgrid is an innovative, multi-year, multi-stakeholder project that aims to undertake a detailed data-led microgrid feasibility for the town of Heyfield (Victoria), built on a platform of deep community engagement and capacity building.

The project received funding under the Australian Government's Regional and Remote Communities Reliability Fund Microgrids stage 1 funding round. It also received funding from the Latrobe Valley Authority as part of the Gippsland Smart Specialisation Strategy.

Citation

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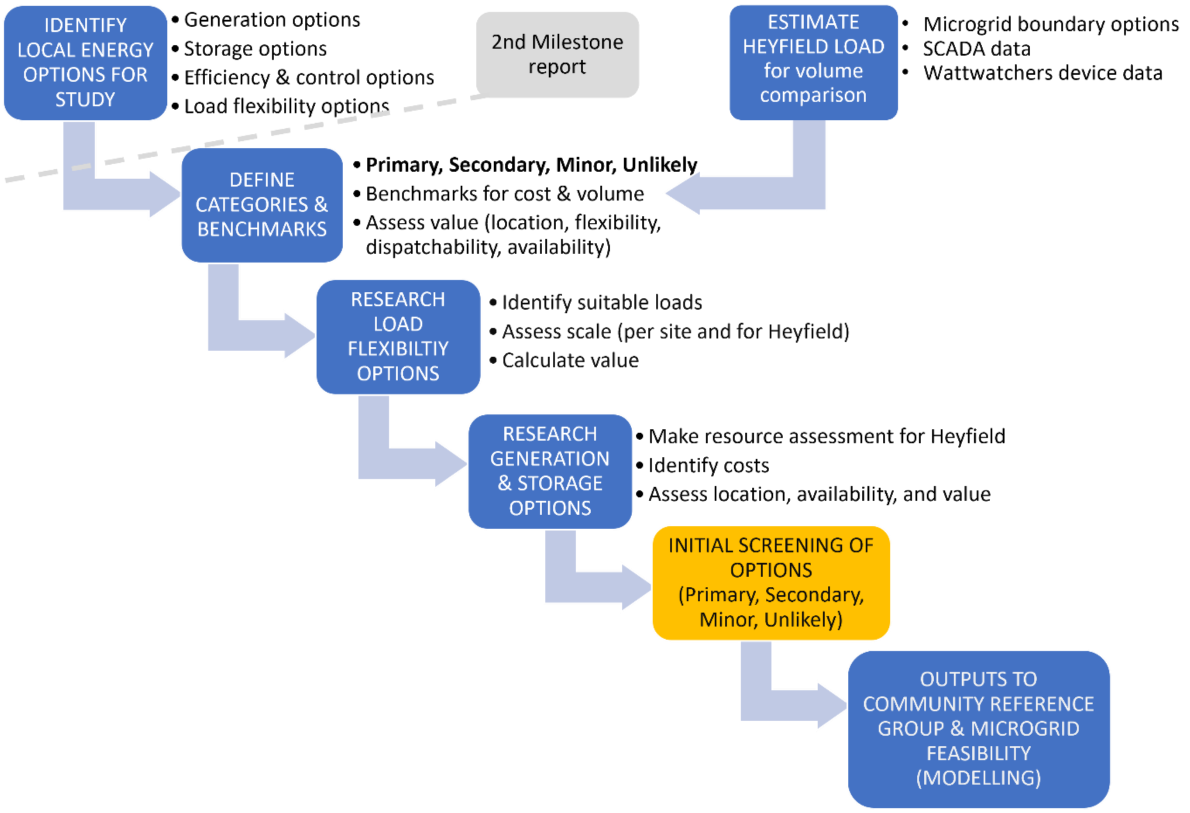
Executive Summary

The Heyfield MyTown Microgrid project is undertaking a detailed data-led microgrid and energy solutions feasibility for the town of Heyfield, Victoria. This analysis of the local energy options is part of the Techno-Economic Work Package and is one element of milestone 3.4. It provides the foundation for further analysis of local energy options, to see whether options meet community aspirations, and are feasible, viable, and desirable. It also covers the process used to arrive at these options. During the next stage of the project results from this work will be used for the initial feasibility study for a microgrid.

The figure below gives an overview of the approach. The options identified in the previous phase were the starting point, followed by defining the classification and benchmarks, and research and analysis to understand the options themselves.



Process for energy option screening

Option classification and benchmarking

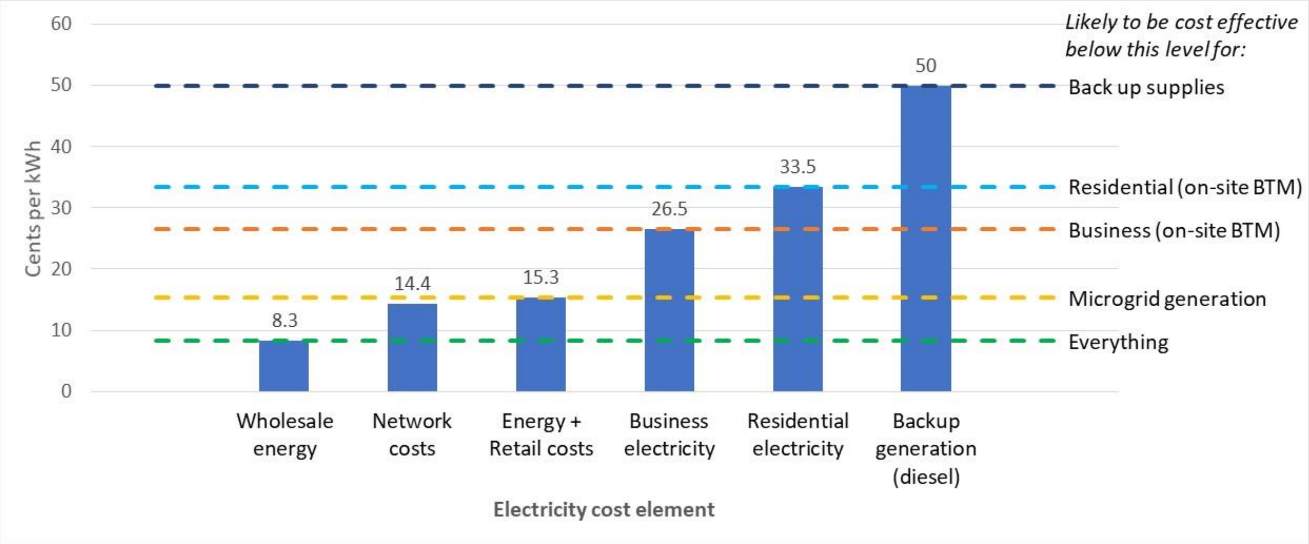
This report classifies local energy options as **primary**, **secondary**, **minor**, or **unlikely**.

- A **primary** role will require accurate assessment of the option for further use in modelling.
- A **secondary** role means the option is worth considering, albeit with less detail
- A **minor** role means the option is unlikely to make a major contribution to Heyfield's energy mix.
- **Unlikely** indicates the option is not feasible at this stage, and the team will not investigate further.

The assessment considers overall costs, usually expressed as Levelised Cost of Energy (LCOE), availability by time of day and season, location with respect to load, energy option volume, and its value in terms of flexibility and dispatchability (that is, the ability to respond to demand, and in the case of storage, ability to respond for minutes, hours, days or months). The resource volume is compared to Heyfield's estimated annual load.

Benchmarking costs

The levelised cost of energy (LCOE) or of storage (LCOS) is the cost per unit of energy over the project lifetime considering the amount of energy generated or stored, the capital cost, the fixed and variable operating cost, and financial parameters such as the discount rate. LCOE is presented in cents per kWh so it can be compared to other energy options and those elements of electricity costs that could be offset. The relevant electricity cost element varies according to where the energy option is located and what it's doing. The figure below shows electricity price elements and indicates when different energy options may be cost effective. For example, a local energy option may need to cost less than 26c/kWh to be cost effective behind the meter at a business premises but might be cost effective up to 33c/kWh behind the meter at a residential premises. Lower than 8c/kWh it's likely to be cost effective anywhere.[1]



When is Victorian local energy likely to be cost effective?

Efficiency and control options

Energy efficiency and load control are frequently cost-effective options and will lead to improved economics for any community-wide solutions. They should generally be considered before other options, as pay back is relatively quick, and they can reduce the cost of more complex options. Both a microgrid and other energy sharing options will work best if they are preceded by a solid investment in energy efficiency and in making key loads flexible via improved control.

Load flexibility and demand response will become increasingly important as we move towards a 100% renewable electricity supply with high amounts of variable renewables such as wind and solar. Demand response is the name given to controlling loads to manage peaks on the network, by switching loads off or down to balance supply and demand; this can be a paid service. To gain the value from load flexibility, either as demand response or just to take advantage of generation behind your own meter or within a microgrid, a means of controlling the load is needed. The best time to set up appliances with control capability is during the purchase and installation process.

Generation options

Heyfield uses around 17 GWh per year of electricity and over 25GWh per year if non-electrical energy is included. For the purpose of screening and classifying generation options, 20 GWh is considered to be "one Heyfield". Solar, wind, biomass, biogas, hydro, and geothermal were considered. Heyfield already has significant uptake of rooftop solar and uses backup diesel generators at a number of sites.

[1] The actual benchmarks (wholesale, energy and retail, network cost, and customer electricity costs) are based on the Essential Services Commission review of the Victorian default offer for 2022.

Biomass is a familiar energy source in Heyfield due to the timber industry, with the majority of homes using wood heating. Australian Sustainable Hardwoods (ASH) is investigating a biomass plant using sawdust, and their resource is approximately equivalent to Heyfield's electrical load. However, biomass is treated as a secondary option because majority control is with the timber mill and usage will be guided by its market and economic interests, so it cannot be assumed a biomass generator would be integrated in a microgrid.

Storage and flexibility options

In a microgrid, Heyfield would require between one quarter to one half of its electricity production to be stored or used flexibly, so the storage requirement is expected to be somewhere between 5 and 10GWh. There are many different types of energy storage and flexible load, categorised here as:

- **Electrical storage** – such as batteries or flywheels.
- **Fuel storage** – in dispatchable generation sources (such as bioenergy or diesel) the fuel is the storage. Hydrogen is a specific example of a fuel which can be produced from electricity.
- **Load linked energy storage –** this includes water storage (associated with pumping), thermal strorage for heating and cooling, flexible loads, and future loads such as electric vehicles.

Electrical storage is needed for variable generation such as wind and solar, as when there is a mismatch between the electricity produced and the electricity required, the surplus needs to be stored, dumped, or exported to the main grid. Fuels may be directly associated with the relevant generation (such as sawdust), or, in the special case of hydrogen, produced from electricity. Load-linked energy storage needs to be weighed against the electrical or fuel storage options because it reduces the capital investment in storage that might otherwise be required for Heyfield, and storage options are not cheap.

Table 1 summarises the energy options considered, with an indication of scale and cost. Efficiency, generation, storage, and load flexibility options are classified as primary, secondary, minor, or unlikely; some of the minor opportunities have been identified as potential candidates for trials or demonstrations.

Table 1 Summary of energy options considered for Heyfield

Energy option	Volume compared to load	Cost	Relevance for Heyfield
ENERGY EFFICIENCY OPTIONS			
Hot water	4% x Heyfield	Medium	Primary
Conversion from LPG	1.5% x Heyfield	Medium	Primary
Heating and cooling	2% x Heyfield	High	Secondary
Lighting	1% x Heyfield	Low	Secondary
Energy efficient appliances	0.7% x Heyfield	Low	Secondary
Additional commercial/ industrial	Unknown	Site specific	Secondary
Refrigeration	0.2% x Heyfield	Medium	Possible trial
Compressed air	0.2% x Heyfield	High	Minor
Pumping	0.3% x Heyfield	Medium	Possible trial
Streetlights	0.5% x Heyfield	Low	Possible trial
GENERATION AND STORAGE OPTIONS			
Solar PV	Many x Heyfield	Low	Primary
Batteries	Budget limited	Medium	Primary
Wind	Many x Heyfield	Low	Secondary
Biomass	1 x Heyfield	Low	Secondary
Hydro	10% x Heyfield	High	Minor
Biogas	1% x Heyfield	Medium	Minor
Geothermal	Many x Heyfield	Very high	Minor (for heat)
Solar thermal	Many x Heyfield	Very high	Unlikely
Flywheels	Budget limited	High	Unlikely
Hydrogen	Budget limited	High	Unlikely

Energy option	Volume compared to load	Cost	Relevance for Heyfield
LOAD LINKED STORAGE OPTIONS			
Hot Water	8% x Heyfield	Low / medium	Primary
New loads	15-30% x Heyfield	Low	Primary
Building heating and cooling	4% x Heyfield	Medium/ high	Secondary
Refrigeration	3% x Heyfield	Low	Possible trial
Pumping and flexible loads	3% x Heyfield	Low	Possible trial

Results

Examining generation and storage options, the load in Heyfield could be met many times over. Quantified energy efficiency opportunities could reduce load by approximately 10%. Looking at load flexibility options, nearly 40% of the load could become flexible as the town grows, with the value of this flexibility estimated to be in the order of several hundred thousand dollars annually. These options can reduce the overall cost or increase the value of most other local energy options, and will almost always be cheaper than storage, However, implementing flexibility options will require a wholistic and co-ordinated approach to energy system development

Next Steps

A program of work should be developed for delivering generation and storage options on an “on-site first”, basis to prepare the town for a microgrid or other energy sharing platform. Starting with short payback projects that can be funded on a no-regrets basis, some of this work will revolve around business models that allow the community to facilitate, fund and deliver projects. An on-site first strategy could create a town full of energy customers who are ready for the future energy system. In the case of the options identified as suitable for a trial or a showcase, there is value in investigating programs willing to provide funding. Many of the investment decisions largely rest with building owners and tenants, however, the community benefits that a program could deliver might be sufficient to prioritise and identify ways to fund some strategic investments.

Community engagement, business model co-design and microgrid modelling are all underway. This report is intended to inform those activities and empower the Heyfield community to choose its own energy priorities. The following next steps are recommended:

1) **Community discussion to choose priority options**: a series of primary, secondary, and minor energy options have been proposed, with suggestions for progressing each option individually. It is recommended the Community Reference Group spends time understanding these options, the proposals and uncertainties, and defining its own priorities.

2) **Microgrid modelling** – initial feasibility: microgrid modelling has commenced and will initially focus on only those generation and storage options identified as primary or secondary, as these are the lowest cost and can easily meet the Heyfield’s requirements. The data collected on cost and load and volume will inform the modelling and initial scenarios.

3) **Investigate missing information**: Around 20% of the measured load has not been well understood in this initial screening. The commercial and industrial loads identified from an inventory of businesses do not cover those that are unallocated, and the number of farms and pumping loads falling inside the chosen boundary is unclear. Further data from Ausnet Services and ongoing discussion with energy users in Heyfield will provide more clarity on these loads and the associated energy opportunities.

4) **Undertake additional investigation into energy efficiency potential**: A deep retrofit strategy targets energy efficiency savings in excess of 30% by investing up front in very energy efficient building form and equipment, and the analysis to date has not included sufficient detail to understand this opportunity.

5) **An “on-site first” strategy is recommended.** This is partially an extension of the activities underway for most of the last decade, however it is recommended promotion of energy packages are extended to include both deep energy retrofits, and significant amounts of load flexibility.

Contents

List of tables and figures

List of abbreviations

Abbreviation	Description
BTM	Behind the meter
CRG	Community Reference Group
CSIRO	Commonwealth Science and Industrial Research Organisation
DELWP	Department of Environment, Land, Water & Planning
DER	Distributed Energy Resources
DRED	Demand response enabling device
kV	Kilovolts
kWh	Kilowatt hour
kWhe	Kilowatt hour electrical (a kilowatt hour is a measure of energy and can refer to either heat or electrical energy. In some systems if is useful to specify which is meant).
kWp	Kilowatt peak
LCOE	Levelised cost of energy
LGC	Large-scale generation certificate
LPG	Liquified petroleum gas
LV	Low voltage
MV	Medium voltage
MVA	Mega-volt ampere
MW/MWh	Megawatt /Megawatt Hours
n/a	Not available
PV	Solar Photovoltaic
STC	Small-scale Technology Certificate

1. Introduction

The Heyfield MyTown Microgrid project aims to undertake a detailed data-led microgrid and energy solutions feasibility for the town of Heyfield (Victoria), built on a platform of deep community engagement and capacity building. Over the three-year duration, the project will also develop the knowledge and tools to make it faster, easier, and cheaper for other regional communities to understand microgrid and other energy solution propositions for their community.

This initial analysis of the local energy options for Heyfield is part of the Techno-Economic Work Package 3 and is one element of milestone 3.4, Analysis Results (techno-economic assessment of energy portfolio options). This report is the Part 1 of Milestone 3.4 and should be read alongside *Part 2 Boundary options: revised results*. During the next stage of the project the results from this work will be used for the initial feasibility study for a microgrid.

This report provides the foundation for further analysis of local energy options, to see whether options meet community aspirations, and are feasible, viable, and desirable. It also covers the process used to arrive at these options.

This analysis aims to serve three purposes. Firstly, it provides a rough assessment of each option to identify those that could play a significant role in the project; secondly, it provides more detailed parameters for those potentially significant options, and thirdly, it aims to provide guidance for future communities on how to identify options suitable for their own circumstances. The report includes:

- An overview of the process used to determine and classify options, and identify those worthy of further investigation
- A discussion of generation options
- A discussion of storage options
- A discussion of energy efficiency and control options
- An option comparison and discussion of next steps.

Details of assessment tools and sources for generation options are provided in Appendices B (wind, solar, hydro, and geothermal) and D (biomass).

This report will form the basis for further analysis of the local energy options for Heyfield. Many of the options described will be applicable for many communities.

2. Approach

Figure 1 gives an overview of the approach to this initial screening of local energy options. The options identified in the previous phase of the project were the starting point, followed by defining the classification and benchmarks to be used.

Considerable work has gone into assessing the load in Heyfield, in to compare relevant volumes, with desk-top research to find the inputs for resource assessments and costs. Following analysis to calculate comparative costs, recommendations are made for the energy options to investigate further, and the parameters such as cost, volume, and value associated with each option are listed.

These options will be considered by the community reference group and the parameters will be used in modelling of the microgrid.

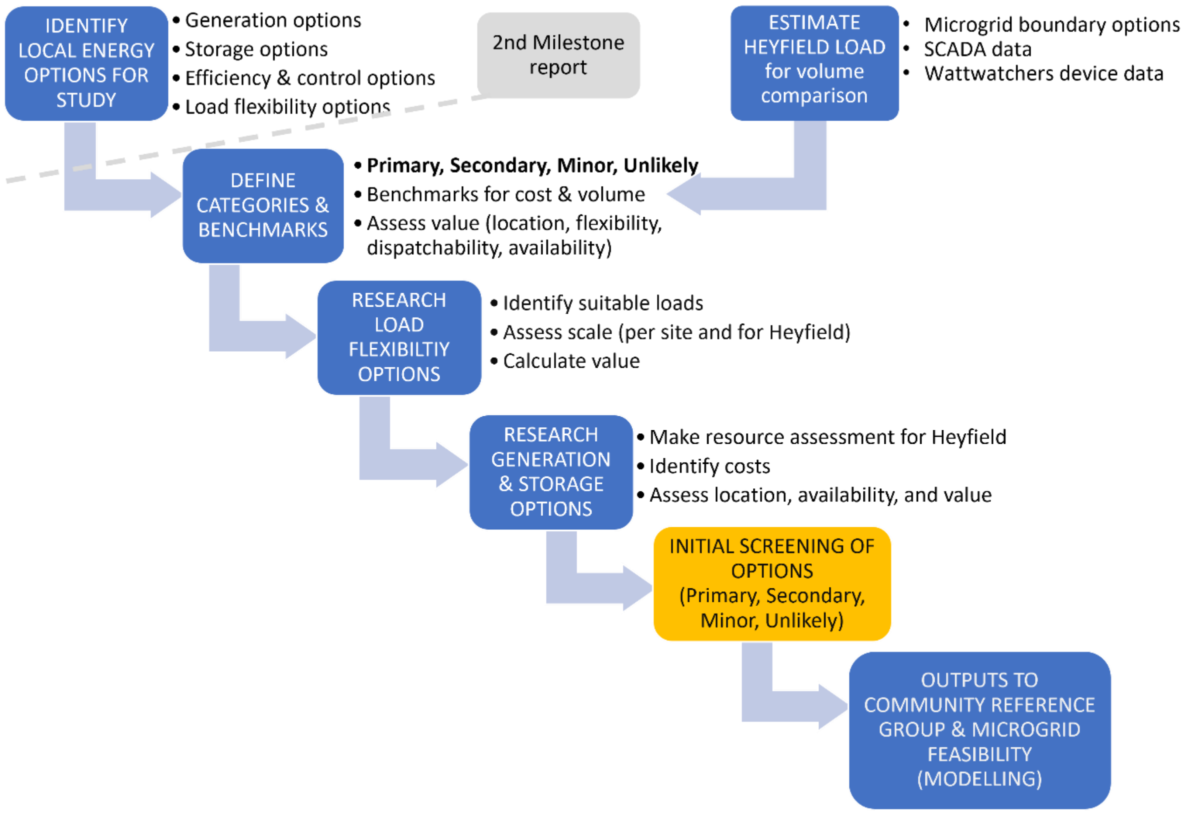


Figure 1 Process for energy option screening

The MyTown Microgrid Heyfield project considers three main areas of activity:

- **On-site investments** – carried out at customer premises, usually paid for by the individual or business. On-site options include energy efficiency, load control, generation, and storage. Investments are ‘behind the meter’ (BTM), and so maximise returns from avoided energy costs, so a more expensive option can still be cost effective.
- **Microgrids**: if grid connected, these have a single meter point where they connect to the grid, and are able to “island” from the main grid and continue to supply electricity when there has been a power outage on the electricity network. Anything on the microgrid would be ‘behind the meter’ from the point of view of the microgrid operator.
- **Energy sharing:** between solar generators with excess and their neighbours has always been a driver for this project. A microgrid is one way to enable sharing, but there are others, such as Virtual Power Plants or community batteries.

Many generation and storage options could be implemented as centralised options in a microgrids or as on-site options, although the threshold for being cost-effective will be different. The scale will also be different, as if an option is not behind a customer meter it would generally be scaled up.

Energy efficiency options are nearly always on-site options, but may be considered differently if they are part of a suite of measures intended to make a microgrid more cost effective. Load control can be implemented either for a single customer response, or as an aggregated response.

This report examines the options suitable for on-site or microgrid application, with the aim of identifying options worth of detailed consideration, but does not investigate sharing options as such.

2.1 Classification of options

This report provides an initial assessment of each option in order to understand the role it is likely to play in local energy options for Heyfield, classified as primary, secondary, minor, or unlikely.

- A **primary** role will require accurate assessment of the option for further use in modelling.
- A **secondary** role means the option is worth considering, albeit with less detail, and any inaccuracies can be represented as project uncertainties.
- A **minor** role means the option is unlikely to make a major contribution to Heyfield's energy mix, and the modelling and microgrid costs would not alter if the option becomes available.
- **Unlikely** indicates the option is n not feasible at this stage, and the project team will not investigate further. Some ideas will be presented about what might make it feasible in the future.

2.1.1 Benchmarking the options

In order to classify each local energy option as primary, secondary, minor or unlikely, the assessment considers these parameters:

- Energy costs, usually expressed as Levelised Cost of Energy (LCOE)
- Value of the resource, according to its availability at time of day and season
- Location of resource with respect to load
- Volume of the resource (for example, wind and solar are abundant, biomass, biogas and hydro are available only in fixed quantities).
- Storability / dispatchability of the resource – can it respond to demand, and if storage is being considered, is it for minutes, hours, days or months?
- The overall diversity of resources will also be considered, as a mixture of sources gives additional resilience.

