



ENGG 2500
Assignment III
Energy Systems Project
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Abstract

The following report is an assessment of potential systems for the Upper Hunter Shire region that will ensure a reliable and renewable energy infrastructure for the next half-century. All options for energy generation and storage methods were assessed and constrained to pumped hydro energy storage, photovoltaic solar panels and wind turbines as they were found to be the most viable for the region. This allowed the optimal system to meet the constraint of renewables providing 50% of the expected load.

To gather assessable data, HOMER Pro, a micro-grid analysis tool, was utilized to quantify and simulate the energy generation and storage, a variety of costs, and operational pollutant outputs. In conjunction with peer-reviewed background research, the overall environmental, economic, and social impacts of potential systems were collated and assessed. The method for assessment of the resulting data was a multi-dimensional criteria analysis, which revealed an optimal system consisting of:

- 100 MW of PV Solar generation
- 37.5 MW of wind generation distributed across 25 wind turbines
- 45 MWh of PHES
- Net present cost of \$91 million

Contents

1	Introduction	1
2	Energy Forecast	1
2.1	Upper Hunter Energy Forecast	2
3	Renewable Energy In The Upper Hunter	3
3.1	Humans, Nature, and Geography	3
3.2	Generation Potential	4
3.2.1	Solar	4
	Environmental	4
	Economic	4
	Social	4
	Political	4
	Ethical	4
3.2.2	Wind	4
	Environmental	5
	Economic	6
	Social	6
3.2.3	Hydro	6
	Environmental	6
	Economic	6
	Social	6
3.2.4	Grid	7
	Environmental	7
	Economic	7
3.2.5	Fossil-Fuel Generator	7
	Environmental	7
	Economic	8
	Social	8
3.3	Storage Potential	9
3.3.1	Pumped Hydro Energy Storage	9
	Environmental	9
	Economic	9
	Social	9
3.3.2	Lithium Ion Batteries	9
	Environmental	9
	Economic	9
	Social	10
4	Energy Modelling	10
4.1	Load And Grid Price	10
4.2	Dispatch And Pumped Hydro	11

5	MCDA	12
5.1	Sensitivity Analysis	12
5.1.1	Project Lifetime	13
5.1.2	Expected Inflation Rate	14
5.1.3	Nominal Discount Rate	15
5.1.4	Scaled Average Daily Load	16
5.2	System Scoring	17
5.2.1	Optimal System	17
	Potential Optimisations	18
6	Conclusion	19
7	Bibliography	19
8	Appendices	24
8.1	MATLAB Code	24
8.1.1	Start Simulation (MatlabStartSimulation.m)	24
8.1.2	Dispatch (MatlabDispatch.m)	25
8.1.3	End Simulation (MatlabEndSimulation.m)	28
8.2	Python Code	30
8.2.1	Graph Generation Tools (main.py)	30

1 Introduction

This report, procured for the Upper Hunter Shire council, is a preliminary study of potential energy supply systems and their various potential impacts when powering the region over the next 50 years. The system is constrained to a minimum of 50% renewable energy methods.

The body of this report is preceded by an overview of the current and forecasted landscape of the energy sector and its related aspects. From this, a trend of rapid growth in renewables as the levelised cost of energy becomes comparable to other energy methods [1], and in turn, fundamental changes occur within the economy, society, and politics [2]. Considering this, there is an expected movement away from fossil-fuel based systems and toward environmentally sustainable, renewable systems and designs.

An outline of data for both system design and assessment of criteria of softer scientific areas is then given. All of which is gathered from reputable sources within a context relevant to Australia and the Upper Hunter Shire region. Design and in-depth analysis of potential systems are expanded upon through data given by HOMER Pro, a software tool for constructing, optimising, and evaluating on and off-grid power systems [3], in conjunction with specialised custom modelling of components and their interactions. This enables evaluation of all empirical-based aspects and impacts, along with the demonstration of overall system efficiency.

The final determination of the optimal system was achieved by a multi-dimensional analysis of the potential systems on a basis of weighted criteria pertinent to the Upper Hunter Shire council. This is concluded with an outline of the optimal system and recommendations.

2 Energy Forecast

The Australian energy market is predicted to undergo a profound transformation in the coming decades as the economic and political incentives for wholesale energy producers begin to shift. This is driven initially by the prospect of the installation of renewable power systems becoming less costly than the renewal of current fossil-fuelled systems with similar replacements as they reach the end of their life cycle [4]. This results in increased widespread public support [2] in transitioning to keep energy prices affordable and fair for consumers. As AEMO's [5] projected cost of energy, shown in Figure 2.1, demonstrates an increase that will make consumers unhappy. This will in turn increase political motivation towards reform of currently lacklustre energy and renewables policy [6].