Technologies and energy options change over time, especially as the drivers for a clean energy future become stronger and costs change, and each assessment makes multiple assumptions about the value, volume and cost. Instead of screening out options completely, two questions are answered:

- Under what circumstances would this option become worth considering again?
- Would inclusion of this option alter the detailed modelling materially?

2.1.2 Community acceptance

Community acceptance also needs to be considered. In mid-2020 a survey of community member[1] included a list of technologies (shown in box 1) and asked the question "*What renewable energy technologies would you like to see being used Heyfield and its local region?"*

BOX 1: TECHNOLOGIES INCLUDED IN SURVEY PICK LIST

- Rooftop solar PV for homes/ business
- Solar farms
- Wind energy
- Small-scale hydropower
- Pumped-hydro storage
- Bioenergy from waste (e.g. wood, food, sewage)
- Bioenergy from any source (e.g. forestry, crops)
- Small scale batteries (in homes and business premises)
- Community batteries (larger batteries shared by multiple homes and business)
- Other

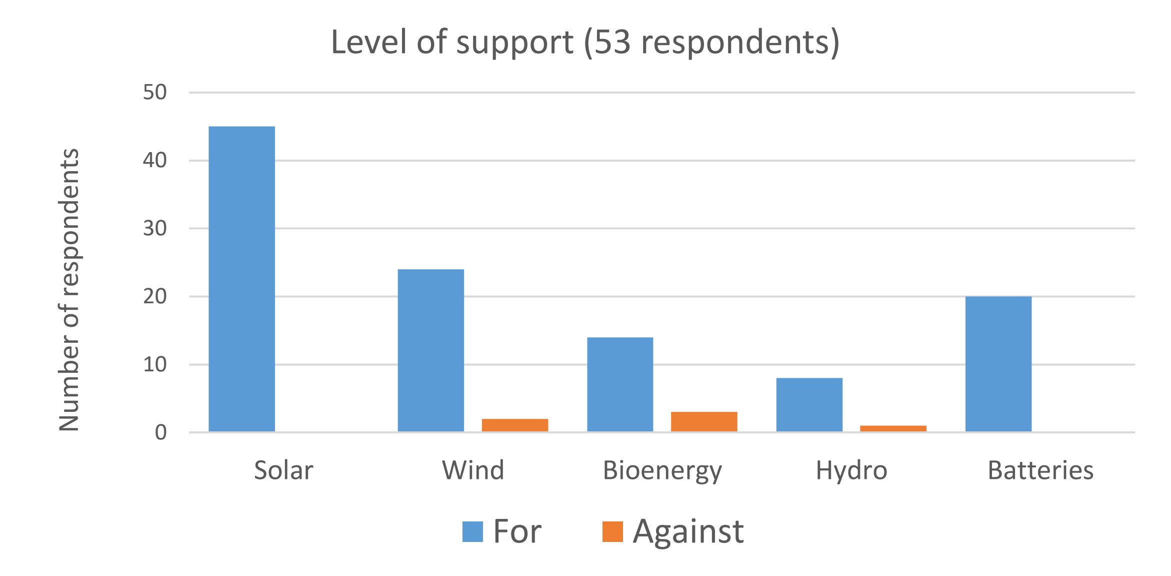


Figure 2 Survey results reflect community attitudes to different renewable resources

There was very high support for solar generation (85% of respondents), with more mixed responses for wind, bioenergy, and batteries. These three technologies raise some issues for community stakeholders that should be considered before implementation.

2.1.3 Community motivations

In vision workshop in May 2021, Heyfield stakeholders gave the following reasons for pursuing a microgrid project:

- **Political**: local ownership, community income, empowering community, providing emergency support
- **Social**: encouraging community, community resilience, emerging support, building a cooperative community, increasing rapport and less opposition, ensuring community trust, and community engagement
- **Economic**: post covid jobs, economic viability, equity and empowerment, community sharing of power, extending to other areas, community income, local jobs creation, Protecting community asset
- **Environmental**: environmental benefits, reduce damage, reduced emissions, environmental sustainability,
- **Technical**: future securing and resilience of system with battery storage, increased efficiency, switch to islanded condition when needed, ensuring energy security

The breadth of issues raised by stakeholders highlights the need to consider all the ways that new approaches to energy supply can improve community life beyond simple financial considerations.

2.1.4 Benchmarking cost

The levelised cost of energy (LCOE) is the calculated cost per unit of energy over the project lifetime taking into account the amount of energy generated, the capital cost, the fixed and variable operating cost, and usually some financial parameters such as a discount rate for future costs and income (such as inverter replacement for PV, and the cost of borrowing).

LCOE is generally presented as a range of possible costs because capital cost, operating costs, the resource itself, and the equipment utilisation can vary significantly. LCOE is calculated based on the kWh generated over the project life, which varies with the resource but also the demand for the equipment – for example, the return on a bioenergy generator will depend a great deal on how much of the time it can be run. LCOE costs should therefore be treated with caution. True costs will be higher if the energy option does not achieve the predicted utilisation.

LCOE is presented as a cost in c/kWh so it can easily be compared to other energy option LCOE, to current electricity prices, or to elements of current electricity costs that the option could offset. These are the main benchmarks that can be used to find out whether a particular energy option is likely to be cost effective (bearing in mind that the benchmarks will change over time, as well as the LCOE for the option).

- **Wholesale energy costs** are predicted to average 8.3c/kWh for residential consumers in 2022[2]. These are often used as a benchmark to understand how competitive different sources of generation are. If a particular local energy option can match the wholesale energy cost it is almost certainly going to be highly cost effective, as wholesale energy costs come from large scale commercially operated generators.

- **Network costs** identify the average cost of delivering electricity across Victoria. Actual costs vary widely, for example Heyfield is rural, and while it is not too far from major power stations, network costs are likely to be higher than average, as costs in urban areas are considerably lower because of the density of occupation. Long lengths of line are costly and associated with serving much of the district. Generation from rooftop solar systems avoid network charges (provided it is used on-site) because the systems are located 'behind the meter', so the generation used on-site is not measured, and therefore not charged. However other local forms of generation or methods of energy sharing are charged under our current system, although they do not use very much of the network and could contribute less to network costs. This is a complicated calculation as much of network cost is determined by the *peak* load at any point on the network rather than the volume of energy that passes through it. Local generation within a microgrid is effectively behind the meter of the microgrid, so would avoid or reduce those network charges – although of course you would still have to pay the costs of maintaining the microgrid itself.

- **Energy and retail costs** are the main charges that can be avoided or reduced by local generation – although local generation may still be associated with some retail costs (mainly customer acquisition and billing). If local energy options are between 8.3c/kWh (wholesale energy) and 15c/kWh (energy and retail), then they are likely to be cost effective for local consumers and should be considered.

- **Electricity charges (business and residential):** these are the charges actually paid by consumers, so if the generation is behind the consumer meter it will be cost effective if the LCOE is less than the relevant per kWh volume charge (noting that electricity charges are made up of fixed charges, volume charges, and load charges) It is worth understanding that business typically pay lower volume charges than households for electricity due to the volume purchased (the default offer prices are based on 4,000kWh/year for households and 20,000kWh/year for small business), and because they usually pay a separate charge for their peak load (called a capacity charge).

- **Backup generation:** if a microgrid in Heyfield will provide energy when the grid has failed, this has a premium value. For this study, the energy costs only of diesel generation backup is used as a benchmark.[b]

Figure 3 shows how these different electricity costs can be used to test whether an energy option is cost effective. Which comparison to make varies according to where the option is located and what it's doing. The different energy option locations and uses are back up supplies, behind the meter at residential premises,

[b] It is very difficult to include the capital costs as you would need to know the utilisation of the backup generator; however the fuel cost dominates in this instance.

behind the meter in business premises, in a microgrid, or just feeding into the main grid. For example, a local energy option would probably need to cost less than 26c/kWh to be cost effective behind the meter at a business premises, but might be cost effective up to 33c/kWh behind the meter at a residential premises. Lower than 8c/kWh it's likely to be cost effective anywhere.

The actual benchmarks (wholesale, energy and retail, network cost, and customer electricity costs) are based on the work of the Essential Services Commission[3] which has reviewed energy costs and defined the Victorian default offer for 2022.

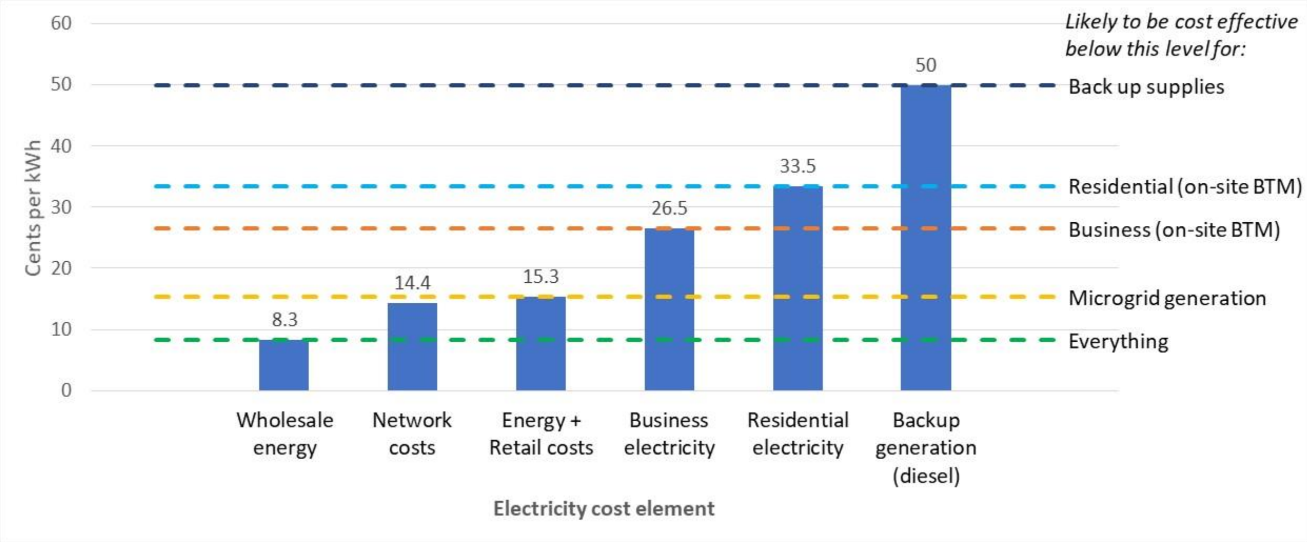


Figure 3 When is Victorian local energy likely to be cost effective?

2.1.5 Dispatchability, diversity, and flexibility

The assessment of energy options includes weighing up how much they contribute to ensuring a reliable electricity supply for every minute of the year.

In a traditional, fossil fuelled electricity system supply followed demand, that is, generators were ramped up and down, or switched on and off, as demand fluctuated. Network managers did what they could to keep demand as steady as possible by, for example, using off-peak hot water systems, as it was cheaper and easier to keep generators running at constant output. Increasingly, in a system dominated by variable, renewable energy, we need to move to a situation where demand follows supply for those loads which can be flexible. Otherwise we will either need an awful lot of storage in the system, or there will be large amounts of renewable generation which cannot be used at times when supply is greater than demand, so the generator is constrained (switched off).

In the future energy system, dispatchability, diversity and flexibility will need to be considered, as all of these will make the generation source more attractive and the system cheaper:

- **Dispatchability**: providing electricity when it's needed is very valuable. This has a time dimension, as it is important to have the ability to react to sudden changes in demand (for example, if there is a fault on the system so a generator shuts down and supply is needed very rapidly to prevent widespread blackouts), as well as to supply energy in times when your main generators – which will be solar and wind – are not available. In other words, you may need dispatchability in the order of seconds or minutes (to regulate the system), hours (to ensure generation at night, when solar is not available), or in the order of weeks or months (to fill in seasonal lows). Fossil fuel generators are dispatchable, as they can be switched on and off, although coal in particular is relatively slow, and so not very suitable at the order of seconds or hours.
- **Flexibility**: how much storage or flexibility does an energy or storage option offer? The losses on some forms of storage, or their cost, mean that they might only be suitable for a few hours worth of energy, while others can store large volumes of energy for months. Duration of flexibility might need to be

measured in minutes or weeks and both short duration and long duration options can help with optimising the overall energy solution.

- **Diversity of resources** is useful in ensuring that some options are available all the time. Even though additional options can create redundancy and surplus, diversity provides for a resilient and adaptable system that is not too reliant on single solutions, and may be the lowest cost overall.

2.1.6 Time of day and season

As well as the cost of a particular energy option, its value is highly dependent on when it is available, both in terms of time of day and season. Generation options that correspond with high demand, or with times when other sources are unlikely to be available, will generally be more valuable.

Wholesale electricity prices are highly dependent on both supply and demand. Demand in the system is smoothed somewhat by charging more for electricity at peak times, with the intention that consumers will move their loads to cheaper times of day when there is less demand (this is less the case for residential customers who frequently pay a single flat rate for the entire year). The higher prices are also needed to ensure that peaking generators are switched on.

Variable sources, such as wind and solar have so much surplus at times that the value of electricity in the market nears $0, or the generator is constrained (instructed to turn off). At those times of excess supply the wholesale electricity cost can be negative, meaning that generators are penalised if they put electricity into the system.

To screen energy options, the relevant time of day and season has been noted throughout this report. When considering any energy option, whether generation, load flexibility or energy efficiency, those which operate primarily in times of surplus (which may be caused by low demand or high generation) are less valuable than those applicable to times of scarcity.

Detailed modelling of a microgrid splits the entire year into 8760 hours and defines the optimal generation outcomes, and provides different costs for each hour of the year. Without this modelling there is no simple way to benchmark the different value of energy at different times. For example, although wind may be more expensive than solar, adding wind to the system may be more valuable than additional solar, as the solar may only add generation when there is already a surplus. This is the benefit of diversity.

Surplus electricity is exported from its immediate area and may incur additional costs, or the generation may be constrained, which means it is wasted. Export capacity and minimum or negative loads are increasingly concerning electricity network businesses, even though they are not yet reflected in many pricing approaches.

Examples of the wholesale energy price and the volumetric differences by time of day and season are provided in Appendix A to illustrate the way both fluctuate at the Victoria-wide level.

2.1.7 Location of resource

The value of generation at different locations is influenced by several scales:

- **Customer scale**: options that are installed behind the customer meter where they are used provide value directly to each customer, although some customers may not have appropriate space for installation.
- **Street-scale (low voltage):** serving a cluster of sites that share a low voltage distribution transformer. The group of houses or businesses (or both) will need to identify a suitable location within their low voltage system for the relevant option, which might be shared solar or shared storage. The maximum allowable capacity of the option will be determined by the size of the distribution substation, the distance from it, and major loads in the vicinity.
- **Community scale (medium voltage)**: if the resource is designed to feed directly into the 22kV MV network, the allowable scale will be determined by its location in relation to the zone substation and

major loads. If the option is located at the end of the line its allowable capacity is likely to be smaller than if it located closer to Maffra or along the the main feeder between Heyfield and Maffra.

Many options will be well below allowable limits, but some will require electricity system modelling to ensure capacity constraints are not breached.

2.1.8 Benchmarking volume

Table 2 shows the volume benchmarks used for the screening technical options. A volume of ‘one Heyfield’ has been used to measure the potential generation resources, equivalent to the estimated total load within Boundary 3 for a Heyfield microgrid. Table 3 shows how this total load is broken down by user, and Table 4 shows the estimated non-electrical load within Heyfield.

As well as the volume of energy used, the tables show the peak load for different elements, to give an idea of what capacity of generation may be needed. Figure 4 shows load profiles for a full year (2019), providing an idea of the daily and monthly patterns of activity.

The relevant volumes of energy are estimated with best presently available network and community data and will be improved as data continues to be collected via the Wattwatcher devices and Ausnet Services. However, these volumes do not need to be accurate for screening energy options; a correct order of magnitude is generally sufficient.

Non-electrical energy use in Heyfield is included because any future energy scenario needs to anticipate the electrification of heating and transport loads. The fossil fuel consumption associated with vehicles and LPG heating and cooking is significant. As these loads electrify, they will impact on the design of a microgrid or energy sharing scheme. Transition away from fossil fuels may be organic, and it takes 15-20 years for equipment and vehicle stock to fully change over, but it also may occur relatively rapidly if adequate incentives are in place.

Table 2 Heyfield annual load (energy use) within Boundary 3

Load	Annual energy (based on 2019)	Peak Capacity (MW)	Additional information
Measured energy	14.64 GWh	4.3 MW	SCADA data has been provided at two switches – SL016 and SL015. The amount for Boundary 3 is calculated by deducting SL015 from SL016.
Existing Solar PV	2.68 GWh	1.83 MWp	Based on Ausnet Services figures for connected solar PV, excluding estimated upstream and downstream installed PV.
Total load	17.32 GWh	4.3 MW	The load is equal to the measured energy plus the generation within the distribution zone

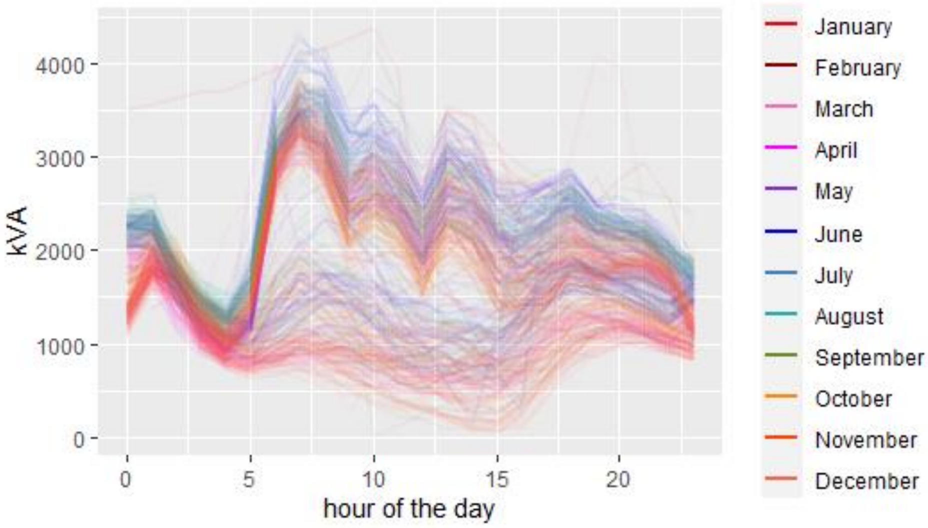


Figure 4 Load profiles for Boundary 3, 2019

Table 3 Break down of load in Heyfield (Boundary 3)

Type of Load	Estimated energy	Estimated Peak Load (MW)	Additional information
Residential	5.01 GWh	2.5 MW summer or winter evening	Based on 754 occupied houses
Industrial	6.98 GWh	3.5 MW at 6am weekday	Two large and one smaller timber mills plus 20 other customers with non-building loads including Gippsland Water. Some milking.
Commercial	3.44 GWh	0.8 MW during heatwave at 4pm	An inventory of businesses identified 40 large and small sites across Heyfield. A further 1 GWh (equivalent to 50 small businesses at 20 MWh/year) has been assumed.
Losses and unmetered	1.02 GWh	300kW at midnight	Unmetered loads are usually streetlights. Losses at the MV and LV level typically account for 4.5% of total energy.
Unallocated	0.87 GWh	Unknown	Many of the rural loads have been excluded in the Heyfield Boundary 3. However, it is expected that the remaining load for dairies, pumping and sheds is not insignificant.

Table 4 Non-electrical loads in Heyfield (Boundary 3)

Type of Load	Estimated energy	Additional information
Timber drying with sawdust	Confidential	This is a significant load. The Timber Mill produces steam from the sawdust to dry the timber.
Wood heating	4,300 tonnes wood	65% of homes have wood heating and a winter's heating requires ~ 10t of wood. We have assumed 80% of these homes rely heavily on wood heating.
LPG heating, hot water and cooking.	3,500 – 5,000 GJ 0.8 – 1.4 GWh of electricity could be used to displace LPG, (as little as 0.2 GWh with heat pumps)	Over half the homes have LPG but tend to use it mainly for cooking. Only one quarter use it for hot water (spread across instant, storage and solar-hot water) and only 4 responses had gas heating. Commercial use is expected to be primarily hot water and cooking.
Diesel and petrol for transport	7,000 – 8,000 GJ ~ 3 – 3.5 GWh would power an EV fleet instead	

3. Efficiency and control options

In 2013 Heyfield won a World Environment Day award from the United Nations Environment Association of Australia[4] for its sustainability flags program. The program encouraged the community to improve energy and water efficiency, reduce waste and move toward renewable energy. Some legacies of this program are:

- Heyfield has a high proportion of smaller and older solar systems, as those were the systems incentivised at the time.
- Heyfield has a much greater proportion of solar hot water systems than the Victorian average.
- Heyfield residents often have energy efficient lighting, such as compact fluoro and LED light globes.

Since 2013 the emphasis of energy technology investments has been changing. Solar PV has become much cheaper and penetration is reaching rates that result in oversupply and curtailment at some periods of the day. Storage technologies are becoming essential if you wish to avoid curtailment but remain very high cost, with long payback times.

Energy efficiency and load control, on the other hand, are frequently cost-effective options in the short term and will lead to improved economics for any community-wide solutions. They should generally be considered before other options, as pay back is usually relatively quick, and they reduce the cost of more complex options.

While a microgrid is the focus of the project, other options for sharing energy and increasing the use of local renewable energy have been identified as potentially valuable to the community. Both a microgrid and the other energy sharing options will work best if there is both a solid investment in energy efficiency and in making key loads flexible via improved control.

Throughout this report, investments have been compared based on the levelised cost of energy (LCOE), although this is not always a useful metric for private investments. Many households and businesses will expect a simple payback of less than 5 years or might be motivated to invest by other considerations. When equipment is due for replacement there is an ideal opportunity for making investments, either with a microgrid in mind, or simply to improve the energy efficiency of a building. At this stage there may be only minimal additional capital cost to choose the efficient option.

The energy efficiency business case can vary widely from site to site. This section compares the key loads that typically attract cost-effective energy efficiency measures and gives general information on energy savings and costs. Energy efficiency cannot replace generation and storage because it typically only targets 10% - 15% of consumption (generation and storage aim at optimising 100% of energy consumption), although this can be expanded if deeper retrofit is considered and energy efficiency is built into planning and renovation decision making. It is also important to consider that energy efficiency can reduce the capital requirement for other measures, particularly solar and storage, by reducing the load that needs to be serviced. Every GWh of annual energy reduction offsets $1.4m in capital cost for solar-battery systems, so the value proposition of efficiency for rooftop solar and on site storage options are included below.

3.1 Control options

Load flexibility and demand response will become increasingly important as we move towards a 100% renewable electricity supply with high amounts of variable renewables such as wind and solar (see Section 5.2 Load Linked Storage). Demand response is the name given to controlling loads to manage peaks on the network, by switching loads off or down to balance supply and demand; demand response can be a paid service. To gain the value from load flexibility, either as demand response or just to take advantage of generation behind your own meter or within a microgrid, a means of controlling the load is needed.

Not all loads can be remotely controlled, but increasingly appliances are being sold with some controllability. For example, smart light globes and smart air-conditioning systems that can be controlled from a phone app, even when no one is home.

Hot water, pool pumps, air-conditioning and electric vehicle charging have been targeted by policy makers as large loads that can contribute to peak load; these may in future be mandated to include demand response capability. A demand response enabling device (DRED) is a simple feature on a unit that can accept an external on/off or part load signal. Bringing this control into such appliances would be via the minimum energy efficiency process where new products are mandated to have the DRED capability; once this has been included in a standard, all appliances of that type will have the feature over time, once the national stock has fully replaced itself.

Control, not necessarily via the approved DRED feature, can also be used to access cheaper electricity. At least one retailer has specialised in automating pool pumps and used this to offer lower prices to customers.

Rooftop solar and batteries will go through a similar change (to enable remote control) and the electricity network companies are already working with platforms to reduce the level of solar energy at key times, for example by making sure load within the house is maximised or that the battery can be charged then. The alternative is that solar energy (and other renewable generation) is curtailed, or switched off, at times when supply exceeds the load.

At the moment it is not clear what control signals the future home will need to respond to and how much load or generation will be expected to respond. The mechanism for households to respond voluntarily to electricity market price signals are also being developed in a variety of ways.

The best time to set up appliances with control capability is during the purchase and installation process (see *Section 5.2 Load Linked Storage* for the most relevant loads).

Using batteries for back-up power is a special case. For a small additional cost, a battery installation can include the capability to operate a home or business when the grid fails. This is known as a stand-alone power system (SAPS). However, this may require that certain loads are not operating when in SAPS mode because a hot water system, for example, uses too much energy. The battery becomes the control centre of the site during these times, and larger loads will need to be controllable.

A microgrid or energy sharing system will generally manage surplus generation and excessive load in the most economically viable way. However, during times of island operation, the matching of supply with demand will need to be exact.

3.2 Value of control

Even if Heyfield doesn't develop a local microgrid, control will be a feature that makes a site better fit for future energy systems and is likely to offer economic benefits to the consumer. The level of savings will be related to the level of flexible capacity the site can offer at different times.

The daytime solar surplus is already creating regular lower prices in the middle of the day. In winter months, and sometimes in summer, surplus wind also creates low prices. Using control to chase financial benefits will lead to different outcomes for energy users compared to other control priorities such as comfort or guaranteed reliability. The design of control systems will need to strike a balance between end user expectations, predictability and lowest cost priorities.

The sum of storage, flexible demand, and dispatchable capacity becomes the total amount of flexible capacity available. Some of this is available on a daily basis. For example, hot water systems can be "charged" each day for hot water use over the next 24 to 48 hours (less if you live with teenagers). Some are more short term, e.g. cycling air-conditioning systems are generally used to shift load by just 15 to 30 minutes.

Control is the key to flexible capacity but the question remains - how should we value control and what should control be programmed to do? Two main behaviours have been identified that generate value:

- Matching cheap renewable generation to demand from loads throughout the day and the year, nominally valued in this assessment at 15c/kWh[c]

[c] The difference between peak and off-peak prices is usually between 8 and 15 c/kWh. The cost of battery storage to use the renewable energy at a different time is 30c/kWh. Value is always dependent on the combination of investments that make up the energy system at any point in time and differs by perspective (customer value or energy operator value), so 15c/kWh has been chosen to use in this assessment as a conservative midway point.

- Back up supply, valued in this assessment at more than 50c/kWh (although for much shorter periods of the year) [d]

In addition, electricity markets value a range of ancillary services that allow them to adequately respond to sudden or unforeseen changes in the supply / demand balance. Access to ancillary services markets might contribute a modest additional amount to the value of a microgrid or to another energy sharing arrangement and should be included in any final feasibility analysis.

There may also be local power quality benefits. Electricity networks are experiencing greater voltage swings on the low voltage parts of their network and might only know about these issues if customers complain. There is no immediate financial benefit to the network of improving voltage fluctuations. Avoiding high voltages can reduce the damage to customer equipment and allow more local generation to be installed and used (known as hosting capacity). The value of improved power quality is not included in this report but can easily be considered when considering the control arrangements, particularly for solar generation and batteries. There are increasingly stringent requirements for the way these technologies interact with the electrical network.

Supply / Demand matching: At an individual site this can be high value, as it allows all the generation to be used behind the meter (this also applies to a microgrid). When matching exported energy, the main value is to better match the cheap and local sources of renewable electricity to the local demand to reduce overall demand on the network and make electricity more affordable for everyone[e]. Most of the time, this matching does not need to be exact because the main electricity system has already been designed to provide adequate electricity and can also absorb a certain amount of generation surplus. The grid, in effect, acts like a large, cheap, long duration battery. Extracting the value of supply and demand matching is known as energy arbitrage when done in energy markets. Electricity is bought when it is cheap and sold when it is expensive. The value is the arbitrage between the two values. In the context of peak demand, this is often called demand management or demand response.

Back up supply: A microgrid is islandable and there will be times when the main grid is unavailable. At those times the matching of supply and demand needs to be exact so the microgrid can move into island mode and maintain the correct voltage and frequency by controlling supply and demand at every second. If a microgrid has no flexible capacity, it cannot do this. The design of flexible capacity for Heyfield will consider a number of scenarios for the timing and duration of outages that microgrid capability needs to cover. Load-linked storage options and flexible loads form the basis of the calculation of how long the battery or hydrogen storage will last and therefore how long Heyfield can operate without support from the main grid.

A final consideration is the importance of being clear about the purpose of any control arrangement. A study by ANU[5] showed that the control algorithms are key to defining the flow of benefits, and optimising control for different purposes, delivers starkly different results in each case. It is important to realise that some benefits are not captured in the value flows defined above but can be genuine benefits to individuals, such as greater self-sufficiency or control simplicity. Some benefits flow to private individuals while others can be captured at the community-wide level. Business models for future energy arrangements will be created based on community agreement about the apportionment of benefits.

3.3 Residential Options

The breakdown and average total electricity consumption for households in Heyfield is shown in Figure 5. The breakdown is drawn from the Residential Energy Baseline Study[6] and a local survey of residents using the Ecologic App self-administered energy audit. There were 74 useable survey results from households; however there is a risk that the sample is skewed in favour of engaged households, whom are likely to be more energy efficient.

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[d] Emergency supplies attract a premium value but the extent to which owners of emergency generators are happy to let an investment lie idle for the moment when it is required varies enormously. Amortising capital costs of back up supply is therefore a subjective process. 50c/kWh is the cost of running a diesel generator without considering the capital investment, and is therefore the minimum value of back up supply.

[e] Matching supply and demand locally can defer investment in the electricity network and centralised generation capacity.

- Hot water is the largest load (22%), even though the average shown includes the 27% of households with no electrical consumption for hot water (these households have LPG instant or storage and solar gas systems) and the 47% of households with low electricity consumption due to the use of solar electric or heat pump systems. The range of hot water costs is shown in Table 6.
- Heating energy in each home is much higher than shown as the bulk of households use wood and the proportion shown represents only a top up from electric heaters and reverse cycle airconditioning.
- Cooling assumes over 80% of homes have some form of cooling, mostly single room systems and fans. The Victorian average indicates that cooling is not required for most of the year.
- Fridges and freezers represent a substantial proportion of the load (17.5%) because these appliances operate continuously with the load cycling on and off 24/7. Across Victoria around 40% of homes have a second fridge and another 40% have a stand-alone freezer.
- Entertainment and IT is a growing proportion of load. Televisions and sound systems are slowly being outnumbered by gaming consoles and computers. This category also includes set top boxes, phone recharging and WiFi devices.

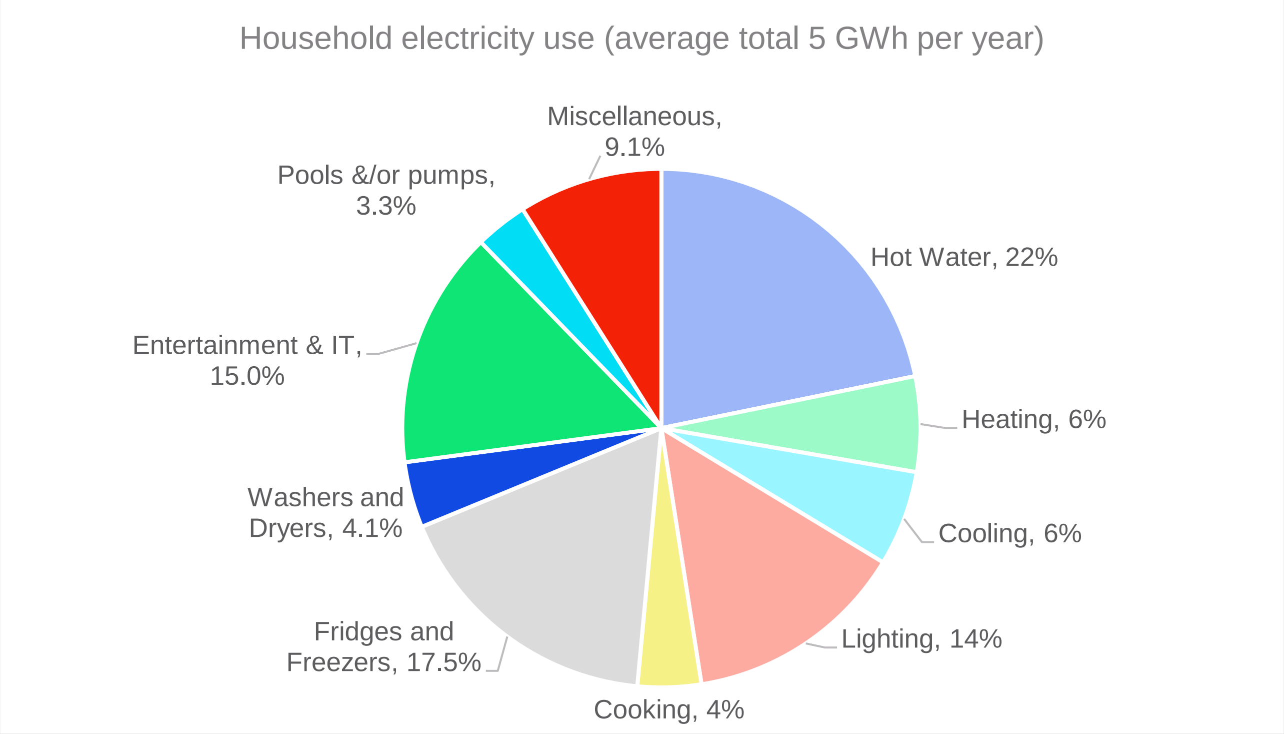

Figure 5 Estimated breakdown of residential electricity use in Heyfield

3.3.1 Summary of potential residential savings

The following statistics apply as averages for the 754 homes within the Heyfield boundary that are the subject of this analysis. The savings are calculated for the energy efficiency options that a residential upgrade program could unlock for Heyfield. The implications of generation and storage options are covered elsewhere in this report but rooftop solar and on site storage options are also included here for the sake of completeness.

The energy efficiency options contribute in small volumes but are a primary component of the My Town microgrid project. It is worth remembering that solar PV was once a minor option for the electricity grid but, by virtue of widespread uptake and falling prices, it has transformed the landscape of energy. Energy efficient, controllable and flexible loads are a key component for a feasible microgrid and it is recommended that households don’t invest in solar or batteries without considering these first.

Table 5 Strategies for home energy upgrade (including efficiency, generation and storage)

Strategy	Savings Potential	Value of controllability	Heyfield wide estimated potential and savings
Hot water	\$50 - \$500 / household per year	24hr flexibility - operate at best time of day	0.4GWh saved, 0.18 GWh added (LPG) \$180,000
Heating and cooling	\$80 - \$200 / household per year	15 minutes to 2 hours without loss of amenity	Electricity use might increase \$60,000
Lighting	~ \$30 / household per year	Lighting can reduce by 50% or more for short periods to provide emergency response	0.07 GWh \$22,000
Energy efficient appliances	~ \$50 / household per year	Some appliances can offer flexibility and demand response	0.12 GWh \$40,000
Solar PV	\$300 - \$500 / household per year without effort to shift load to solar times	Control essential, can only control to reduce output	1 GWh used on-site 2 GWh exported \$150,000
Battery installation	Further \$300 - \$500 but might not be cost-effective investment.	Batteries can be both a load and generator. Ultimate flexibility across a number of days.	1 GWh \$150,000

3.3.2 Subsidies - Victorian Energy Upgrades Program

The Victorian Government places obligations on electricity providers to ensure a certain level of energy efficiency is achieved each year. This means many energy upgrades are subsidised. The site[7] lists the following activities:

- Lighting
- Hot Water
- Heating and cooling
- Shower heads
- Weather Sealing
- Glazing
- Pool Pumps
- In-home displays
- Fridges and Freezers
- Televisions
- Insulation
- Clothes dryers

The Government still supports gas appliances as an option to reduce emissions but these are not recommended. A gas strategy for Heyfield would undermine the opportunity to eliminate emissions and pursue cheaper, renewable electricity solutions. Many of the subsidies align with the recommendations below and can offset as much as 100% of the capital cost.

3.3.3 Hot Water strategies

Table 6 shows the typical cost of operating different hot water systems in Heyfield. Up to \$500 per year can be saved by replacing hot water systems with efficient heat pump based systems and improving the overall system efficiency and use at the same time.

Efficient hot water systems: heat pump hot water is recommended for all system replacements, with the possible exception of systems with very low utilisation. Heat pumps have an “efficiency” (known as a coefficient of performance) of 350% or more. Heyfield has a number of low energy solar hot water systems and these could be converted when replacement becomes necessary because the energy savings are minimal. The trade off between recommending heat pumps over solar hot water comes in a difference in winter and summer electricity consumption and in the ability to move load to daytime.

Reduce losses from hot water systems: reducing the distance between the system and taps, insulating pipework and the storage tank, operating at a lower temperature can all reduce the amount of heat lost before the hot water is even used.

Reduce hot water consumption: efficient shower heads, shorter showers and other habits around the use of hot and cold water.

Table 6 Estimates of the proportion of residential hot water types in Heyfield and indicative energy cost

Hot water type	Estimated proportion of households	Annual energy Consumption	Average annual cost[f]
Off peak electric storage	26%	2,653 kWh electricity	$660
Electric boost solar hot water	20%	1,034 kWh electricity	$260
Heat Pump hot water	27%	1,065 kWh electricity	$270
Gas boosted solar hot water	14%	2,233 kWh LPG	$470
Instant gas (LPG) hot water[g]	14%	3,383 kWh LPG	$715

3.3.4 Heating, cooling and ventilation strategies

An efficient building envelope provides comfortable spaces that require little heating and cooling and make the most of outdoor ventilation, temperatures and daylight when available. Most building performance is locked in during the initial build or during major renovations. Heating and cooling peaks in homes in the evening. There is often an increase in load in the morning as well. Unlike many European climates, Australian homes benefit from a mild spring and autumn and a well designed home will need no heating or cooling in mild weather.

Over time we need our building stock to become much more efficient so that the building fabric can store heat and cold energy generated during the daytime and use it through the evening and morning peaks.

Building improvements should reduce energy consumption but the main benefits are often improved comfort and healthier living conditions.

Reduce building losses. Insulation, draught proofing, shading, managed ventilation, double glazing.

Heat and cool only what is needed. Closing doors to optimise the area heated or cooled.

Efficient system. Reverse cycle air conditioning systems have the advantage of producing both heat and cold at over 400% efficiency (working on the same principle as heat pumps). A high energy star rating means a more efficient system. Often a combination of heating options will work best for people.

Minimise losses from the system. The location of the system and insulation of pipes and ductwork can support high performance.

3.3.5 Lighting

Efficient lighting: lighting is a significant residential load in Heyfield, at approximately 17% (see Figure 5). LED lights are becoming standard as the cheapest lighting to operate over the lifetime of the globe. Controls and sensors can easily be built in as standard on many lighting types such as security lighting.

Efficient habits. Lighting is one of the loads that is often left on for long periods unnecessarily. Sensors and timers can play a role but changing habits is the cheapest investment. Night time loads will become more scrutinised as this becomes an expensive time to service.

[f] Priced at 25c/kWh for off peak electricity and 21c/kWh for LPG
[g] Limited LPG storage hot water exists and is similar to instant LPG

3.3.6 Appliances

Purchase high efficiency appliances with controllability: this is especially important for fridges and freezers, as they are on 24/7. Many second fridges are only needed for part of the year and should be turned off at other times. A consistent price signal might see these loads become genuinely flexible. Induction cooking is the most efficient cooktop. Pool pumps are a useful flexible load.

Think about time of use: dishwashers and washing machines might be the easiest appliances to set going in time to use surplus solar energy. Slow cooking might come back into fashion. Charging of phones and other IT equipment is still a relatively small load but households are increasing the number of gadgets they own.

3.4 Commercial Building Options

Forty commercial and public buildings were identified across Heyfield of varying sizes. The main street has a supermarket and hotel with substantial solar installations. The largest commercial operations are the DELWP fire management and crisis centre, the hospital and aged care facility and two schools. Loads for around 10% of Heyfield's electricity consumption have not been identified and some of this will be building-based commercial energy use.

Commercial buildings use energy in many similar ways to households because the loads are associated with operating a building – heating, cooling, lighting and sometimes hot water. The differences are worth highlighting but the strategies to improve efficiency are similar to those in the residential sector. However, it is highly recommended that detailed efficiency audits are done for the commercial premises in town, perhaps with a view to economies of scale in delivering a town wide commercial program.

- Hot water is a minor load in an office based setting but a major load wherever there is cooking and washing. It will often be LPG and, if electrical, often not linked to off-peak rates. Shifting to heat pumps remains the recommended strategy.
- Lighting upgrades in commercial buildings aim at improving both the lighting and the efficiency. Older fitouts usually warrant a full replacement of luminaires and lamps. Commercial operations are usually only 40-60 hours per week so lights should be switched off when not needed. Automated LED systems can work well for lights with occasional use – security lighting, toilets, car parks etc.
- Heating and cooling are dominant energy users and usually set to operate whenever the building is occupied. Any flexibility will depend on the performance of the building envelope and how well it retains temperature when the system is off.
- Refrigeration can be a major load in the commercial sector. This is especially true for the IGA, the hotel and dairies which chill their milk. Many shops have refrigeration cabinets.
- Many commercial premises have roofspace and load that suits solar PV. Some rent the space so tenant/landlord split incentives can make the investment more difficult.
- Some commercial premises can readily justify a modest battery storage investment on the basis of business continuity or protecting stock. As battery prices fall, more applications for storage investments will emerge. The hospital and the DELWP centre, for example, have both installed emergency generators.

It is estimated that 3.44 GWh is used in commercial and public buildings. Almost 1 GWh of this is already provided by solar PV. Over half of the load is thermal energy in the form of hot water, heating, cooling and refrigeration. Some sites rely on LPG which should be shifted to efficient electrical heat and hot water production. Upgrades and efficiency programs for thermal loads lend themselves to adding thermal storage and creating flexibility. The level of energy efficiency that can be achieved will vary at each site.

Table 7 Commercial buildings – indicative potential

Energy Option	Heyfield wide potential	Associated savings
Energy Efficiency, assume potential of 15%	0.5GWh saved, 0.15 GWh added (LPG)	$130,000 per year
Solar PV	1.5 GWh saved 1 GWh exported	$230,000 per year
Batteries	0.5 GWh	$130,000 per year but will only be cost-effective for some businesses

3.5 Industry, pumping, farm options

Industrial loads are the hardest to characterise because each business is different. Some have only modest energy intensity and still benefit from the strategies, already covered, to improve the energy efficiency of the buildings. Others do not even have buildings.

Heyfield has a large timber mill which dominates industrial energy use. It also has other timber based industries that also use automated timber handling and cutting machinery. Compressed air is a large energy user in manufacturing settings and may be an area where efficiency audits followed by upgrades have a very rapid payback. It is often used to operate tools because compressed air can be safer to work with than electricity and machinery is often pneumatically controlled. Dairies also have compressors and vacuum pumps. Like other forms of energy, compressed air needs a high efficiency compressor, an efficiently designed system, reduced losses throughout the system and thoughtful users.

In the more rural settings pumping loads might be significant because much of the land is irrigated and some farms need to move water further than others. Gippsland Water operates seven main pumps to handle the raw water supply and the sewage for Heyfield.

Energy can be a significant component of product costs for manufacturers so the opportunity to reduce energy costs with on-site solar PV can be very attractive. Larger manufacturers will pay demand charges based on the peak load used on site. This complicates the economics of PV and incentivises the business to control loads in order to manage maximum demand. An energy audit or feasibility study is recommended for businesses to ensure that energy investments are well designed. The Victorian Government offers a range of programs targeted at supporting business and reducing energy costs[h]. The federal government offers a free advisory service for business[i].

3.6 Unallocated load

Little is known about 20% of the load as calculated from the SCADA data, and there may be additional energy options to pursue once there is a better understanding of unallocated energy consumption.

Some unallocated load has been assumed to be used by commercial, industrial and farm customers and included in the analysis. Around 4.5% has been accounted for as losses. These generally increase during peak electricity flows and may reduce as a function of using more electricity immediately and locally. Losses can be reduced, and capacity of the system increased, if reactive power in the system is reduced. More information is required from Ausnet Services to ascertain the level of opportunity related to improving system power factor and reducing the losses associated with higher than necessary current.

An estimated $20,000 per year would be spent on electricity for street lights. These are an unmetered load, and councils pay a standard fee for Ausnet services to provide the electricity. The Victorian Government promotes upgrade to LED lamps[8]. LEDs offer the additional benefits of sensor control and some Heyfield locations might be suitable for only switching on when there are people moving around.

[h] https://business.vic.gov.au/business-information/sustainability/managing-energy-costs
[i] https://businessenergyadvice.com.au/

4. Generation options

Heyfield uses around 17 GWh per year of electricity and 25GWh per year if non-electrical energy is included[j]. For the purpose of screening and classifying generation options, 20 GWh is considered to be "one Heyfield" noted as 1 x H in the Table 8 (see section *2.1.8 Benchmarking volume* for more details). This does not include commercial and freight transport.

The following renewable energy resources were identified for consideration as sources of energy for both direct use as heat and for electricity generation:

- Solar
- Wind
- Biomass
- Biogas
- Hydro
- Geothermal

Heyfield already has significant uptake of rooftop solar, and uses backup diesel generators at a number of sites. Backup generation is particularly important to the dairy industry because animals can suffer if there is no power for milking.

Bottled Gas (LPG) is common throughout Heyfield and is used for heating, hot water and cooking. Wood is also used for heating and the town has traditionally had access to offcuts from the timber industry.

Transport is the other significant user of fossil fuels in Heyfield.

4.1 Generation options comparison

Generation options are ranked based on levelised cost (LCOE) and volume of the resource available to be used with dispatchability and possible locations also considered.

Figure 6 shows the LCOE oF alternative generation sources, while Table 8 summarises the options considered.

The LCOE has a large range for several options, reflecting the different scale of both resource and the generators themselves. The LCOE of wind energy, for example, can vary from 7.3 c/kWh to over 130 c/KWh.

Rebates and incentives have a material impact on LCOE, and are likely to change significantly in the next decade.

For larger systems (greater than 100kW for solar, 10kW for wind, and 6.4kW for hydro) the relevant incentive is Large Scale Generation Certificates (LGCs), which are currently valued on the spot market at approximately $45/MWh[k] 2030. LGCs are set to continue until 2030, although their value is likely to decline as more renewable energy comes into the market. These are payments on output, and are dependent on registering the system and selling the certificates.

Small systems (up to 100kW solar, 10kW wind, and 6.4kW hydro) are eligible for Small-scale Technogolgy Certificates (STCs), which are in most cases available as an upfront subsidy. The subsidy reduces each year, and is set to disappear by 2030. However, the cost of solar is also dropping year by year.

Here we include the effect of the LGCs in the minimum LCOE but not in the costs at the high end of the range. The LGCs will continue to provide income until 2030 and an assumed price of $45/MWh has been used. For rooftop PV we present costs both without and with the effect of the STC capital rebate.