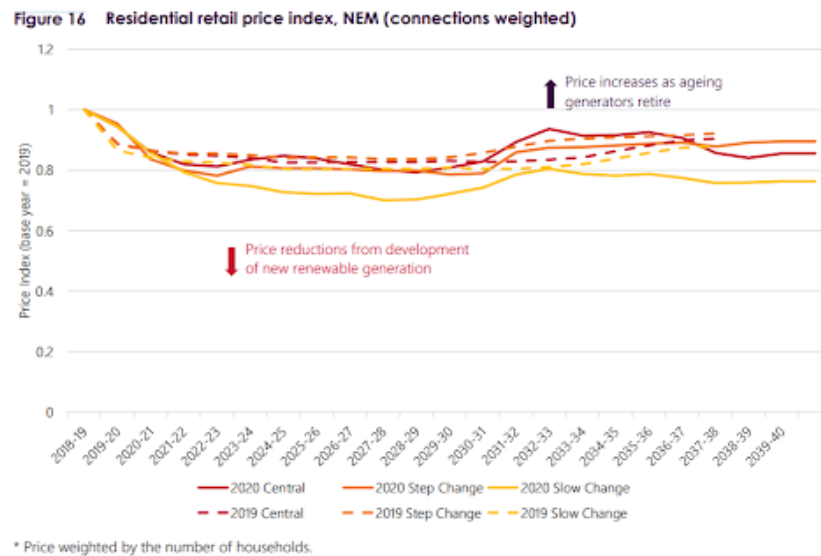


Figure 2.1: Residential Price Index

As of 2021, 24% of Australia's electricity comes from renewable energy [7] with an annual upward trend. As traditional energy generation is replaced with renewables, the consistently smooth production that reliably meets load requirements comparatively to the inconsistent renewables production ability must be accounted for. The root of this issue is renewable's reliance on weather conditions that are conducive to energy generation, which can be difficult to accurately predict.

To mitigate this issue, run-off energy must be stored. Currently, there are multiple projects within Australia in situ regarding this. For short-term storage, there is Tesla battery in SA [8] and for long-term storage, there is the Snowy Hydro project in NSW [9]. These scalings of storage reflect the predicted seasonal inconsistencies of a variety of renewables.

2.1 Upper Hunter Energy Forecast

Within the scope of the Australian local government, there has been a development towards internal projects for community renewable energy, especially within rural councils [10]. Some of which the Upper Hunter Shire is already engaged in [11]. The scope of action however has been limited due to perceived financial and regulatory barriers, making higher-level government support essential. Hence, in the current political climate, collaborations and partnerships with other local governments and stakeholders for bottom-up renewable energy initiatives have become essential. Neighbouring region's power usage and natural energy resources can be accounted for, allowing for the development of more efficient and cost-effective renewable systems.

In further studies for this proposed project, consideration of similar action should be taken along with a projection of regional energy demands. A move for economic diversification through various industries and expansions in the Hunter is planned, with government support and funding to enable it [12]. This is an indicator that larger-scale energy systems will be required in the future to compensate for the myriad of new load demands. With more research in this area, an accurate prediction of increased energy demand in this specific region should

be made for the purpose of future-proofing potential energy systems.

3 Renewable Energy In The Upper Hunter

To meet the energy demands of the region while still satisfying the requirement of minimal impact to the local environment and economy, well-engineered solutions are required. This will entail a thorough analysis of the geography and natural energy resources of the Upper Hunter region to determine the optimal placement of assets. This is determined through mapping interpolation using QGIS [13].

3.1 Humans, Nature, and Geography

Residing over the Hunter-Mooki thrust fault, the region is dominated by the Brokenback range to the north and the extremes of the Blue Mountains to the south. The majority of residents live in small towns throughout the valley. Many live and work more rurally, including a large population of cattle farmers and a number of prominent wineries. A preliminary investigation was sought to visualise the population density and protected zones surrounding the Upper Hunter LGA (Figure 3.1). Population density data is from the Australian Bureau of Statistics (ABS) 2011 census, available as a 1km² population grid [14], and protected zones are sourced from the Collaborative Australian Protected Areas Database (CAPAD) [15].