[j] Plus significant volumes of sawdust for drying timber which are outside this analysis.
[k] https://www.demandmanager.com.au/certificate-prices/

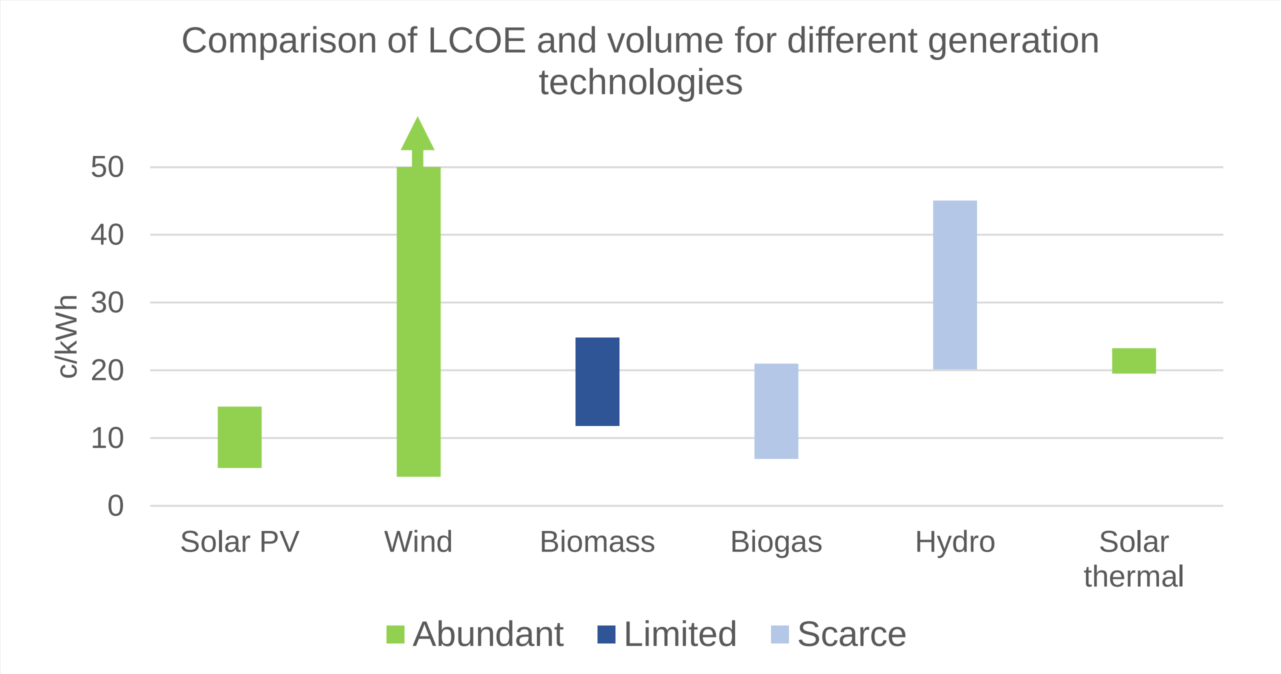

Figure 6 Comparison of LCOE and abundance for different generation technologies
Note: LCOE for wind varies from below $5c/kWh (1-5MW turbine at 100m) to above $1 per kWh for small turbines (30-300kW), and is uncertain without wind speed data and pricing information for small turbines.

Table 8 Summary comparison of generation options with approximate capital investment requirement
Note: volume of load and cost is compared to remaining Heyfield load after existing solar (14.16GWh per year). Minimum LCOEs include subsidies.

Resource	Volume available	Cost	Cost to supply Heyfield load	Dispatchabiliy	Location	Relevance for Heyfield
Solar PV	Many x Heyfield	5.6 – 14.7 c/kWh	$9 million	Daytime/ summer	Anywhere	Primary
Wind	Many x Heyfield	4.3 – 128 c/kWh	$14 million	Afternoon, early morning and some winter	Restricted	Secondary
Biomass	1 x Heyfield	11.8 – 24.8 c/kWh	$17 million	anytime	Mill	Secondary
Biogas	1% x Heyfield	6.9 – 21 c/kWh	n/a	Daily/ weekly	Dairy	Minor
Hydro	10% x Heyfield	20 – 45 c/kWh	n/a	Sept-April	Channels	Minor
Solar thermal	Many x Heyfield	20 – 23 c/kWh	~ $38 million	Daily/ weekly depending on storage	Restricted	Unlikely
Geothermal	Many x Heyfield 70°C	Not competitive for electricity, may have role for heat	n/a	Anytime	Unknown	Minor (for heat)

Table 8 shows the range of LCOE for each option, and gives some notes on dispatchability and time aspects. The last column shows the classification of each optoin into relevance for Heyfield. It quickly becomes clear that solar will have a primary role in any solution and, to a large extent other options are assessed in the context of the value-add to a solar-based microgrid. Table 8 also indicates the cost to supply the entire load for Heyfield, beyond the existing rooftop solar generation and based on relying on the single technology (noting that using a mixture of resources creates a stronger energy system and is likely to be more cost-effective).

The rest of this section goes through each generation resource in turn, with the level of detail corresponding to the potential role in local energy options for Heyfield. Appendix G presents all the LCOE results for each generation type, with and without subsidy.

4.2 Solar Photovoltaics

Solar is low cost, abundant and can be located on most roofs, i.e. in close proximity to the load. It is therefore a fundamental resource for any package of local energy solutions, and it is important to look at the solar opportunity in detail. Solar is considered a primary energy solution for Heyfield.

Appendix B provide details on tools and sources for solar, and Appendix C gives additional information on solar PV and how the parameters given here have were derived. Most cost data is taken from CSIRO 2021[9].

4.2.1 Resource

The Global Solar Atlas[10] maps the solar resource in Heyfield at between 1400 and 1500kWh for every kW of solar panels as shown below. This is summed across the whole year and is based on the local weather data and energy of sunshine throughout each day. The Atlas assumes solar panels are optimally placed with a northern orientation and tilt of 34 degrees. It is based on an average year because weather fluctuations will alter the annual output slightly and daily output can be quite different in overcast weather.

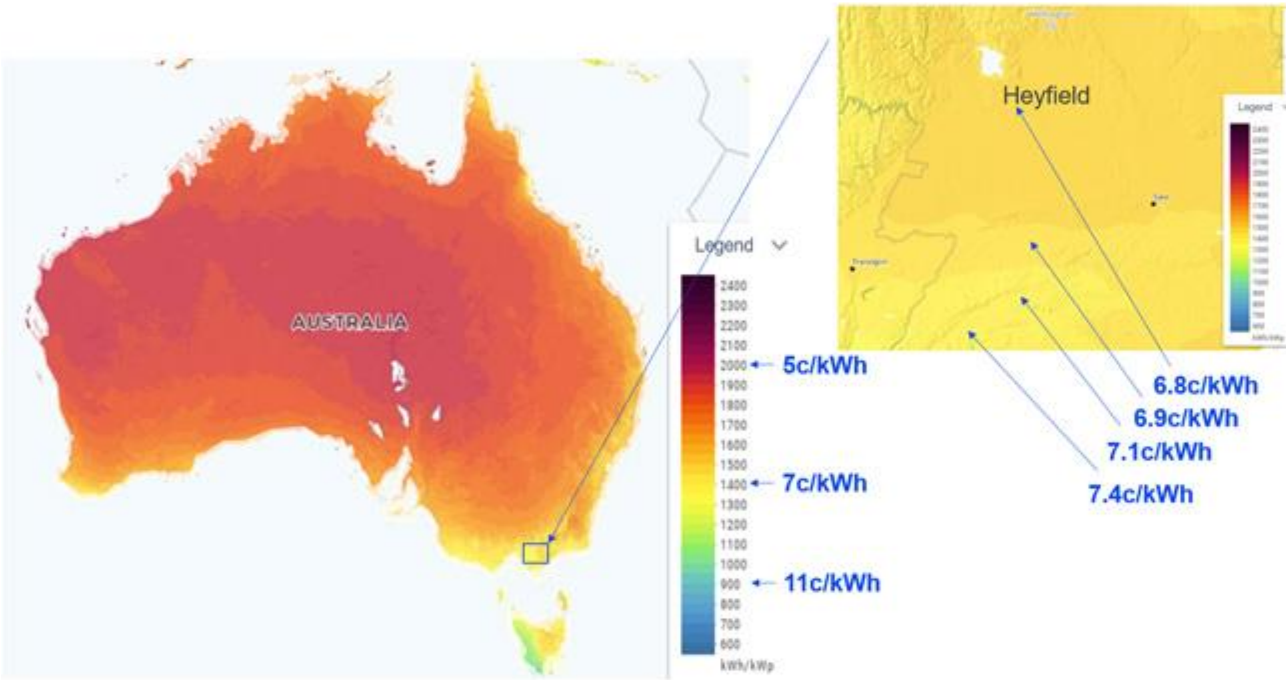

Figure 7 Australian and Heyfield solar resources and indicative pricing (LCOE)

See Appendix C for additional details on how potential solar production in Heyfield is assessed.

4.2.2 Key parameters

LCOE: If all its energy can be used, solar generally has the lowest costs of any form of generation. According to the CSIRO, utility scale wind and solar can both achieve a levelised cost of energy (LCOE) of around 5c/kWh under good conditions[9]. Over the next decade wind might drop to 4.4c/kWh but solar costs are expected to continue to fall and could go as low as 2.8c/kWh. This should be compared to the cheapest, fossil fuel technology in the CSIRO analysis, high emissions gas generation, at 6.7c/kWh[11].

Capital cost is the major component of cost. Solar panels require minimal maintenance but performance can suffer if the surface is not clean. Inverters have a life span of around 15 year, compared to over 25 years for solar panels.

Output will decline over time with a wide range of performance recorded through the existing WattWatcher devices and also from different web-based tools. The production chosen is expected to be a realistic approximation for a variety of panels 1-5 years old.

LCOE is calculated based on full utilisation of solar output. It is worth noting that households can use as little as 25% of solar production and receive only 6c/kWh for exported surplus. The value of exported solar is declining so the self-consumption rate will impact on the LCOE in future.

Table 9 Key parameters for small-scale rooftop solar (3-100kW)

Parameter	Estimated	Range	Notes
Capital cost	$930 / kW $1,410	$870 - $1,300 $1,350 – 1,600	With rebate Without rebate Smaller systems are more expensive but prices remain steady above 10kW
Operating costs	$250 / kW in year 15	$100 - $400	Inverter replacement
Annual production	1,464 kWh/kWp	1,100 – 1,600	
Percentage utilised (self-consumption)		25% - 80%	
Associated LCOE"	6.3c/kWh 9.1 c/kWh	5.6 – 8.5 c/kWh 8.3 - 11.2 c/kWh	With rebate Without rebate Future projections from CSIRO drop to as low as 5c/kWh by 2030

* A discount rate of 5.99% is used for the LCOE calculation, as in CSIRO (2021)[12]

Table 4 Key Parameters for mid-scale solar (500kW – 5MW)

Parameter	Estimated	Range	Notes
Capital cost	$2,128 / kW	$1,505 - $2,750	Cost is lower if existing transformers and connections can be used.
Operating costs	$17 / kW annual	n/a	
Annual production	1,603 kWh/kWp	1,350 – 1,650	
Associated LCOE"	10.2 c/kWh 11.6 c/kWh	7.1 – 13.2 c/kWh 8.5 – 14.7 c/kWh	Includes effect of LGC (assumed to be 4.5 c/kWh until 2030) Without LGC Future costs could drop to 6.8c/kWh by 2030 if mid-scale remains 1.5 times cost of large scale[l].

* A discount rate of 5.99% is used for the LCOE calculation, as in CSIRO (2021)[12]

[l] CSIRO consider a capital cost of $750/kW for large scale PV feasible in 2030. This scenario also includes highest possible production.

4.2.3 Availability

Solar energy provides a challenge for any system because production is only during daylight hours and weighted toward summer. January typically produces twice the energy of that in June. Deliberately producing surplus solar energy in summer may be a viable consideration and will have a price trade-off point.

Storage options and load flexibility to better use solar are discussed later in this report. The benefits of solar thermal, which can include storage, is also reviewed further below.

4.2.4 Locations and space required

Rooftop solar is the priority option on a cost-basis for growing the level of solar used and available in Heyfield, and the resource could provide many times the energy use of Heyfield.

The current contribution from homes could easily be tripled taking the proportion of Heyfield's load served by household solar from 7% to over 20%. Commercial and industrial installations could also triple solar production. Beyond 50% of Heyfield electricity consumption, it is less clear whether adequate roofspace, close to usefully sized loads, would be available. The Timber Mill is an obvious candidate and should weigh the opportunity to produce solar PV against the biomass option that it is considering.

If solar panels are placed on the ground, a number of locations have already been identified by the community reference group[m]. The area required for solar PV is 5 to 7m^2 per kW, which means the whole Heyfield load could be served by a solar area slightly larger than two football ovals.

The major consideration for larger systems will be electricity infrastructure. The Timber Mill is the largest load in Heyfield with a number of existing 1 to 1.5 MVA transformers. If a larger solar system needs to build its own transformer and connection, the cost could be in the order of $200,000 – to $1million.

The small area required for solar PV highlights the abundance of the resource.

4.2.5 PV economics behind the meter

If a solar panel's production is directly connected between a load and its meter it is known as a "behind the meter" installation. The advantage of this arrangement is that every kWh used by the load is not bought from the electricity retailer at rates of 26 – 34c/kWh. This is profitable when the electricity costs around 5-10c/kWh and leads to fast simple payback times of 5 years or less.

Rooftop solar economics have always been subject to a variety of value considerations. For systems up to 100kW the capital cost is subsidised with a solar rebate based on certificates. The price of certificates is subject to market variations, usually trading at between $26 and $38/MWh. The number of certificates is bundled for the panels for the number of years between now and 2030 when the Renewable Energy Target scheme finishes.

In Victoria a minimum feed-in tariff is determined each year by the Essential Services Commission and this has been declining steadily. Electricity retailers sometimes choose to offer more generous pricing for export solar in order to acquire and retain customers. Feed-in and export tariffs are an important part of solar economics because solar panels typically only provide 25%-50% of a household load due to the amount of energy used at night time. This means a large solar system of 7kW can easily find itself exporting 75% of its energy production. By contrast, commercial loads often occur primarily during the daytime and can be very effective at using their own solar production. Even if these systems are not able to export solar energy

Ausnet services have different approval processes for larger systems that will export more than 15kW of solar power. In rural systems the network provider may limit the amount of energy exported, sometimes to zero, in order to avoid voltage problems, overloading or to reduce risks to adjoining customers. The MyTown project is expecting to identify any potential issues on the Heyfield network with modelling of the network.

Renewable Energy Certificates for systems 100kW or over, are assigned after production so these larger systems do not benefit from a lump sum rebate upfront. Like the small scale certificates, LGCs, as they are known, are subject to market prices.

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[m] The Timber Mill has been approached by larger solar system developers to build a 30MW or larger system on adjacent land. None of the systems proposed in the district of this scale have been built yet so it is unclear to what extent the local network needs to be upgraded to accommodate these larger proposals. They are too big for the microgrid concept.

4.3 Wind

Wind is the second-most competitive energy source but was not high priority for the community reference group. The wind resource at Heyfield is not considered high quality because wind speeds are not often above 5m/s. Wind has advantages as a companion to solar energy because it is often available at night and for some of winter. Even with relatively poor wind speeds, wind energy could provide energy for many times the consumption of Heyfield.

Because the community has not considered wind seriously, a substantial effort would be required to genuinely find sites that might be suitable. Wind is treated as a secondary energy option for Heyfield and all figures below should be used with caution.

Appendix B provide details on tools and sources for wind; most cost data is taken from CSIRO 2021[12].

4.3.1 Wind resource

The Global Wind Atlas[13] maps the wind resource in Heyfield at between 138 and 400 W/m^2 depending on the height of the turbine. This highlights the abundance of wind as a resource, however to exploit it, the community would need to consider preferences between a few large turbines or many smaller systems sized to be connected to distribution substations at low voltage. The prevailing wind direction is up the Latrobe Valley. The wind profiles in Figure 9 show how the Heyfield wind resource has a daytime peak in most months and production is significantly higher in July compared to January.

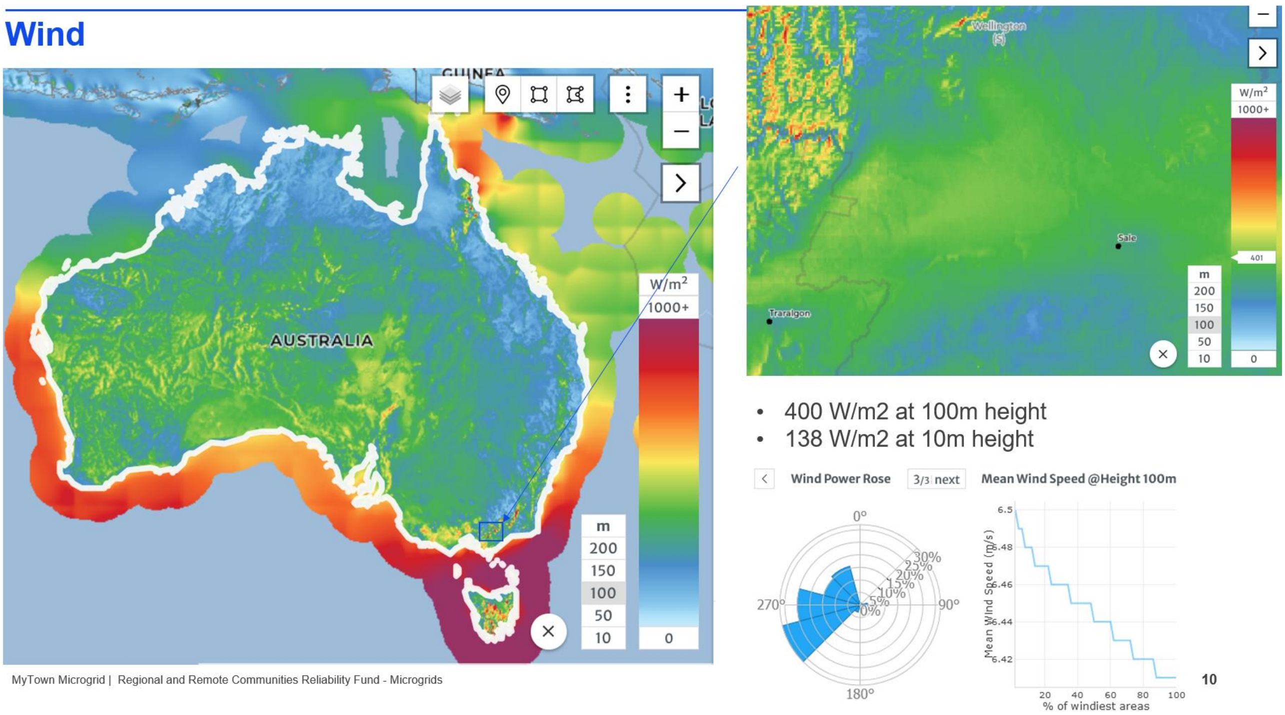


Figure 8 Australian and Heyfield wind resources with wind speeds, energy, and direction

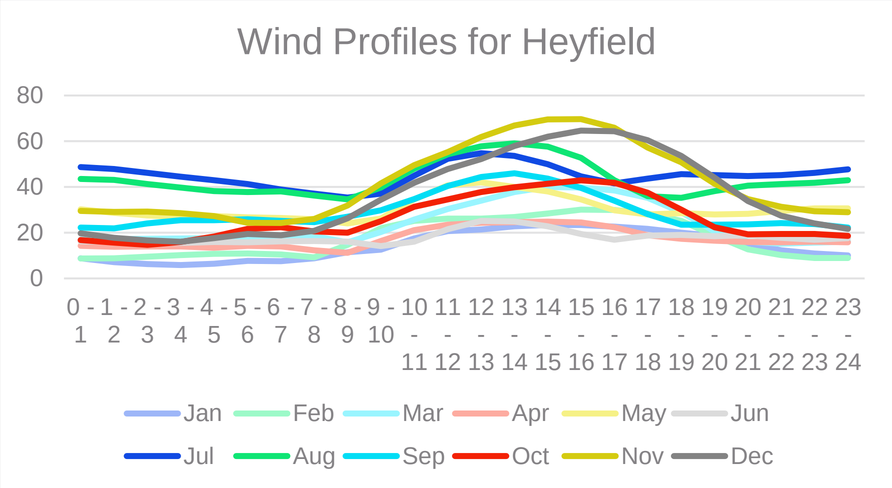


Figure 9 Wind profiles for Heyfield based on a 50m height and turbine optimised for lower wind speeds

4.3.2 Key parameters

LCOE: According to CSIRO**Error! Bookmark not defined.**, utility scale wind, which is generally installed at high quality s ites, can achieve a levelised cost of energy (LCOE) of around 5c/kWh. This tells us little about the opportunities in Heyfield:

- A low wind speed (by industry standards) requires a more expensive turbine with larger blades
- Smaller wind turbines operate at lower heights and are also relatively more expensive.

It is difficult to estimate the cost of wind from lower quality sites, or when smaller turbines are used.

Capital cost is the major component of cost and the market for high capacity (low wind speed) turbines in Australia is under developed so this information is not readily available.

Wind production is also a key parameter. Solar production can be verified by using information from current sites, but there is no precedent for wind in Heyfield. The normal process for developing a wind project is to set up an anenometer at the correct height and measure the resource for at least two years.

Wind production at different scales: Height is the significant factor in wind turbine output. 100m makes an enormous impact on the landscape but gains 50% more energy density over a 50m installation because of the higher wind speeds at that height. An estimate for Heyfield is that a 100m turbine will produce 3,605kWh/kW and experience an average wind speed of 6m/s, but the same turbine at 50m will only produce 824kWh/kW due to the lower average wind speed of 3.6m/s

As examples of scale, the turbines at Bald Hills are 85M hub height and at Hepburn Springs is 68m.

Impact of Scale: Like solar, a behind the meter installation can benefit from serving a load at premium rates (26-34c/kWh). In the Heyfield surrounding are larger farms have significant loads. Keeping milk cold, for example, can require ongoing refrigeration. Many farms rely on irrigation and pumping. IN this case a much less cost effective wind turbine may still be economic, as it is displacing higher value electricity. In addition, small wind turbines (less than 10kW) may be eligible for up-front rebates under the Renewable Energy Target .

At low voltages, the size of the distribution substation will be the constraining factor, and the maximum is likely to be 100-300kW. At this scale 10 to 20 smaller wind turbines would be required for production equivalent to a single larger wind turbine. Estimates of cost at this scale range from $4,000 to $10,000 per kW[14].

Larger turbines are expected to cost $1,940 (CSIRO) to $4,000 per kW.

Information about small scale wind and larger turbines suited to lower wind speeds is not readily available because the Australian market has not been encouraging for these installations. After a flurry of information in the mid 2,000s, small wind promotion was rapidly overtaken by solar PV opportunities. This ignores a future in which utilising both sources might provide a better outcome.

Table 10 Key parameters for low voltage wind (100 - 300kW turbines)

Parameter	Estimated	Range	Notes
Capital cost [n]	$4,000 / kW	$4,000 - $10,000	Cost is lower if existing transformers and connections can be used.
Operating costs	$25 / kW annual	$25 /kW/year	Costs based on CSIRO (2021)[12] O&M costs.
Annual production	824 kWh/kWp		*Limited information available at appropriate turbine height*
Associated LCOE [o]	41c/kWh	51 – 128 c/kWh	This would only be developed if costs fall and with certainty about the wind resource and lifetime of turbine.

Table 11 Key parameters for wind with a turbine height of 50m (1 MW – 5 MW turbines)

Parameter	Estimated	Range	Notes
Capital cost [n]	$2,976 / kW	$1,950 - $4,000	Cost is lower if existing transformers and connections can be used.
Operating costs	$25 / kW annual	$25 kW/ year	Costs based on CSIRO (2021)[12] O&M costs.
Annual production	824 kWh/kWp		Requires wind speed data for accurate estimate
Associated LCOE[o]	29.8 c/kWh 31.3 c/kWh	20 – 39.5 c/kWh 21.5 - 41 c/kWh	Includes effect of LGC (assumed to be 4.5 c/kWh until 2030) Without LGC This would only be developed if costs fall and with certainty about the wind resource.

Table 12 Key parameters for wind with a turbine height of 100m (1 MW – 5 MW turbines)

Parameter	Estimated	Range	Notes
Capital cost [n]	$1,950 / kW	$1,950 - $4,000	Cost is lower if existing transformers and connections can be used.
Operating costs	$25 / kW annual	$25 /kW/year	Costs based on CSIRO (2021)[12] O&M costs.
Annual production	3,066 kWh/kWp		2 years wind monitoring recommended to verify resource
Associated LCOE[o]	4.3/kWh 8.4 c/kWh	4.3 – 9.5 c/kWh 5.8 – 11 c/kWh	Includes effect of LGC (assumed to be 4.5 c/kWh until 2030) Without LGC

Buying wind from afar: A microgrid without wind could still be fully renewable if the consumption was matched to renewable production elsewhere. Such arrangements exist in the electricity market as power purchase agreements (PPA). They are valued by renewable energy producers because they are often signed for long periods up to 10 years and provide certainty for an installation to proceed. The PPA signed

[n] Good information on cost does not exist for small scale wind in Australia
[o] A discount rate of 5.99% is used for the LCOE calculation, as in CSIRO (2021)[12]

by the ACT Government with Sapphire Hill Wind Farm included a requirement to also open the investment opportunity to community investors.

The key costs for small wind turbines are estimated in Table 10 to

Table 12, with the LCOE and operating costs calculated disregarding current subsidies, for comparison to other sources. There is considerable uncertainty about these estimates as good information on small wind turbines does not exist for Australia.

4.3.3 Availability

Wind blows fairly regularly but the differences between a calm month and a windy month are significant enough to cause challenges for a system. In Heyfield with a 100m high wind turbine, January produces only 61% of average production, while July produces 135%, more than double the low month.

4.3.4 Locations and space required

Wind is fickle and highly influenced by the local terrain and micro-climate. The resource maps show a shadowing effect close to the mountains with the faster wind speeds across the plains. A small rise, such as along Riverview Road, can have a local positive effect as the wind gets 'squeezed' and speeds up to go over the rise. Most locations will need an investment in a transformer and access to the Medium Voltage system. The exception might be sites near the Timber Mill where larger transformers already exist.

Any possible site will need to be monitored for at least one year, and a mast with anenometer at the correct height will need to be erected.

The small area required for wind highlights the abundance of the resource.

4.4 Biomass

Biomass is a familiar energy source in Heyfield due to the dominance of the timber industry. In Victoria, use of old growth forest is being phased out and wood heating in homes is reducing in response to concerns about the health impacts of wood smoke. Heyfield is in the midst of this transition. Three quarters of homes still have wood heating. Those who rely on wood can spend around $900 every winter. The timber industry in Heyfield is concentrating increasingly on manufacture and adding value to timber logs and slabs. Australian Sustainable Hardwoods (ASH) is adding two new manufacturing sheds in 2022. Some timber is now imported to Heyfield for further processing rather than being reliant only on local sources.

The biomass resource associated with the timber mill is approximately equivalent to the Heyfield load. However, biomass is treated as a secondary energy option because the majority control of the resource is with the timber mill and usage will be guided by its market and economic interests. It cannot be assumed that this resource would be available for a community microgrid (although this should certainly be explored).

The main timber mill is actively investigating the option of electricity generation from waste sawdust. The costs and quantities used below are generalised in order to maintain confidentiality associated with mill data and the operating considerations of two other timber-based businesses in Heyfield.

It's not clear whether wood consumption for home heating will decline or increase as there are valid reasons for either scenario and social attitudes toward this renewable fuel are evolving.

Appendix D provides details on tools and sources for biomass.

4.4.1 Availability and dispatchability

The bulk of the resource is at the main mill, which produces dry sawdust with its manufacturing. Like many other low value resources, the value of biomass diminishes rapidly if it needs to be transported, so on-site use has the highest value.

Electricity generation at the mill attracts a higher value because it can offset both energy costs and network costs. Use of existing electrical infrastructure, biomass handling equipment, boiler and steam infrastructure all contribute to reducing capital costs.

The dispatchable nature of biomass-based electricity makes it inherently more valuable than generation from solar or wind electricity (for example, winter evenings throughout 2021 reliably paid 3 to 12 times the average wholesale market price of 4.4c/kWh). However, realising this value brings with it some additional costs. Firstly, the capacity of the plant would need to be oversized and operated for shorter (high value) periods. Secondly, the biomass would need storage for longer periods. Finally, additional labour would be needed at the mill to manage electricity generation in high priced evening periods. While these would increase the LCOE, these additional costs are relatively cheap compared to other forms of storage. However, the timber mill may wish to operate the bioenergy plant entirely to reduce their costs, rather than taking on additional capital and operating costs, even if these bring in additional revenue.

More accurate costings are expected to be available to the project by mid 2022.

4.4.2 Key considerations

Resource: The resource in Heyfield is estimated to be sufficient to cover the annual electricity consumption of the timber mill, even with current allocations toward wood drying. This makes biomass a resource that should be considered in the modelling for this project.

Market: Unlike other resources, biomass has alternative uses, therefore the cost of the feedstock for electricity generation can vary. Dry sawdust, wood chips, green sawdust and offcuts are all biomass waste products looking for a market. At the main mill, the boiler uses some of the sawdust in drying operations via a steam system. Chicken bedding, retail garden products, pelletised waste for burning and sales of offcuts to the local community have all been explored as markets for this abundant, waste resource.

Various reports value waste biomass at between $7 and $90 per tonne. ABARES[15] calculate a value of $101 to $143 per tonne if shavings or sawdust are used to produce electricity and heat in a co-generation[p] arrangement, suggesting that electricity generation is one of the higher value uses.

Technology and capital cost: Several sources have investigated biomass-based generation costs for the timber industry over the past two decades. Costs tend not to change significantly because the technology remains stable. Smaller installations of 1 to 5MW are relatively more expensive than larger options. The timber mill, however, is currently investigating a solid waste gas turbine technology where the main attraction is the low capital cost of the equipment. The gas turbine blades would need to be replaced annually and recent changes in the IP associated with the equipment means this can now be done relatively cheaply.

Final capital cost will depend heavily on the amount of existing equipment that can also be utilised for biomass generation. Costs from different sources range from $2,000 /kW up to $7,300 /kW[q]. Clearly, assumptions about capital cost have a significant impact on LCOE calculations.

Geothermal and Solar thermal technologies are also considered below. They share, with biomass, the need for a heat to electricity conversion technology such as a steam turbine or engine. One scenario that may be worth considering is the use of a single turbine for energy from several sources.

LCOE

CSIRO provide a range of LCOEs for small scale biomass of 15-25c/kWh. ITP Renewables[16] has developed an analysis that specifically considers the storage costs needed for different technologies if they are dispatchable. Costs of feedstock from $42 to $85 per tonne are used. Operating conditions from 6 hours per day to 24 hrs per day are considered. Under these variations LCOE ranges from around 9-27c/kWh.

4.4.3 Parameters

Capital cost, feedstock cost and operating hours per year all make a significant difference to the levelised cost of energy that can be expected from biomass. The fuel cost has a significant effect on the LCOE, and the alternative value which could be obtained for the fuel – in this case sawdust – should be considered.

[p] Co-generation occurs when the waste heat from electricity production is also used productively. Electricity generation based on combustion of fuels is often only 30% efficient, with 70% of the energy converted to heat. Using some of the heat boosts overall plant efficiency to anywhere from 55%-80%.
[q] CSIRO include an additional $11,000 /kW if the combustion process includes carbon capture and storage. Biomass is a renewable fuel because the trees draw carbon from the atmosphere when growing. Like fossil fuels, carbon can be captured from the flue gases of biomass generators.

Table 13 Key parameters for biomass (750kW – 5MW)

Parameter	Estimated	Range	Notes
Capital cost	$3,650 / kW	$2,000 - $5,300	Assumes system is installed at timber mill
Operating costs - feedstock	$30 / tonne = $ 2.7 c/kWh$_e$	$19 - $60 / tonne -1.7 to 5.3 c/kWh$_e$	Fuel cost is highly variable, and the alternative value that could be obtained for the sawdust considered
Operating costs – parts and labour	$200 / kW	$131 / kW annual fixed + 0.84 c/kWh variable	Fixed costs are per capacity (kW), Variable costs are per unit produced (kWh)
Conversion efficiency	24%	15% - 30%	Assumes waste heat is used in a co-generation arrangement but produced “for free”
Annual production	3,000 kWh / kW	2,250 – 8,000 kWh/kW	Relates directly to operating hours / year
Associated LCOE*	16.8 c/kWh 18.2 c/kWh	11.8 – 23.4 c/kWh 13.2 – 24.8 c/kWh	Includes effect of LGC (assumed to be 4.5 c/kWh until 2030) Without LGC

* A discount rate of 5.99% is used for the LCOE calculation, as in CSIRO (2021)[12]

4.5 Biogas

Biogas is a minor energy option for Heyfield, based mainly on the size of the resource. There are two potential sources of waste for anaerobic digestion.

Heyfield has its own sewage plant. The owner, Gippsland Water, does not usually consider developing biogas generation at sites as small as the Heyfield Wastewater treatment plant.

The district surrounding Heyfield is filled with dairy farms. These are sometimes considered viable sites for biogas because the waste is collected at a single point.

Manure can be mixed with other waste, such as straw to increase the volume of the resource. After digestion, the biogas can be burnt directly for heat or converted to electricity in a gas engine.

4.5.1 Quantifying the resource

The following figures capture the readily availble resource in Heyfield.

- 20 herds (400 cattle each) – 250m^3
- 1000 people – 20 m^3
- ~ 0.6 GWh of heat
- ~ 0.16 GWh of electricity or 1% of Heyfield’s electricity requirements.

4.5.2 Cost and value

Large biogas plants, typically at metropolitan landfill sites or wastewater treatment plants can have an LCOE as low as 7c/kWh. Higher prices of 15-20c/kWh are considered more realistic for Heyfield dairies due to the size of the system and lower operating hours. The small scale of these plants means that the energy could be used directly “behind the meter”. Biogas also has value as a dispatchable energy resource with relatively cheap storage costs.

4.6 Hydropower

Hydropower is another energy technology for consideration in Heyfield, although it is only expected to pay a minor role. Developing mini-hydro could service up to 10% of Heyfield's load if a concerted effort was made across all main channels. It is considered as a minor source for this assessment.

The Heyfield district has discussed mini-hydro opportunities for over a decade, with one local advocate actively attempting to develop a mini-hydro technology. 4MW of hydro power already exist on Glenmaggie Dam, but the turbines are connected via a different feeder to the Maffra zone substation and cannot be used in a Heyfield microgrid. Southern Rural Water sell water from the Glenmaggie Dam and Cowarr Weir on the Thomson River. The water flows along 4 main irrigation channels and farmers also have some rights to extract water from the Thomson river and aquifers.

Pumping is a large load in the area. At least one farmer has a 100kW pump and has added a 100kW solar system to reduce its operating costs.

Southern Rural Water has been investigating a US mini-hydro technology developed for irrigation channels. It is also considering the possibility of covering the channels with solar panels to reduce algal growth and produce electricity.

Figure 10 Hydroelectric turbines and dam wall at Glenmaggie

4.6.1 Resource

Hydroelectric generation (or "hydro") catches the potential energy of water as it falls from one height to another. Water is often dammed in one place in order to create the height difference. The irrigation channels around Heyfield have been designed to deliver the energy many kilometres to beyond Maffra, a height drop of around 25m. At the Glenmaggie dam wall the 4MW turbines produce 9 GWh per year from the release of water into the Southern Channel[17]. The height varies with water level in the dam and is probably 15-25m at different times. Harvesting energy from these same water flows around Heyfield will produce a fraction of this energy because the height drop (known as the head) is much smaller. A rough estimate of the potential is 100 small turbines producing up to 10% of Heyfield's electricity consumption.

In many mini hydro settings, the turbine harvests the energy as the water flows past without a dam. This run-of-the-river concept works on a principle similar to the way wind turbines harvest energy from the air. Minimum flows will be needed before the turbine starts production and higher flow rates produce significantly more energy. The figure below shows the turbines in action. The turbines below are sold in a size range of 10kW-25kW and can be placed in series with each other, as shown in Figure 11, without slowing the water significantly and impacting the production of each turbine.

Figure 11 Hydro turbines at work along an irrigation channel (each produces 10-25kW)

4.6.2 Availability and Dispatchability

Like wind, the hydro resource will only be exploited in locations that make the resource cost-effective. This might require adjacent loads, like pumping or nearby farms so that the generators can be connected behind the meter, allowing some electricity to be available at a higher value and allowing use of existing electricity connection infrastructure.. It might require a concrete channel to already exist so that civil works are limited and capital costs kept low. Only some parts of the Southern channel are built in concrete, such as the channel shown in Figure 13.

Like biomass, the hydro resource is controlled by another entity with commercial considerations so the exploitation of the resource will need to be negotiated. The channel locations closest to Heyfield are shown below. In Figure 14, the average monthly flows reflect the commercial demands of farmers. Irrigation water is booked when fields are dry. Some water is released a number of days in advance because it takes that long to flow to the customer at the end of the channel.

Hydro is only a dispatchable or flexible resource to the extent that water flows can be varied. Irrigation mainly occurs from October to March and there will not be any seasonal flexibility. The Southern Channel has the capacity to operate at over 1,400ML/day but the average hovers between 300 and 600ML/day so there is some daily flexibility in the existing capacity of the system. There is a time lag between the release of water at the dam and the flow in the channel so serving optimal times of day (breakfast and dinner times) would be most easily programmed for releases at the dam and the channel turbines would produce electricity some time later.

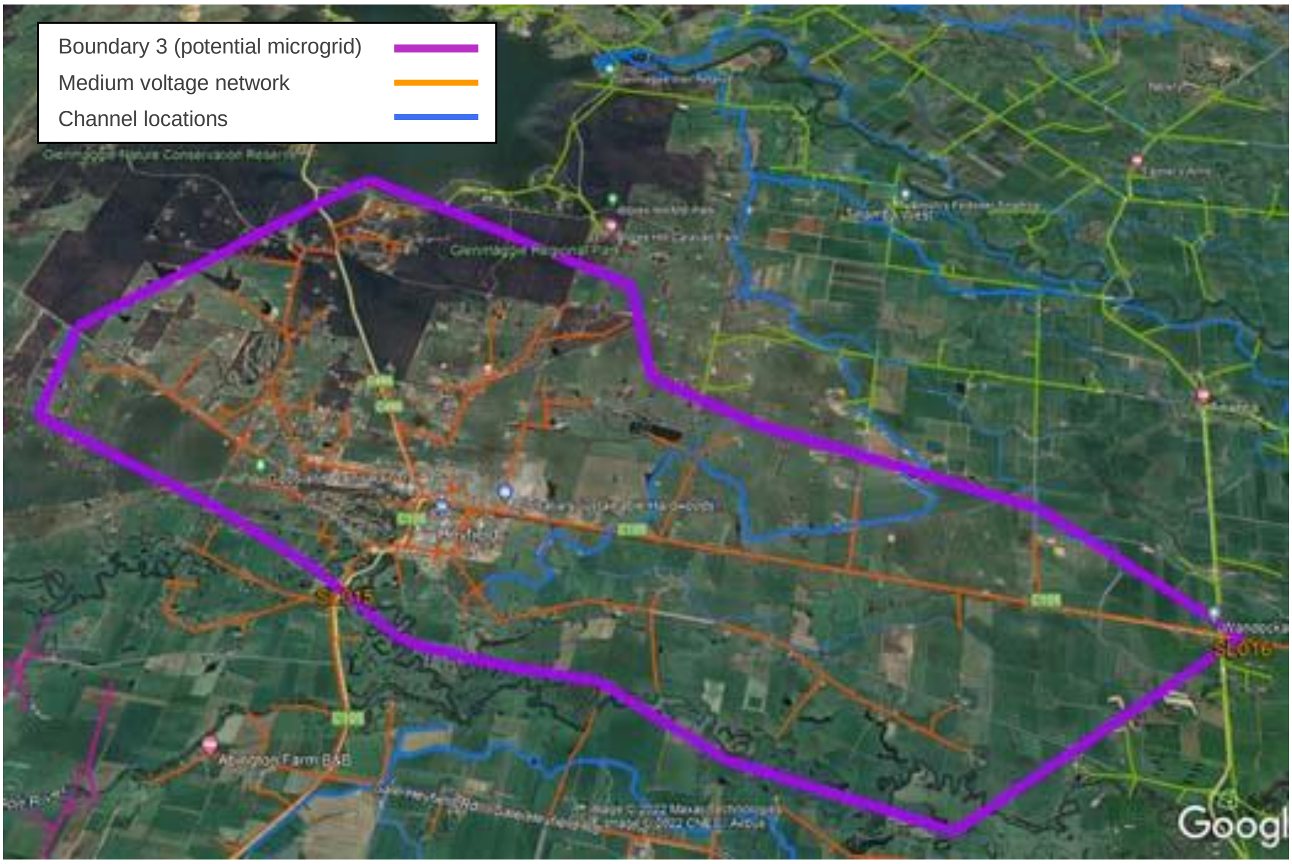


Figure 12 Channel locations compared to potential microgrid boundary and the MV network

Figure 13 Southern Rural Water's southern irrigation channel

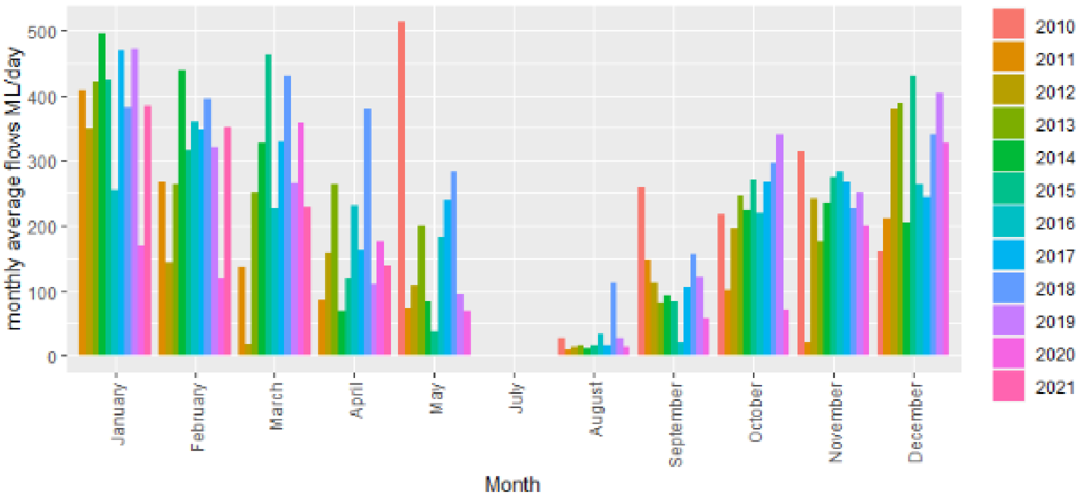


Figure 14 Variation in average daily flows reflect the climate dependence of each year

4.6.3 Cost

Hydro-power has long been touted as the cheapest renewable resource, however this claim disguises much variability in the resource, scale and the civil works associated with a good project. $4,000 to $10,000 per kW seems to be a reasonable range to assume for capital costs and this results in LCOE costs between 20c/kWh and 50 c/kWh. Finding locations that reduce the capital cost and optimise the water flows will be the key to making this resource work for Heyfield. Appendix B gives additional details on tools and sources for hydro, and Appendix E gives additional details on the potential cost of hydro in the Heyfield area.

4.7 Solar Thermal

Solar thermal could supply many Heyfields, even though the location is not optimum for Australia. However, the economics means this is unlikely to play a role in Heyfield's local energy options at present.

Solar thermal prospects have been derated by the CSIRO in recent years as the international market has shifted and a key supplier has folded. It puts capital costs at $7,400/kW, up from $4,000/kW a few years ago.

As a stand alone proposal, solar thermal cannot compete with solar PV on cost. However solar thermal comes with storage and the cost of expanding the storage is minimal compared to the cost of the solar collectors and the steam turbines or engines to convert the heat to electricity. Solar thermal is therefore valuable as a dispatchable source of electricity. When six hours of storage are needed, ITP argues that that solar thermal is cost-effective compared to wind and solar PV.

Appendix B gives additional details on costs and sources for solar thermal.

4.7.1 Costs

Biomass is the main dispatchable option that has been explored in this report so far. One option to make solar thermal cheaper would be to combine it with biomass and use the same generator for both sources of heat. The analysis below compares solar thermal based heat, with the costs associated with using sawdust to produce the same heat.

From the ITP analysis modified for smaller scale, the breakdown of costs are:

- Collector costs $870/ kW of thermal energy
- Each kW thermal of installed collectors would produce 1330kWh of thermal energy annually in Heyfield
- Storage costs $60 / kWh of storage capacity.
- In the ITP analysis, collector costs are around half the final LCOE of 13c/kWh. Storage accounts for 7-10% depending on the choice of 6hrs or 12 hrs of storage.

For solar thermal to displace biomass, the sawdust would need to be worth $200/tonne. Even without inflating ITP costs to account for the small scale, sawdust would need to be worth $85/tonne.

Solar thermal feasibility, therefore, relies on a reduction in the cost of collecting the solar energy. ITP expects storage costs for holding wood waste to be much lower than the molten salt storage associated with solar thermal plants. This option is not explored further for Heyfield.

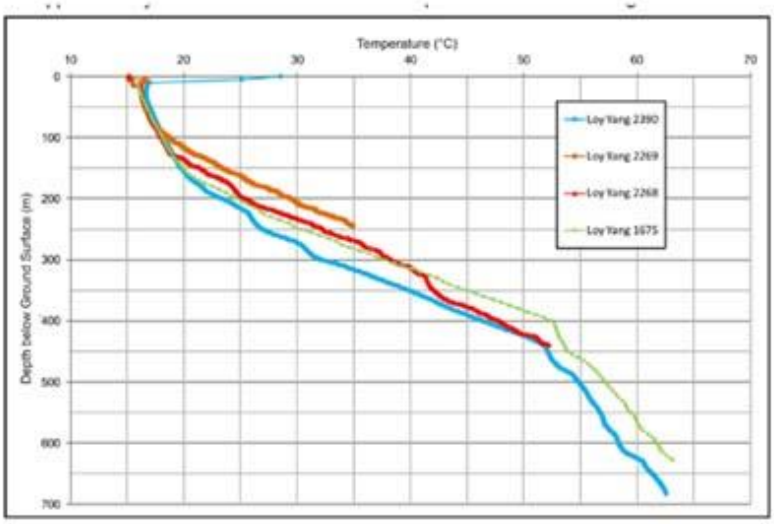
4.7.2 Rooftop solar collectors for hot water

34% of households in Heyfield that filled in the energy use survey reported having solar-electric or solar-gas hot water systems. This is another use of solar energy and will be assessed alongside other types of hot water production.

4.8 Geothermal

Heyfield sits above a vast reservoir of heat associated with the whole Latrobe Valley. Efforts to develop this resource have been underway for some time and a multi-million dollar project in Traralgon will heat the swimming pool. Similar projects, all with price tags over $1m were constructed for a number of Perth swimming centres. A large heating load can make the cost of drilling a hole to the geothermal resource worthwhile. Some of the swimming pool projects mentioned were saving over $500,000 per year in gas costs.

As Figure 15 shows, the Heyfield resource is likely to be around 65°C at 650m below ground.



Bore Number	Logged Depth (m)	Maximum Temperature (°C)
Loy Yang 1675	628.0	63.2
Loy Yang 2268	439.9	52.2
Loy Yang 2269	244.9	35.0
Loy Yang 2390	683.0	62.6

Table 1: Temperature data collected from the Precision Temperature Logging work program.

Figure 15 Data on drilling for geothermal resource at four bores east of Traralgon Reproduced from Driscoll & Beardsmore, 2011[18]

4.8.1 Electricity Generation

Electricity generation from lower temperature heat is based on an organic rankine cycle engine and is not very efficient (~ 10% of the thermal energy is converted to electricity as shown in the table below). Steam cycles at higher temperatures with traditional steam turbines can achieve up to 45% conversion efficiency.

The WA government[19] concluded that bores of 2,000m with 100°C termperatures would be considered non-prospective unless they had already been drilled for another purpose (eg petroleum prospecting).

Table 14 Typical energy capacity and conversion from geothermal bores
From Table 10, Government of WA, 2014[19]

Geothermal source temperature (ºC)	Typical thermal power input	Typical electrical output
90	120	10-12
150	2000	50-100
280	11,000	500-2000

4.8.2 Heat uses and value

Geothermal energy could be used directly as a heat source. The following opportunities have been considered:

- **The timber mill**: the temperature is much lower than 150°C currently used for drying timber in the form of steam, so geothermal is not appropriate. .
- **The Heyfield swimming pool:** does not operate in winter time and will include little if any heating.
- **The hospital and aged care facility:** is likely to be the largest user of low grade heat in Heyfield. If a bore displaces efficient wood heating at $90 per tonne of wood then the value of a 100kW bore would be around $8,000 per year. This increases to $28,000 per year if reverse cycle airconditioning or hot water heat pump is displaced and would displace more in the case of LPG heating. Of course, these costs are annual while most of the cost associated with geothermal is capital to set up the system, so it may be worth investigating the cost of drilling a bore to 650m, and the actual termperature of the resource, in order to assess this opportunity in more detail.
- **Residential heating:** The highest cost heating that might be worth investigating for displacement by geothermal heat is a home that uses LPG for space heating and hot water. Most homes in Heyfield use wood for heating with only four reporting LPG as the main source of energy for space heating.

5. Storage and flexibility options

In a microgrid, Heyfield would require between one quarter to one half of its electricity production to be stored or used flexibly[r]. For the purpose of screening, this is related back to the whole town's annual consumption of 20GWh (Section 2.1.8 Benchmarking volume), so the storage requirement is expected to be somewhere between 5 and 10GWh.

There are many different types of energy storage and flexible load categorised here as:

- **Electrical storage** – such as batteries or flywheels.
- **Fuel storage** - dispatchable generation sources (such as bioenergy or diesel) use the fuel as their storage, while hydrogen is a specifc example of a fuel which can be produced from electricity.
- **Load linked energy storage –** this includes water storage (associated with pumping), thermal storage for heating and cooling, flexible loads, and future loads such as electric vehicles.

Electrical storage is needed for variable generation such as wind and solar, as when there is a mismatch between the electricity produced and the electricity required, the surplus needs to be stored, dumped, or exported to the main grid. Fuels may be directly associated with the relevant generation (such as sawdust), or, in the special case of hydrogen, produced from electricity.

Load-linked energy storage needs to be weighed against the electrical or fuel storage options because it reduces the capital investment in storage that might otherwise be required for Heyfield, and storage options are not cheap. Electrical storage in the form of batteries, hydrogen and flywheels will only be limited by budget and business case. By contrast, load-linked forms of storage will be limited by the end load to be served because they store the energy in its final form, for use when needed. The forms are identified below as thermal storage, water storage, flexible loads and future loads. The distinctions between each category do not need to be clear as the loads identified below all contribute to total flexible capacity.

Energy efficiency options are likely to be implemented in advance or at the same time as flexibility options and the scale of some of these options will therefore reduce over time, although there will be drivers in the opposite direction as well associated with population or economic growth in Heyfield.

Many generation options have specific storage associated, and the benefits of storage and dispatchability have been discussed in Section 4. Biomass is best stored in its sawdust form. Solar thermal is stored as molten salt. Hydro power is already stored in Glenmaggie dam with generation dictated by water releases. Biogas can be stored as a gas in between the digestion and conversion phases. These generation specific storage options will not be discussed further in this section.

This section summarises the main types of storage in Table 15, and compares the cost of these options in Section 5.1, and looks at load linked storage in Section 5.2. Appendix F gives more details on the main storage types that could be used to store or use excess electricity, that is, batteries, flywheels, and hydrogen.

Table 15 Summary of storage types

Type	Examples	Notes
Electrical	• Batteries • Flywheels	Energy markets also consider pumped hydro[s] and compressed air storage which work at very large scales, and supercapacitors for thousands of short duration storage cycles.

[r] This is an approximate figure, estimated as half Heyfield energy consumption currently occurs at night so cannot be supplied directly by solar. A number of options will be explored in the microgrid modelling to reduce the storage requirement.

[s] Note that pumped hydro needs an upper and lower dam with generation and pumping – Lake Glenmaggie provides the upper dam and the generation but a pumped hydro solution would rely on a suitable location for lower level storage with cost-effective pumping design.

Type	Examples	Notes
		These options are not considered in this section as they are not relevant at the community scale for Heyfield.
Fuels	• Hydrogen • Biomass (sawdust) • Biogas	Hydrogen is the main storage medium under investigation in Australian electricity markets at the moment due to the relative simplicity of producing hydrogen from renewable electricity. Sawdust and biogas are considered under generation options.
Thermal	Loads • heating for buildings, • hot water • cooling for buildings • refrigeration For generation • Molten salt	Thermal energy can be stored in water, ice and other materials. The amount of energy stored in water is directly related to the temperature difference. When water changes phase to ice is stores much more energy associated with the change from a liquid to a solid. Phase change materials are sometimes used to store energy at building heting and cooling temperatures (eg 22°C).
Flexible loads	• Pool pumps • Appliances (e.g. dishwashers and washing machines) • Appliances with asociated storage (e.g. phone charging, water filtration) • Traditional demand management	Flexible loads can compete with storage as a suitable way to use surplus electricity. Instead of storing energy to use later, the timing of the load is changed to use the energy directly, when it is surplus and cheap
Future loads	• Bus • Car • Bike • Scooter • Gopher • Farm vehicles • Forklifts • Freight • Hot water and heating loads curently served by LPG	It will be valuable to design the systems that encourage future electrification of our energy systems in such a way that the loads are flexible and optimise any in-built storage or excess capacity. Electric transport is likely to rely on battery technology and there is significant discussion in both he electricity industry and the transport industry about the value of using those batteries for electricity system storage at times when the cars are idle. The possibilities are discussed in the section on batteries, scale and location below
Water storage	• Water storage to enable pumping to become a flexible load	Gippsland water and farmers may already have adequate capacity to schedule pumping to occur when renewable energy is surplus to other requirements, and building new storage can be relatively cheap

5.1 Storage Option Comparison

Most of the storage and flexible load options are targeted at solving a daily imbalance between daytime generation and night-time load but some could contribute to a week of low renewable production. Hydrogen could serve a longer storage need. Heyfield also has a seasonal mismatch between generation options and load. For example, solar energy is produced at a rate of 130%, i.e. above average in summer and at 70% of the annual average in winter. Seasonal mismatch might be better served by oversizing initial generation capacity or by not aiming for self-sufficiency (that is, not aiming to cover 100% of the Heyfield load at all times).

Table 16 Levelised cost of storage options and estimated value of flexible loads

Option	Volume	Levelised Cost OR Annual Value (per site or load)	Main Usage	Relevance for Heyfield
Electrical Storage				
Batteries	Budget limited	25 – 40 c/kWh	Daily Balancing	Primary
Flywheels	Budget limited	10 – 100 c/kWh	Multiple cycles per day, smoothing variability	Unlikely (possible trial)
Hydrogen	Budget limited	33 – 60 c/kWh	Long term storage, transport, emergency generators	Minor
Load Linked Storage (flexible loads)				
Hot Water	8% x Heyfield annual energy	$150 to $800/yr	Charge hot water with surplus solar or wind	Primary
Building heating and cooling	4% x Heyfield annual energy	$70 up to $750/year large sites	Build thermal mass into buildings. Heat and cool when surplus available	Minor
Refrigeration	3% x Heyfield annual energy	$90 to $1,500/year high use sites	Ice or chilled water storage	Minor
Pumping and flexible loads	3% x Heyfield annual energy	Variable - eg $33/year washers	Move to cheapest time	Secondary
New loads	15-30% x Heyfield annual energy	~ $2,000 transport ~$300+ - LPG	Electrify and use at times of surplus, cheap renewables	Minor

5.2 Load Linked Storage

Load linked storage will occur at multiple sites across Heyfield, each with unique circumstances in terms of capital cost, specific technologies and solutions chosen and the storage or flexibility to be unlocked.

Since capital cost and uptake are uncertain, the annual value of converting the load to a storage or flexible option is presented below. This is based on a standardised value of 15c/kWh. Usually the value differential between peak and off-peak is less than 15c/kWh but this value has been chosen on the assumption that the flexible load is available to use energy that would otherwise be surplus. It also assumes that the value offsets an investment in batteries which would cost around 30c/kWh. In other words, this is the battery Heyfield will not need to buy.

Each option is discussed more fully under the energy efficiency section in order to develop the alternative options. For example, many loads will require more than a simple shift to daytime, surplus solar generation times. As an example, hot water is likely to involve:

- Change hot water system to efficient and cost effective option
- Move to controllable system or at minimum install timer for daytime
- Reconnect and change tariffs

The table below calculates the estimated annual value for making each load flexible so that a project can be pursued with this annual income in mind. The total value across the Heyfield community is also calculated. Improving the local economy is a stated aim of the project and helps motivate stakeholders to advocate for widespread uptake of these energy options.

Table 17 Estimated annual value of load linked storage (per site and for Heyfield)

Load Linked Storage	Potential (GWh)	Estimated Annual Value per site at 15c/kWh value	Heyfield-wide annual value with 100% uptake
Hot Water	1.1 GWh residential 0.37 GWh commercial	$400/year standard elec hot water $150/year solar boost & heat pump $800/year across 70 sites	$190,000
Building heating and cooling	0.35 GWh residential 0.35 GWh commercial	$70/year average across all homes $750/year	$105,000
Refrigeration	0.44 GWh residential 0.09 GWh commercial	$90/year average across all homes $1,500/year high refrigeration sites	$80,000
Pumping and flexible loads	0.52 GWh	Variable Eg washers = $33/year per home	$80,000
New loads	Heating and transport loads from LPG, wood and fuel will *add* to total electricity consumption	~ $2,000 per year for EV ~$300 to $500 for hot water from LPG	3 GWh equivalent to $450,000

5.2.1 Valuing loads

Storage and flexibility offer a variety of services, including matching supply and demand, energy arbitrage, and some network services such as voltage and frequency control. The value of control has been discussed (Section 3.2). In order to arrive at a value for flexible loads, much depends on the interplay with wholesale energy markets, the negotiated network value with Ausnet Services (if relevant). The purpose for which flexibility is needed is also key, as in situations where flexibility can prevent a major blackout, the value could be many hundreds of dollars. We have used a mid-range value for energy arbitrage (15c/kWh), acknowledging that the back-up supply cost (50c/kWh) is more appropriate some of the time when flexibility contributes to emergency supply.

Energy Arbitrage: 15c/kWh is used below as a representative figure for the difference in value between times of abundance and times of scarcity. These used to be known as peak and off-peak times and Australians are only beginning to understand that off-peak (times of abundance) no longer occurs regularly at night and the economics have shifted with the arrival of abundant solar and wind. Peak times that were originally driven by winter heating and then shifted to 4pm during a heatwave in February have now moved again to 6:30pm on the same hot weekday. When located behind the meter, a battery or flexible load can shift energy from a high priced time (costing anywhere from 20c/kWh (controlled load pricing) to 39c/kWh depending on the tariff and retailer) to use on site, compared to surplus solar which is only paid 6.7c/kWh and the value is falling).

Back up supply: 50c/kWh is the minimum cost of back up diesel generation. The value of having back up supply is difficult to price. The electricity industry generally had at least one back up option for every main point of failure, so a value is placed on permanent availability of a second and sometimes third source of energy. This value is not explicitly priced in the market but rather bundled with all other costs. For small outages, measured as few customers and short durations, not serving the load at all is generally the cheapest option.

6. Conclusion and next steps

The MyTown Microgrid Heyfield project considers three main areas of activity, on-site investments, microgrids, and other means of energy sharing

On-site investments can add value to householders and businesses directly, by implementing cost-effective options which reduce energy use, improve load control and flexibility, or add on-site energy generation and storage. Load flexibility can achieve the same effect as storage but at a much lower cost. On-site investments are "behind the meter" so the value to the consumer is far greater than the same investment made and connected directly to the electricity grid (e.g. 33c/kWh avoided costs for rooftop solar used on-site, compared to 8c/kWh or less when connected directly to the network). On-site investments also benefit a community-wide solution (a microgrid or energy sharing system), as every investment in energy efficiency means lower capital cost for generating and storage plant in a wider system. On-site investments are therefore recommended as the first step in any energy program.

A potential microgrid boundary has been identified in the companion report for this milestone, *Part 2 Boundary options: revised results.* Boundary 3, including most of the town, was identified as the preferred boundary for modelling and assessment, so this study identified each energy option that could reasonably be contemplated within that boundary, and compared the scale of the resource to the total load. The location of energy resources - wind, hydro and biomass in particular – means many of these options are not available for smaller scale solutions.

Energy Sharing has always been a driver for this project. People with solar panels want to see their surplus go to good use in their community, and the motivation for a microgrid is partly driven by wanting to share energy. There are other options for energy sharing, such as Virtual Power Plants, community batteries, or various retail offers or network tariff arrangements that are designed to facilitate energy sharing while reducing system costs. These have not been investigated at this stage of the project, and it is recommended that they are investigated either alongside microgrid feasibility, or if initial feasibility for a microgrid is not promising.

Each of the three areas of activity involve the contribution of new energy options that improve the efficiency and flexibility of energy use, generate energy from renewable resources and store some of that energy. This work has analysed their potential contribution and ranked them as primary, secondary, minor, or unlikely, to highlight the priorities for the Heyfield community to pursue.

Initial screening of options is important so that relative performance, cost and contribution for each option are understood during the modelling and co-design processes so effort can be concentrated on the most promising. However, while options have been assessed to highlight the considerations for each individual technology, the final energy solution will consist of multiple technologies contributing to an optimal solution. Balancing appropriate contributions of each technology is the role of future modelling and discussions with community stakeholders. Table 18 summarises the energy options that have been considered in the report, with a brief note of either next steps or explanation.

Table 19 shows only those options considered primary or secondary, and their scale relative to Heyfield's total load. Only energy efficiency options with rapid paybacks are included, and those alone could reduce the Heyfield load by approximately 10%. Examining generation and storage options, Heyfield's load could be met many times over.

Looking at load flexibility options, nearly 40% of Heyfield's load could become flexible as the town grows, and the value of load linked storage could be in the order of several hundred thousand dollars annually. These options can reduce the overall cost of the system or increase the value of other local energy options, and will almost always be cheaper than storage. However, implementing flexibility options will require a wholistic and co-ordinated approach to energy system development.

Table 18 Summary of energy options considered for Heyfield

Energy option	Volume	Cost	Payback	Relevance	Notes
EFFICIENCY AND CONTROL OPTIONS					
Hot water	4% x Heyfield	Medium	6 years	Primary	Transitioning to heat pumps has a strong business case.
Conversion from LPG	1.5% x Heyfield	Medium	6 years	Primary	On site solar and off-peak electricity are cheaper than LPG
Heating & cooling	2% x Heyfield	High		Secondary	Relies on the user education, building design, and heating replacement.
Lighting	1% x Heyfield	Low	2 - 3 years	Secondary	Can be achieved as light globes need to be replaced.
Efficient appliances	0.7% x Heyfield	Low	1 year	Secondary	Can be achieved as appliances need to be replaced.
Further commercial/ industrial efficiency	Unknown; likely to be significant	Site specific	??	Secondary	It is recommended that commercial and industrial site audits are undertaken to identify significant opportunities that are likely to exist.
Refrigeration	0.2% x Heyfield	Medium	??	Possible trial	Trial site such as IGA or dairy to showcase efficient system design.
Compressed air	0.2% x Heyfield	High	??	Minor	This could be an opportunity for the timber manufacturing sector.
Pumping	0.3% x Heyfield	Medium	??	Possible trial	Trial premium site, e.g. collaboration with Gippsland Water or larger farm.
Streetlights	0.5% x Heyfield	Low	??	Possible trial	Worth investigating an upgrade to LEDs if current streetlights are old.
GENERATION OPTIONS					
Solar PV	Many x Heyfield	Low	5 years	Primary	A rooftop solar strategy is recommended, in collaboration with Ausnet.
Wind	Many x Heyfield	Low	5-15 years	Secondary	First step is to identify possible locations and commence monitoring.
Biomass	1 x Heyfield	Low	8 years	Secondary	Feasibility study underway at mill; collaboration needed to include in microgrid.
Hydro	10% x Heyfield	High	10 years	Minor	Collaboration with Southern Rural Water to investigate is recommended.
Biogas	1% x Heyfield	Medium	8 years	Minor	A feasibility study of biogas for dairy is recommended.
Geothermal	Many x Heyfield	High	Very long	Minor (for heat)	Pre-feasibility study for Laurina Lodge recommended.
Solar thermal	Many x Heyfield	High	Very long	Unlikely	If storage becomes easier to value, this should be re-investigated.
STORAGE OPTIONS					
Batteries	Budget limited	Medium	10 years	Primary.	Commence identification of suitable technologies and costs for Heyfield.
Flywheels	Budget limited	High	Long	Unlikely	Keep costs under review.
Hydrogen	Budget limited	High	Long	Unlikely	Keep costs under review.
LOAD LINKED STORAGE OPTIONS					
Hot Water	8% x Heyfield	Low/medium	??	Primary	Setting as a storage asset can be done simply while upgrading to heat pumps.
New loads	15-30% x Heyfield	Low	??	Primary	Consider load flexibility when electrifying heating and transport loads.
Building heating & cooling	4% x Heyfield	Medium/high	??	Secondary	Educate building owners about thermal mass. Monitor market for building integrated thermal storage products.
Refrigeration	3% x Heyfield	Low	??	Possible trial	Trial premium site such as IGA or farm to showcase cold thermal storage.
Pumping & flexible loads	3% x Heyfield	Low	??	Possible trial	Discuss with irrigators and Gippsland Water while investigating mini hydro.

Table 19 Energy options considered of primary or secondary importance for Heyfield

ENERGY EFFICIENCY OPTIONS			GENERATION AND STORAGE			LOAD FLEXIBILITY OPTIONS		
Option	Volume	Outcome	Option	Volume	Outcome	Option	Volume	Outcome
Hot water	4%	Primary	Solar PV	Many	Primary	Hot Water	8%	Primary
Conversion from LPG	1.5%	Primary	Batteries	Budget limited	Primary.	New loads	15-30%	Primary
Heat & cooling	2%	Secondary	Wind	Many	Secondary	Heat & cooling	4%	Secondary
Lighting	1%	Secondary	Biomass	1	Secondary			
Efficient appliances	0.7%	Secondary						

Next Steps

A program of work should be developed for delivering generation and storage options on an “on-site first”, basis to prepare the town for a microgrid or other energy sharing platform. Starting with short payback projects that can be funded on a no-regrets basis, some of this work will revolve around business models that allow the community to facilitate, fund and deliver projects. An on-site first strategy could create a town full of energy customers who are ready for the future energy system. In the case of the options identified as suitable for a trial or a showcase, there is value in investigating programs willing to provide funding.

Community engagement, business model co-design and microgrid modelling are all underway. This report is intended to inform those activities and empower the Heyfield community to choose its own energy priorities. The following next steps are recommended:

1) **Community discussion to choose priority options:** a series of primary, secondary, and minor energy options have been proposed, with suggestions for progressing each option individually. It is recommended the community reference group spends time understanding these options, the proposals and uncertainties, and defining its own priorities. Many of the investment decisions largely rest with building owners and tenants, however, the community benefits that an on-site program could deliver might be sufficient reason to prioritise and identify ways to fund or part-fund some strategic investments. This is especially true for critical sites which might benefit from battery storage investments.

2) **Microgrid modelling – initial feasibility:** microgrid modelling has commenced and will initially focus on only those generation and storage options identified as primary or secondary, as these are the lowest cost and can easily meet Heyfield’s requirements, noting that the community may at a later stage wish to include other options. The data collected on cost and load and volume will inform the modelling and initial scenarios.

3) **Investigate missing information:** Around 20% of the load has not been well understood in this initial screening of energy results. The commercial and industrial loads were identified from an inventory of businesses extended to include those that have not yet been identified, and the number of farms and pumping loads falling inside the chosen boundary is unclear. Further data from Ausnet Services and ongoing discussion with energy users in Heyfield will provide more clarity on energy opportunities associated with this uncertain proportion.

4) **Undertake additional investigation into energy efficiency potential:** A deep retrofit strategy targets energy efficiency savings in excess of 30% by investing up front in very energy efficient building form and equipment, and the analysis to date has not included the level of detail required.

5) **An “on-site first” strategy** is recommended. To some extent this is an extension of the solar bulk-buy and energy efficiency activities underway for most of the last decade, however it is recommended this is extended to include consideration of both deep energy retrofits, and the creation of significant amounts of load flexibility.

Appendix A – Price differences by time of day and year, Victorian electricity market

The figures below illustration the fluctuation of electricity demand and price across the Victorian wholesale energy market.

Detailed modelling of the microgrid splits the entire year into 8760 hours and defines the optimal generation outcomes against each hour. This method will provide different costs for each hour of the year. Without detailed modelling there is no simple way to benchmark the different value of energy at different times. Wind might help balance out solar so creating a diversity of energy sources is more valuable than simply relying on solar energy, for example. When considering generation options, load flexibility and energy efficiency we consider the imbalance of production and consider times of surplus as being less valuable than times of scarcity.

Surplus electricity is exported from its immediate area and may also incur additional costs, or constraints leading to the electricity not being used. Export capacity and minimum or negative loads are increasingly concerning electricity network businesses but are not reflected in any pricing approaches at the moment.

Examples of the wholesale energy price and the volumetric differences by time of day and season are provided below to illustrate the way both fluctuate at the Victoria-wide level. 2021 data is used even though this is atypical due to COVID. 2019 would have better representation of typical volumes but worse representation of price because the level of wind and solar in the electricity system continues to grow. For example, high prices in May are partly attributed to low wind and earlier sunsets. Negative prices in October are likely to be caused by the combination of low loads (little heating or cooling) and plenty of sunshine.

Load - fluctuation of volume by time of day and season (GW)

Hour of Day \ Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0 - 1	5.5	5.7	5.4	4.9	5.2	5.4	6.0	5.2	5.0	4.9	4.8	5.1
1 - 2	5.3	5.5	5.2	4.7	5.1	5.1	5.7	5.0	4.8	4.7	4.6	5.0
2 - 3	5.2	5.3	5.1	4.6	4.9	4.9	5.5	4.8	4.6	4.5	4.4	4.9
3 - 4	5.1	5.2	5.0	4.5	4.8	4.7	5.3	4.7	4.5	4.4	4.3	4.8
4 - 5	5.1	5.2	5.0	4.5	4.8	4.7	5.3	4.7	4.4	4.5	4.4	4.8
5 - 6	5.2	5.4	5.2	4.5	4.8	4.8	5.3	4.7	4.3	4.7	4.6	4.9
6 - 7	5.4	5.7	5.5	4.7	5.0	5.1	5.6	4.9	4.6	5.0	4.9	5.1
7 - 8	5.7	6.0	5.8	5.2	5.4	5.6	6.0	5.3	4.9	5.3	5.3	5.5
8 - 9	6.0	6.2	5.9	5.5	5.8	6.1	6.4	5.6	5.1	5.3	5.4	5.8
9 - 10	6.2	6.3	6.1	5.5	5.9	6.3	6.6	5.7	5.2	5.3	5.5	6.0
10 - 11	6.4	6.4	6.2	5.6	5.9	6.2	6.6	5.8	5.3	5.5	5.6	6.1
11 - 12	6.5	6.5	6.3	5.7	5.9	6.1	6.5	5.8	5.4	5.5	5.6	6.1
12 - 13	6.6	6.6	6.3	5.7	5.9	6.1	6.5	5.8	5.3	5.5	5.6	6.2
13 - 14	6.7	6.6	6.3	5.7	5.8	6.1	6.4	5.8	5.3	5.4	5.6	6.2
14 - 15	6.7	6.7	6.3	5.7	5.7	6.0	6.4	5.7	5.2	5.3	5.5	6.1
15 - 16	6.7	6.7	6.2	5.6	5.6	5.9	6.3	5.6	5.2	5.2	5.5	6.1
16 - 17	6.7	6.7	6.3	5.6	5.6	6.0	6.4	5.5	5.2	5.2	5.6	6.1
17 - 18	6.7	6.7	6.3	5.7	6.0	6.6	6.7	5.8	5.4	5.4	5.7	6.1
18 - 19	6.6	6.6	6.2	6.0	6.4	7.1	6.9	6.4	5.8	5.7	5.7	6.0
19 - 20	6.5	6.5	6.2	6.0	6.3	7.0	7.0	6.5	5.9	5.8	5.7	5.9
20 - 21	6.2	6.3	6.1	5.7	6.1	6.6	7.0	6.2	5.7	5.7	5.6	5.7
21 - 22	6.0	6.1	5.9	5.4	5.9	6.3	6.8	5.9	5.5	5.4	5.4	5.5
22 - 23	5.7	5.9	5.6	5.2	5.6	5.9	6.4	5.5	5.3	5.0	5.1	5.3
23 - 24	5.5	5.7	5.4	5.0	5.4	5.5	6.0	5.3	5.0	4.9	4.9	5.2

Figure 16 Average load in Victoria by month and time of day

Note: the average hourly load for the year is 5.6GW, data used is Dec 2020 to Dec 2021

Price - fluctuation of wholesale electricity price by time of day and season $/MWh

Hour of Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0 - 1	35	30	33	54	44	72	78	60	43	35	45	37
1 - 2	27	24	28	42	33	60	66	48	32	27	37	29
2 - 3	21	18	24	31	25	52	50	31	20	19	29	21
3 - 4	19	17	23	27	19	45	36	21	13	15	24	21
4 - 5	20	19	26	26	18	47	31	17	13	17	30	24
5 - 6	26	24	33	32	23	49	42	27	20	31	43	28
6 - 7	31	33	48	55	35	68	67	39	35	44	48	29
7 - 8	24	30	51	92	74	98	91	69	39	22	46	25
8 - 9	16	18	31	57	66	137	123	67	18	7	33	18
9 - 10	14	15	27	38	40	109	113	52	13	- 8	17	7
10 - 11	11	9	21	26	35	83	93	29	1	- 19	12	9
11 - 12	9	9	19	18	26	69	77	8	- 4	- 24	5	10
12 - 13	10	8	18	18	25	62	61	0	- 6	- 24	3	9
13 - 14	6	9	17	19	26	64	60	- 5	- 12	- 24	5	3
14 - 15	6	11	18	22	32	78	69	0	- 7	- 20	9	8
15 - 16	12	14	21	27	41	85	78	10	3	- 12	13	14
16 - 17	21	16	27	48	69	116	109	29	14	3	23	20
17 - 18	24	23	36	83	168	169	137	70	45	31	48	25
18 - 19	32	34	49	135	540	181	225	148	99	77	66	36
19 - 20	42	41	45	96	140	111	146	115	88	80	85	47
20 - 21	40	35	37	75	91	100	137	84	63	56	68	45
21 - 22	35	30	32	62	71	90	121	76	50	42	54	37
22 - 23	32	27	32	53	58	87	102	69	48	34	47	33
23 - 24	32	28	33	52	48	77	88	63	39	32	47	35

Figure 17 Average electricity wholesale price in Victoria by month and time of day

Note: the average hourly price for the year is $44/MWh, data used is Dec 2020 to Dec 2021.

Appendix B – Solar, wind, hydro tools and sources

Solar tools

There are many paid tools on the market, but the following are free with small sacrifices on detail.

Many solar tools calculate higher yields than are seen in practice. When losses of around 15% are taken into account, non-ideal orientation and tilt, plus an early degradation of output in the first year the tools and reality start to align. Comments below are designed to assist in choosing realistic output figures over the longer term to support your early feasibility assessment.

Timestamps can be tricky. Take the time to understand how the local time is handled so that you know if your are adjusting correctly for daylight saving.

Many microgrid modeling tools have inbuilt capacity to lookup weather files and assume default PV system information to easily provide similar information commensurate with the outputs of the tools below.

Tool	Link	Comments
Renewable ninja	https://www.renewables.ninja/	Provides hourly data based on real weather files, and in the local time as dictated by your computer. Setting a loss factor of 0.2 gives a realistic output.logging in can give you access to more years of data.
Solar atlas	https://globalsolaratlas.info	Gives monthly by hourly averages with downloadable reports and graphs for a site. Like renewable ninja, the default settings expect slightly high yield.
PV Watts	https://pvwatts.nrel.gov/	This online NREL calculator also provides an hourly download and has default losses of 15%. It uses a different approach to yield calculation, with a 10 year typical sunshine file rather than the actual weather so will provide better insight to the average across different weather years.
System Adviser Model	https://sam.nrel.gov/	SAM is software for downloading to design and model many types of renewable generation. It can take some time to work out how to string panels together and how to access the correct solar data for Australia.

Wind tools

Wind data is much more site specific than solar, and therefore yield from the following tools is less reliable. Wind farms will typically collect a few years of wind data at the correct height before determining turbine design and feasibility. Wind energy is related to the cube of the wind speed so twice the speed contains eight times the energy. This explains why taller turbines and windy locations are prized. The local topology can create locations with an advantage, and the top of even a small rise can mean more wind energy.

Wind turbine design can also affect yield and it is worth understanding if you need a turbine for high or low wind conditions before selecting a turbine within each tool. In low speed locations longer blades harvest wind energy by sweeping a larger area. (see, for example, https://www.lmwindpower.com/en/stories-and-press/stories/learn-about-wind/what-is-a-wind-class)

Tool	Link	Comments
Renewable ninja	https://www.renewables.ninja/	Provides hourly data based on real weather files, and in the local time as dictated by your computer. I chose "Goldwind GW82 1500" to try and simulate a low speed wind turbine.
Wind atlas	https://globalwindatlas.info/	Allows for analysis with Class 1 to Class 3 (windy to low speed) wind turbines. Provides reports of power density and wind speed at different heights and wind direction.
Downloadable and online calculators	https://windexchange.energy.gov/tools including small wind economic model www.omnicalculator.com/ecology/wind-turbine	The small wind economic model provides some sample data for smaller wind turbines
Turbine marketplace	https://en.wind-turbine-models.com/marketplace	Specification sheets for many wind turbine models and a marketplace for second hand turbines.

Hydro tools

There are a range of hydro calculators online. This one provides options for a system with a dam or a run-of the river calculation based on water flow. https://www.omnicalculator.com/ecology/hydroelectric-power

Solar PV: values used in calculations and sources

Solar PV	Unit	Value	Notes/ sources
Degradation year 1	%	3%	This figure directly affects annual output. Warranties are often set at 3%[20,21]. Wattwatcher data shows that solar panels in Heyfield are producing between 1600 and 1100 kWh/kWp
Degradation subsequent years	%	0.50%	Compendium of PV degradation rates[22] confirmed by blog posts referenced above which tend to use 0.5% as an industry standard. Different panel types can exhibit degradation in the range 0.2 to 1% per year.
O&M: inverter replacement (3-100kW systems)	$/KW	$400	Inverter prices vary widely, and are 20-50% of initial system cost. Inverter standards and technologies are changing. Replacements are one-off costs and don't benefit from mass ordering. The CSIRO[23] cost of $17/year is equivalent to a $250/kW cost for larger systems (which includes cleaning and repairs; however the major cost will be inverter replacement.)
Year for inverter replacement	Year	15	Inverter warranties can be in the range 5 to 15 years.
O&M mid scale 500kW - 5MW	$/KW	$17	CSIRO (2021)[23]
Capacity factor, rooftop	%	16.7%	Capacity factor is based on annual output of 1464 kWh/kWp. This is drawn from Wattwatcher data and interacts with the degradation factors chosen above.
Capacity factor, ground mounted.	%	18.3%	Jacobs (2020)[24] offer a higher production rate for ground mounted systems. This is based on the ability to optimise tilt and orientation and to maintain panels to a higher standard of cleanliness and repair.

Solar PV	Capital cost			Capacity factor	Lifetime	Note / Source
	Mid $/kW	Low $/kW	High $/kW		years	
VALUES USED IN REPORT						
Rooftop 3-5kW		1,409	1,784	16.7%	25	
Rooftop 10-100kW		1,345	1,594	16.7%	25	
Mid Scale 0.5 - 5MW		1,505	2750	18.3%	25	Actual costs can be higher than projections because real values for land and electricity connection are included – as per Majurah example.
SOURCE VALUES						
Rooftop 3-5kW		1,409	1,784			Solar choice (Feb 2022) [25]
Commercial (10 - 100kW)		1,345	1,594			Solar choice (Feb 2022) [25]
Rooftop current cost (2020)	1439					CSIRO (2021)[26]
Rooftop future costs (2025)		861	1246			CSIRO (2021)[26] for low CSIRO (2021)[27] for high
Mid scale (0.5 – 5 MW)						
CSIRO current (2021)	1505			22%	25	CSIRO (2021)[23] This is taken as the low value, as CSIRO mainly considers large scale.
CSIRO future (2025)		874	1301			CSIRO (2021)[26,27]
Mt Majurah 1MW, 2018	2750					SolarShare (2018)[28]
Mid-Scale solar PV modelling report	1330	880	1650			Green Energy Markets (2021)[29]
Mid-Scale PV projections	1,353			17-21%		Jacobs (2020)[24]

Wind: values used in calculations and sources

Wind	Unit	Value	Notes/ sources
Capacity factor – 30-300kW	%	9.4%	All wind data is calculated by the renewable.ninja wind calculator[30]. In order to be cost-effective, Heyfield would need to identify the best wind resource at a manageable height and the best turbine design to harvest such low wind speeds. Small turbines are assumed to need the same capacity factor as a 50m wind turbine to be considered.
Capacity factor – 50m	%	9.4%	The Goldwind121 2500 was used to simulate a long-bladed turbine because it would produce higher capacity and be suited for low wind speed. 9.4% was the highest capacity factor achieved in the calculator, although a more suitable turbine might be able to improve production at 50m and below.
Capacity factor – 100m	%	35%	The wind resource at 100m is significantly better. This height is chosen for indicating the power range. 100m may be considered too high for Heyfield. Many larger turbines are built at heights between 50m and 100m.
Lifetime	years	25	CSIRO (2021)[23]. A shorter lifetime of 15 years was used for smaller wind turbines which is a general lifetime for mechanical equipment with associated wear and tear.
O&M	$/KW	$25	CSIRO (2021)[23]

Wind	Capital cost Mid $/kW	Low $/kW	High $/kW	Capacity factor	Lifetime years	Note / Source
VALUES USED IN REPORT						
Wind (low voltage) 30-300 kW		4000	10000	9%	15	
Wind at 50m hub height 1 - 5 MW		1951	4000	9%	25	
Wind at 100m hub height 1 - 5 MW		1951	4000	35%	25	
SOURCE VALUES						
Small wind guidebook	11620					Windexchange.energy.gov[31]
On farm power generation guide		1750	4000			Applied Horticultural Research (2014)[32]
2018 Distributed wind market report, PNNL		5600	15400			PNNL[33]
Larger wind turbines						
CSIRO current (2021)	1951			35%	25	CSIRO (2021)[23]
CSIRO future (2025)		1901	1908			CSIRO (2021)[26,27]

Hydro, solar thermal and geothermal - values to in LCOE comparisons

Channel hydro	
Potential resource	The maximum number of turbines was estimated based on the length of channels and suitable distance between turbines.
Capital cost range $4,000 to $10,000/kW	No capital cost information was available from the turbine manufacturer under consideration by Southern Rural Water. This range is consistent with the range presented for small hydro systems in the IRENA hydropower cost database[34].
Operating hours 2000 hrs/yr	Releases from Glenmaggie suggest 2000 hours per year of full hydro production on average.
LCOE comparison 14 to 38 c/kWh	IRENA range for small hydro systems in European settings.

Solar Thermal	
Capital cost range for collector and storage only (no generation) $1230 - $2000/kW Capital cost range with generation 10,950 – 12,390 $/kW	Lovegrove et al (2018)[39] provides a basis for calculating collector and storage costs with and without generation. It also provides scaling factors which were used to derive costs for smaller installations. However, these may be unreliable when the installation is less than 10 MW. These capital costs provide a cost of thermal energy greater than 9c/kWh thermal, ie. four times greater than burning sawdust. Including a steam turbine, with 12 hours storage, the range of capital costs is 10,950 – 12,390 $/kW, with the lower end for 2MW and the upper end for 1 MW.
50% capacity factor	If storage and collectors are sized for 12 hrs of storage
20 – 24 c/kWh	Calculated LCOE
LCOE comparison (noting that these are all for large plant, in the order of 100 MW)	
18 – 22 c/kWh	Lazard (2021)[35]
14.7 – 15.4 c/kWh	IRENA (2020)[36]
17.2 – 21.3 c/kWh	CSIRO (2021)[23]
12 – 18 c/kWh	Lovegrove et al (2018)[39]. Price depends on storage thus 12 c/kWh is 12-24 hours of storage and 18 c/kWh is for 1 hour of storage only.

Geothermal	
Capital cost largely unknown; estimated at $15,500/kW	Lovegrove et al (2018)[39] suggests a cost of $6.3m/MW for a 50MW generator on a hot sedimentary aquifer and a scaling factor of 0.7. . A small 1MW generator might not scale correctly due to larger costs associated with setting up the original bore.
50% capacity factor	Could be higher given that the aquifer is permanently available

Appendix C - Solar PV additional information

Range in solar production

In Australia the economics of solar have led to a strong market of rooftop solar. A decade ago 1.5kW systems were the norm but households can now buy 10kW for a similar price and the size installed is often determined by the space available on the roof. Additional frames to orient the panels for optimum production are rarely considered worthwhile, so solar panels face all directions from East, North to West, driven by the exisitng roof orientation. Likewise, the tilt of the panel will usually be set at the slope of the existing roof.

The annual output can be reduced by 10 – 20 % with different roof orientations and tilts. And the production that does occur will have a different profile. Steeper rooves preference winter production when the sun is lower. Easterly orientation will produce more in the morning and westerly in the afternoon. It is rare that a roof has no overshadowing and this can also impact production.

A recent trend, as rooftop solar systems grow in size is to oversize the panels compared to the inverter. The inverter is the most expensive part of the installation after the panels. The panel size, not the overall system size, dictates the solar rebate that is obtained. In areas with more hours at low solar irradiation, this practice has only a small impact on production. (In Heyfield the peak production will be curtailed if inverters are undersized and this could reduce annual production by somewhere between 2 and 13%). A similar feature appears in utility scale solar where reducing inverter costs might save millions of dollars. Including battery capacity with larger solar systems has become a regulated requirement and any production 'lopped' off peak production will not be lost. Lopping changes the shape of the production at peak times.

Existing PV

The age of the solar panels impacts on production. It should also be noted that most systems will need to replace the inverter at around 15 years. Panel performance usually degrades more in the first year (up to 3%) and then at a slower rate for the remaining life. Warranties typically build in expectations of 80 to 84% performance after 25 years. Heyfield was an early adopter of solar panels with many small systems installed by 2013. It is estimated that 1.83MW of rooftop solar exist within the Heyfield boundary already. Much of this is on residential homes, 39% of which have solar at an average system size of 4.2kW. The MyTown project may need to consider the value of replacing smaller, older systems. Some systems installed before October 2011 may still be attracting premium feed-in tariff rates of 60c/kWh for exported solar.

Impact of Scale

Solar Choice[37] tracks panel prices around Australia and is a good reference for out-of-pocket costs that bundle in the value of rebates. As panel prices fall, the labour component of an installation becomes more dominant. This is evidenced in a the variation in price between a 3kW system and a10kW system. The heuristic for costs is around $1,000 per kW but 3 kW is higher at $1,200 and 10kW is slightly cheaper at $850. Even 100kW systems sell for around $850 per kW. In Heyfield the rebate is worth $400/kW based on a regulated annual output for solar of 1178kWh/kWp.

Rooftop installations make use of existing roof space and existing electricity infrastructure. Larger systems need land, foundations and new transformers and connections. When comparing rooftop systems with utility scale costs, CSIRO Gencost 2020-21 finds them to be about the same. $1,386 for rooftop PV and $1449 for utility scale solar.

In between 100kW and 200MW are scales suitable for Heyfield. 500kW up to 5MW of solar is likely to cost more than $1449 because the one-time costs like network connection aren't spread over a large investment. The following examples provide indicative costs, noting that none of them have been built:

- Hepburn Wind is proposing a 7.4MW solar farm at a cost of $6.5million, exploiting the $1.6million that has already been spent on connection costs for the wind farm.
- Majurah Solar has a price of $1560/kW for its 1.3MW community solar farm.
- The Solar Gardens project, funded by ARENA, has calculated costs ranging from $1,700 to $2,000/kW for its 1MW solar farms in NSW and Queensland.

The value of solar from a larger system is limited to a wholesale energy price (ie around 8.3c/kWh).and projects typically arrange a power purchase agreement with a customer or retailer before proceeding, so that they are not exposed to volatile market prices. The likely value or solar output will decline as more and more solar comes into the market. Hepburn Wind and the community energy sector generally have been lobbying for a community energy feed-in rate to support projects of this scale that are matched to local networks and loads.

Appendix D – Biomass metrics and sources

Biomass: values used in calculations

Biomass	Unit	Low	High	Notes/ sources
Value of dry sawdust	$/GJ	1.12	3.53	At 17MJ/kg, this equates to testing a range from the lowest value of $19/tonne up to $60/tonne.
Energy content	MJ/kg	17		Eg see graph from RIRDC report (2004)[38] for dry sawdust at 5-10% moisture content. The green mill produces green sawdust with a moisture content of up to 50% but was not the main focus of this analysis.
Conversion efficiency: fuel to electricity	%	24%		Lovegrove et al (2018)[39]
Fuel cost	$/kWhe	0.017	0.053	Calculated
Capacity factor	%	34%		This is equivalent to 3000 operating hours per year at full capacity. A full time plant might achieve 75% capacity and would need allocated labour. The sawmill operates less than 3000 hours but the boiler house and dryers operate almost continuously.
Lifetime	Years	30	30	CSIRO (2021)[23]. Biomass generators (turbines, engines, steam systems etc.) require ongoing operation and maintenance.
O&M fixed	$/KW	$200	$200	Lovegrove et al (2018)[39] A range of costs are proposed in different sources. CSIRO[23] put O&M at $131/kW plus $8.4/MWh, equivalent to $156/kW while RIRDC (2004)[38] suggests $300/kW. O&M costs would be spread across current boiler house operations.

Biomass	**Capital cost** Mid $/kW	Low $/kW	High $/kW	**Capacity factor**	**Lifetime** years	**Note / Source**
VALUES USED IN REPORT						
Biomass 750kW – 2MW		2000	5300	34%	30	
SOURCE AND COMPARISON VALUES						
CSIRO	7265			40%	30	CSIRO (2021)[23]
Dispatchable Power ARENA report	4900				25	Lovegrove et al (2018)[39]
Bevan Dooley	2000					Verbal estimate from Bevan Dooley.
RIRDC report	2500	1500	5300			RIRDC (2004)[38]
CSIRO future (2025)		7254	7254			CSIRO (2021)[26,27]

Biogas: values used in calculations and sources

Biogas	Useful metrics from Sustainable Sanitation and Water Management site[40]
Value of biogas	6 kWh/m^3
Biogas generation	0.3 – 0.5 m^3 gas/m^3 digester volume per day
Human yields	0.02 m3/person per day
Cow yields	0.4 m^3/Kg dung
Other information for calculations:	
Cattle per farm	Assume one farm has 450 cattle (based on site visits)
Kg dung per dairy	33kg/day produced by 400 cattle was used for initial sizing, however this may not be a reliable figure.
Capital cost	Largely unknown. Horticulture Australia (2014)[41] have a case study with $6,400/kW for a 500kW plant. Scaled costs from Lovegrove et al (2018)[39] for 100kW are $15,000/kW with 75% of costs associated with the digestor.
LCOE range 8.4c/kWh to 21c/kWh	IRENA Biomass Study (2012)[42] (converted using 1.4 AUD:USD)

Key reports

The following reports have been used to derive the biomass metrics used in this report:

Lock, P & Whittle, L 2018, Future opportunities for using forest and sawmill residues in Australia, ABARES, Canberra, November.	This report is an economic analysis that compares electricity production with other markets for the same resource. Capital cost assumptions are less clear and market value is only tested at 10c/kWh and 12c/kWh for the value of electricity
Biomass energy production in Australia: Status, costs and opportunities for major technologies, originally printed in 2004. C.R. Stucley, S.M. Schuck, R.E.H. Sims, P.L. Larsen, N.D. Turvey and B.E. Marino for the Rural Industries Research and Development Corporation (RIRDC)	This report is old but little has changed for capital costs and technology in biomass-based generation. It gives an overview of many energy conversion technologies used to generate electricity or produce useable energy in other forms. It provides a clear breakdown of capital and operating costs at different scales of plant.
Opportunities for using Sawmill Residues in Australia, 2012. Prepared for Forest & Wood Products Australia by Dean Goble, Malcolm Peck.	Like the report above, this canvasses various technologies and identifies costs and conversion efficiencies based on case studies of operating plant. The report includes energy densities and transport costs for different biomass waste streams.
Comparison of dispatchable renewable electricity options: Technologies for an orderly transition, 2018. K Lovegrove, G James, D Leitch, A Milczarek A Ngo, J Rutovitz, M Watt, J Wyder	This report is part of an ARENA funded project which also provides a spreadsheet with full details of costs, assumptions and calculations. Considering the dispatchability of biomass creates additional value

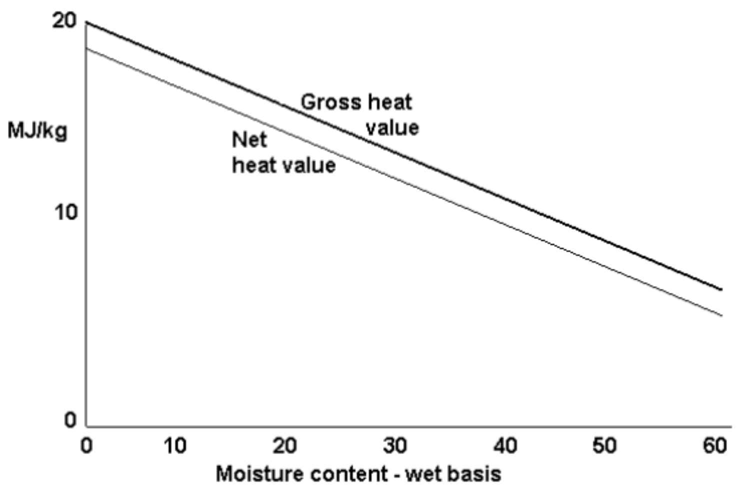
The following figures were drawn on to produce the biomass analysis:

Final product	Units	Prices
Woodchip—hardwood native	$/bdt	$158
Woodchip—hardwood plantation	$/bdt	$175
Woodchip—softwood	$/bdt	$160
Hardboard	$/m³	$1,054
Medium-density fibreboard	$/m³	$464
Particleboard	$/m³	$461
Bioethanol	$/kl	$600
Briquettes	$/t	$120
Wood pellets	$/t	$200
Kiln—heat	$/GJ	$7
Cogeneration electricity **a**	$/GJ	$62–$89
Biomass power plant electricity	$/GJ	$28

a The retail price of electricity differs across states.

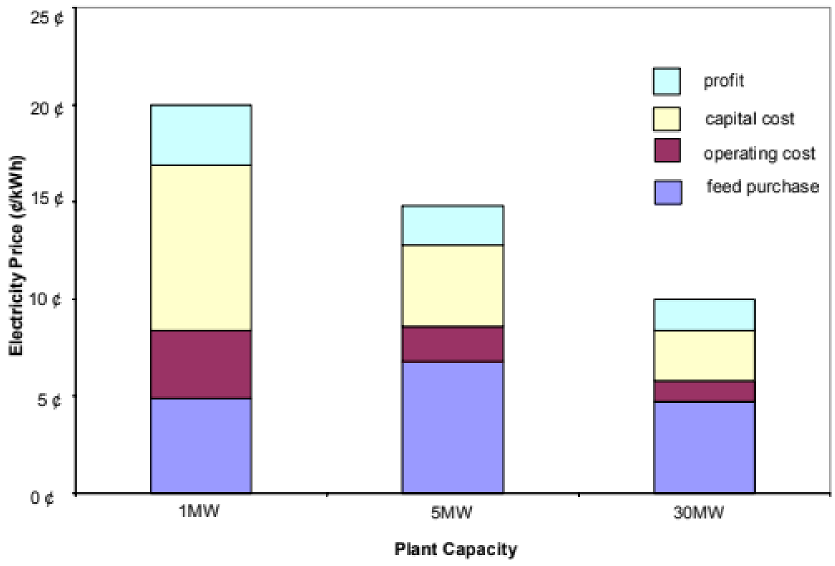
Hierarchy of value for biomass. From ABARES 2018. Table 11

In the table above, the value of using sawdust to produce heat is compared to the cost of gas. The cogeneration value takes into account alternative costs for electricity and heat. Stand alone electricity is based on wholesale electricity prices and renewable energy rebates.

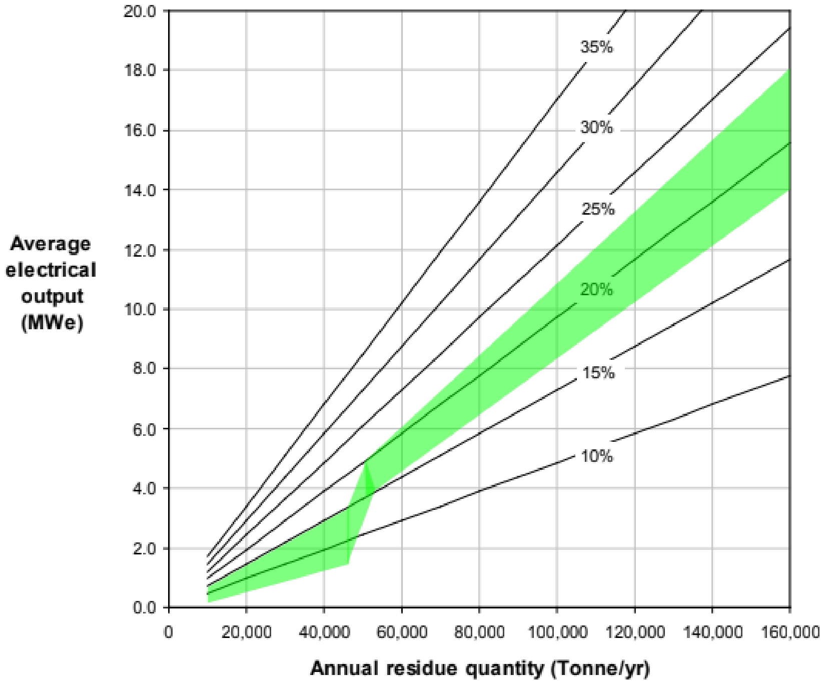


	1 MW	5 MW	30 MW
Gross Electrical Output (MWe)	1.0	5.0	30.0
Feed Requirements (green kt/yr)	13.7	91.2	375.3
Capital Cost (M$)	$5.3	$12.5	$47.4
Operation & Maintenance Cost (M$/yr)	$0.3	$0.8	$2.9
Unit Capital Cost ($M/MW)	5.3	2.5	1.6

Reproduced from Stucley et al, 2004. (Figure 2.4). Energy value of biomass and variation with moisture content, and (Figure 10-1) Breakdown of electricity generation costs. From RIRDC report



Reproduced From Stucley et al, 2004. (Figure 10-2) Electricity prices as a function of plant capacity.



Reproduced from Goble and Peck (2012). Average electrical output for various conversion efficiencies.

The graph provides an easy conversion from tonnes of biomass to electrical generating capacity, based on conversion efficiency. The resource is hardwood residue with gross heating value of 14 MJ/kg (25% moisture content wet basis). The green band represents the likely conversion efficiency for a given system capacity.

The graph sows the effect of overall system conversion efficiency on electrical output. A 10 MW steam turbine could have overall conversion efficiency of 20% and would require about 100,0000 tonnes per year of residue.

Appendix E - Hydro additional information

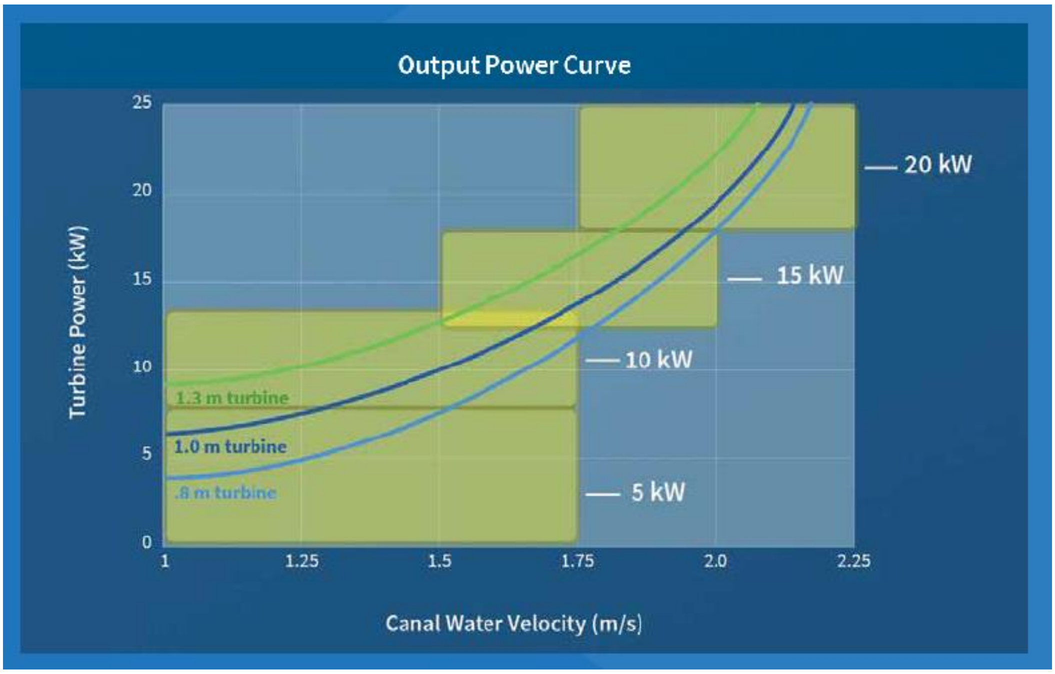


Figure 18 Power curves for Emrgy turbines - note the relationship between power and water flow

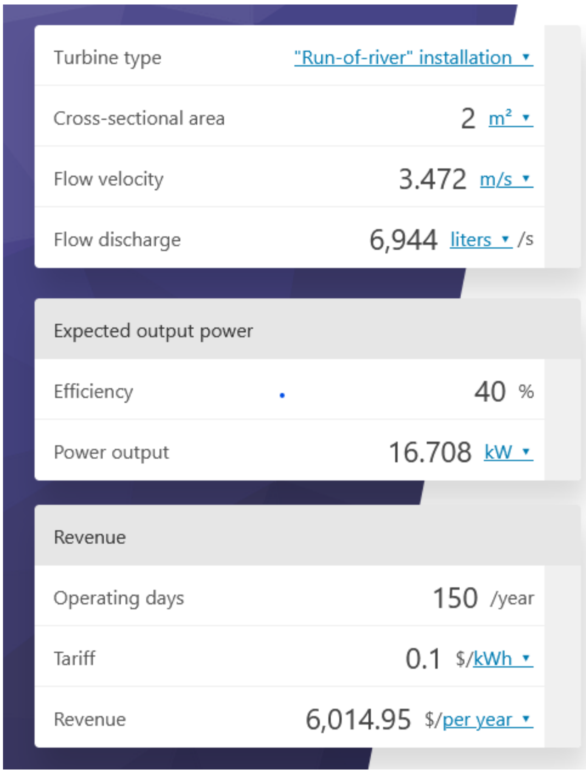


Figure 19 Possible results for channel hydro from online hydro calculator

Calculated from https://www.omnicalculator.com/ecology/hydroelectric-power

Appendix F – Batteries, flywheels, and hydrogen additional information

Batteries

Batteries have developed for many decades, with different chemistries competing for dominance in the market. Lead acid batteries were standard for off-grid systems for many years based on price and widespread availability, since this is the technology used in cars. Lithium Ion has started to dominate based on weight advantages. It also benefits from large markets because Lithium Ion batteries are used in phones and computers. The size of electric vehicle markets are accelerating in size leading to expectations that Lithium Ion batteries will dominate the energy storage market in future.

The ARENA funded battery test centre[t] tracks the performance of a range of household scale batteries that are on the market. Most technologies have a Lithium based chemistry, but one is based on Sodium Nickel Chloride and one is a flow battery based on Zinc-Bromine. Chemistries tested in the past include advanced lead acid and saltwater batteries.

Different chemistries offer performance, lifetime and degradation, and environmental advantages. Battery energy storage is a sufficiently nascent market for technologies to be expected to continue to change.

Flow batteries are a possible exception with a different process for producing electricity. In theory, flow batteries promise cheaper, long duration batteries without performance degradation throughout the battery life. Redflow have one 10kW product with 10kWh of storage, i.e. nominally one hour of storage. This is similar to other household battery products so it appears Redflow is not competing based on longer storage capability. At a larger scale, ARENA has recently announced funding for a 2MW battery with 4-6hours of storage.

Battery technology for the grid came to prominence when Elon Musk promised to build the biggest battery in the world – 100MW and 129 MWh in “100 days or its free”. Since 2017 when the HPR battery was built at the Hornsdale wind farm, large batteries have become standard for utility scale renewable developments. Governments and electricity businesses have also funded substantial ‘big battery’ investments.

There appears to be a gulf in cost between these larger batteries and the 10kW to 5MW scale that would suit Heyfield. Lazards provide a LCOE[u] range of 18c/kWh – 35 c/kWh for the utility scale batteries which jumps up to 60c – 80c/kWh for smaller systems. CSIRO offer 14c/kWh - $37c/kWh. The new Queensland University installation (1MW / 1MWh) appears to be achieving 35c/kWh and the HPR is at 26c/kWh – lower if it is cycling more than once per day.

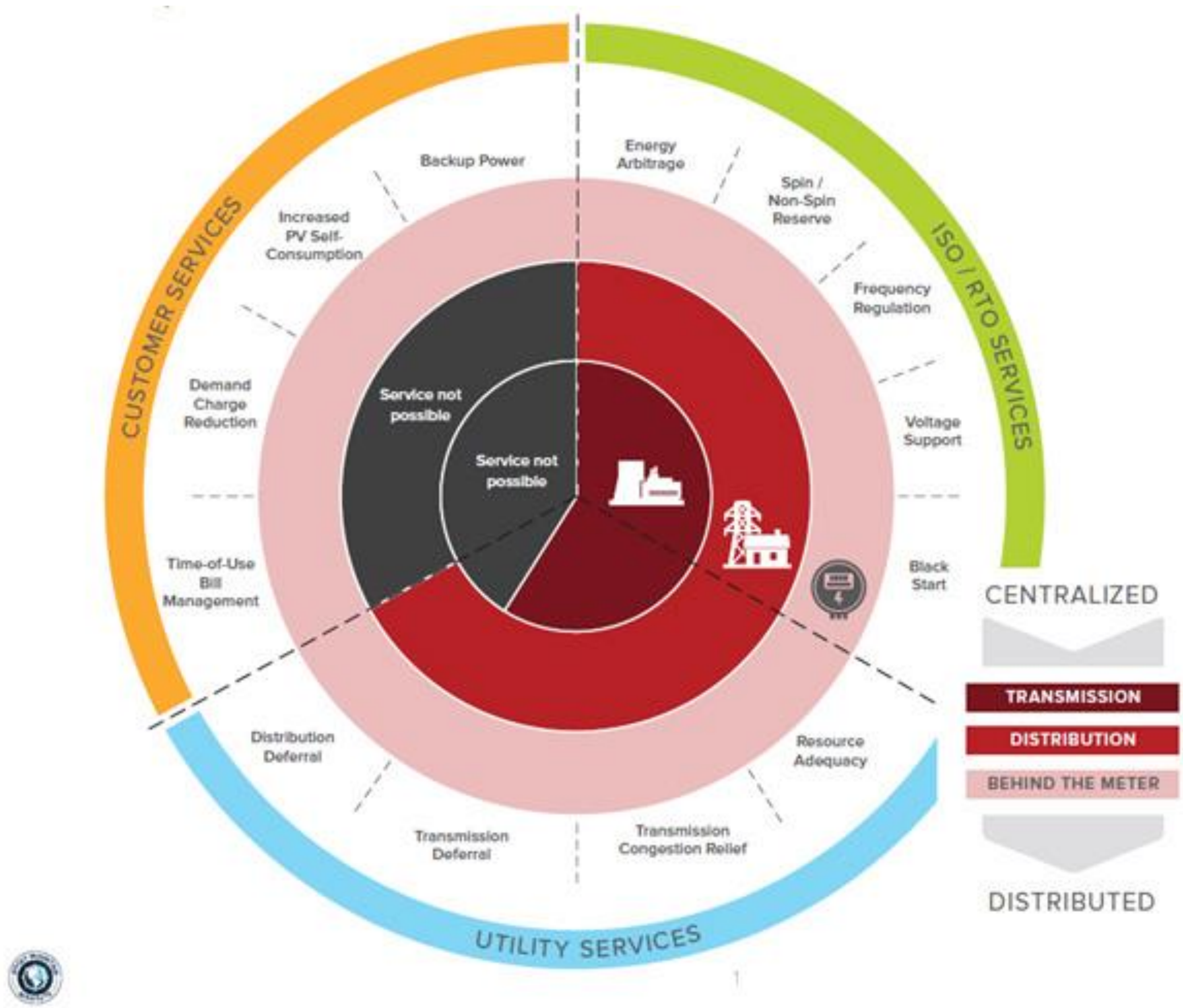
The levelised costs and value produced by batteries depend on the production a battery can achieve in a year. If it cycles once a day – e.g. charging once and discharging once every 24hrs, the value produced is halved compared to a battery that cycles twice a day. However battery cycles reduce battery life and warranties (anecdotally) are starting to settle at around 10years based on a daily cycling regime.

The language used to create the business case for battery investments is the “value stack”. That means that batteries earn money from a variety of different activities beyond simply matching supply and demand. This is best captured in the figure below from the Rocky Mountain Institute.

The Australian market is still experimenting with battery investments. Big batteries provide electricity into the wholesale market and charge at times when electricity prices are low or negative. They also bid into the frequency control markets which bring on emergency supply when there are sudden, unscheduled failures in the system. ARENA has funded a series of trials to allow fleets of household batteries to also access these revenue streams. A fleet of household batteries charging and discharging based on signals from the electricity market is known as a Virtual Power Plant or VPP.

[t] https://batterytestcentre.com.au/batteries/

[u] When referencing storage systems LCOE tends to be called the levelised cost of storage (LCOS). LCOE and LCOS are calculated in the same manner.



Characterisation of battery value to three customer types at three scales
Reproduced from Rocky Mountain Institute, 2015[43]

Household batteries attract rebates in Victoria which helps bring down the capital cost. The batteries can be designed to disconnect the whole household during a power failure and 'keep the lights on' in the house. The batteries can be controlled to charge from surplus rooftop solar and discharge at peak price times. Household demand for batteries can therefore be based on a different value proposition when compared to the larger batteries.

Different options for a microgrid design will be modelled. A fleet of small batteries can provide the same storage as a single large battery but the latter is easier to control when the microgrid needs to operate in island mode.

Flywheels

Flywheels are not readily available in Australia and not widely used. In 2010, before battery technology costs fell, ABB flywheels were used on two remote area supplies in Western Australia, allowing Marble Bar and Nullagine to use solar energy and drastically reduce diesel costs. ABB still sells the Powerstore™ system, and customers can choose flywheel or battery based storage. The Powerstore™ is sold in conjunction with ABB's microgrid control system that supervises the storage and any associated generation.

Heyfield could investigate flywheels for trial operation and should bear in mind that suitable flywheel products can be experimental. The ABB flywheels were not cheap and most suppliers of smaller systems are start-ups without a track record. Flywheels should offer competitive costs. Some start-ups boast 7c/kWh. Much of this is premised on the fact that flywheels can have a very long life and withstand frequent charging and discharging without loss of life expectancy. Recent articles[44] suggest that flywheels have not produced long duration storage due to ongoing losses and that newer technologies might improve this element of performance.

A more sober assessment of flywheel costs puts the LCOE at over 30c/kWh for most realistic applications of flywheel storage capacity.

Hydrogen

Hydrogen is attracting significant Government support at the moment. The opportunity to export Australian renewable energy to the world will need a storage medium like hydrogen or a long cable to Indonesia. Some of the interest in developing a hydrogen sector comes from the gas industry. Hydrogen can be produced from gas relatively cheaply. It can be transported in some gas networks. Hydrogen might give the natural gas industry a stay of execution.

The CSIRO and other institutions like the International Energy Agency and IRENA have also modelled hydrogen. For fossil fuel based hydrogen, modelling often tries to determine the additional cost of adding carbon capture and storage to the hydrogen production.

The benefits of hydrogen as a long term storage medium has already been discussed. The improved efficiency by using hydrogen directly in transport has also been briefly explained. Cost of production is the key challenge in the hydrogen sector.

In 2020 ARENA announced a stretch target of $2 per kg for production of hydrogen[45] and it has invested in multiple projects to assist in driving down costs. The article quotes a cost of $6-$9 for renewable-based hydrogen compared to fossil-based production which already achieves the $2 target but comes with the greenhouse emissions associated with burning fossil-fuels.

For capital-heavy investments like renewable energy, every LCOE figure will be lowest when the capital cost is highly utilised. Hydrogen is no different. Lower figures often assume that the electrolysers, which convert electricity into hydrogen, are utilised for most of the year producing hydrogen. The UK energy department's assessment considered free renewable energy that would otherwise be curtailed, to be available 25% of the time and priced hydrogen at $8.50/kg. In 2015, the CSIRO considered building cheap solar specifically to produce hydrogen and achieved around $18/kg.

The final step in calculating the cost of hydrogen as a storage medium is to convert the hydrogen back into a useful energy form. The table below shows the value of the final electricity produced based on two conversion technologies – an engine with a 35% conversion efficiency or a fuel cell at 55% efficiency. The table takes a shortcut on true costs by not adding capital investment requirements for the hydrogen storage and the fuel cell or engine.

Table 20 Levelised cost of hydrogen

LCOH $/kg	LCOH (chemical) c/kWh[v]	LCOE c/kWh if converted in 35% efficient engine	LCOE c/kWh if converted in 55% efficient fuel cell
$ 2 /kg	6 c/kWh chem	17 c/kWhe	11 c/kWhe
$ 6 /kg	18 c/kWh chem	51 c/kWhe	33 c/kWhe
$ 9 /kg	27 c/kWh chem	77 c/kWhe	49 c/kWhe

[v] For comparison, diesel at $1.50 / litre converts to 14c/kWh chem.

Appendix G – LCOE calculations and results, all generation technologies

Table 21 LCOE calculation inputs and results by generation technology

Technology	Size	Rebate	LCOE			Capital cost			Capacity factor	Lifetime	Degradation		O&M fixed
			(mid)	(low)	(high)	(mid)	(low)	(high)			year 1	subsequent	
Unit			$/kWh	$/kWh	$/kWh	$/kW	$/kW	$/kW	%	years	%	%	$/kW
Rooftop Solar	3-5kW	yes	$0.063	$0.063	$0.085	$932	$932.00	$1,307.00	16.7%	25	3%	0.50%	
Rooftop Solar	3-5kW	no	$0.091	$0.091	$0.112	$1,409	$1,409	$1,784	16.7%	25	3%	0.50%	
Rooftop Solar	10-100kW	yes	$0.056	$0.056	$0.070	$868	$868.00	$1,117.00	16.7%	25	3%	0.50%	
Rooftop Solar	10-100kW	no	$0.083	$0.083	$0.098	$1,345	$1,345	$1,594	16.7%	25	3%	0.50%	
Mid Scale Solar	500kW - 5MW	yes	$0.102	$0.071	$0.132	$2,128	$1,505	$2,750	18.3%	30	3%	0.50%	17
Mid Scale Solar	500kW - 5MW	no	$0.116	$0.085	$0.147	$2,128	$1,505	$2,750	18.3%	30	3%	0.50%	17
Wind (low voltage)	30-300 kW	yes	$0.885	$0.510	$1.260	$7,000	$4,000	$10,000	9.4%	15			25
Wind (low voltage)	30-300 kW	no	$0.904	$0.530	$1.279	$7,000	$4,000	$10,000	9.4%	15			25
Wind at 50m hub height	1 - 5 MW	yes	$0.298	$0.201	$0.395	$2,976	$1,951	$4,000	9.4%	25			25
Wind at 50m hub height	1 - 5 MW	no	$0.313	$0.215	$0.410	$2,976	$1,951	$4,000	9.4%	25			25
Wind at 100m hub height	1 - 5 MW	yes	$0.069	$0.043	$0.095	$2,976	$1,951	$4,000	35.0%	25			25
Wind at 100m hub height	1 - 5 MW	no	$0.084	$0.058	$0.110	$2,976	$1,951	$4,000	35.0%	25			25
Biomass (low fuel cost)	750kW - 2 MW	yes	$0.158	$0.118	$0.198	$3,650	$2,000	$5,300	34.2%	30			$200
Biomass (low fuel cost)	750kW - 2 MW	no	$0.172	$0.132	$0.212	$3,650	$2,000	$5,300	34.2%	30			$200
Biomass (high fuel cost)	750kW - 2 MW	yes	$0.194	$0.154	$0.234	$3,650	$2,000	$5,300	34.2%	30			$200
Biomass (high fuel cost)	750kW - 2 MW	no	$0.208	$0.168	$0.248	$3,650	$2,000	$5,300	34.2%	30			$200
Channel hydro	10 - 25kW	yes	$0.319	$0.201	$0.436	$7,000	$4,000	$10,000	22.8%	25			120
Channel hydro	10 - 25kW	no	$0.334	$0.216	$0.451	$7,000	$4,000	$10,000	22.8%	25			120
Solar thermal	500kW - 5 MW	yes	$0.207	$0.195	$0.219	$11,670	$10,950	$12,390	50%	30			120
Solar thermal	500kW - 5 MW	no	$0.221	$0.209	$0.233	$11,670	$10,950	$12,390	50%	30			120

Table 22 LCOE inputs common to all calculations and biomass fuel values

Discount rate	5.99%	
Large scale Generation Certificate	0.045	$/kWh
Number of years for LGC	5	years
Biomass fuel (low cost)	0.017	$/kWhe
Biomass fuel (high cost)	0.053	$/kWhe

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