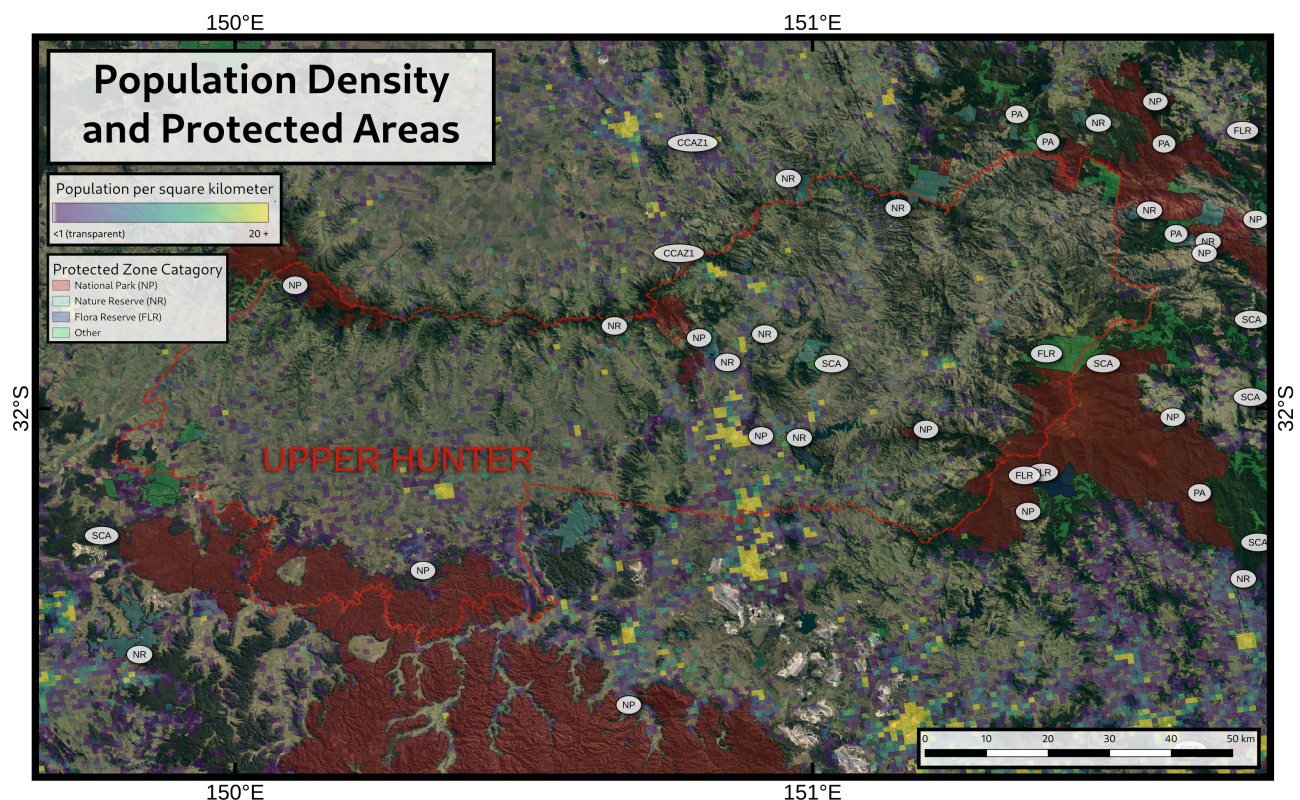


Figure 3.1: Residential Price Index

3.2 Generation Potential

3.2.1 Solar

The two main forms of solar energy capture are photovoltaic (PV) and thermal. Thermal solar has been excluded due to its lower efficiency in comparison to PV [16].

Environmental

PV solar has many advantages due to it being a well-established technology. Its production process has been industrialised, resulting in a relatively low emission, due to production, of $33.67 \frac{g CO_2}{kWh}$ [17]. The bulk of PV manufacturing occurs in the region of China, with the transportation of PV panels emitting $8.89 \frac{Kg CO_2}{kWh}$.

Economic

The cost of PV solar manufacturing ranges from 22 to $177 \frac{\$}{kW}$ [18] with depreciation of 5% p.a. [19]. Long-term operational maintenance cost $25 \frac{\$}{kW}$ p.a. [20]. The cost of salvaging PV panels at the end of its 20 year life cycle equates to $240 \frac{\$}{kW}$ [21].

Social

The bell curve of visual pollution due to PV solar is reaching the crescendo as the number of installations increases. This will result in the general population becoming familiar with PV panel due to the emergence of panels on residential and commercial rooftops, hence, a general acceptance becoming the norm [22] [23].

Political

The Australian government is beginning to recognise the importance of reliable renewable energy, resulting in the development of a Long-Term Emissions Reduction Plan. One of the proposed strategies from the federal government is the investment of \$35 billion [24] into the renewable energy sector, in conjunction with the increased support from environment departments of the NSW government. [25]

Ethical

To maintain PV's cost competition within the energy generation market the manufacturing of PVs is mainly international in countries with cheap labour and minimal legislated environmental impact restrictions. From this, concerns about byproducts of the manufacturing process being released into the environment should be noted. The main byproducts potentially released into the environment are hydrochloric acid, which can result in acidification of soil and the emission of harmful fumes [26].

3.2.2 Wind

The Upper Hunter region has exceptional potential for wind-based power generation. The mountainous terrain creates natural funnels creating an increased wind velocity that remains

stable on average, throughout the year. Optimal sites that account for this are shown in Figure 3.2, alongside their recommended set back distance. Average wind velocity data is sourced from the Australian Bureau of Meteorology climate data sets [27].

Many projects are already underway that utilize the immense energy generation potential. The Upper Hunter Energy Park, located just outside Scone, was approved as early as 2010 and consists of 34 turbines situated over nearby grazing land [28]. The Liverpool Range Wind Farm was approved in 2018 and upon completion will comprise 288 turbines, providing power for over 500 000 homes [29].

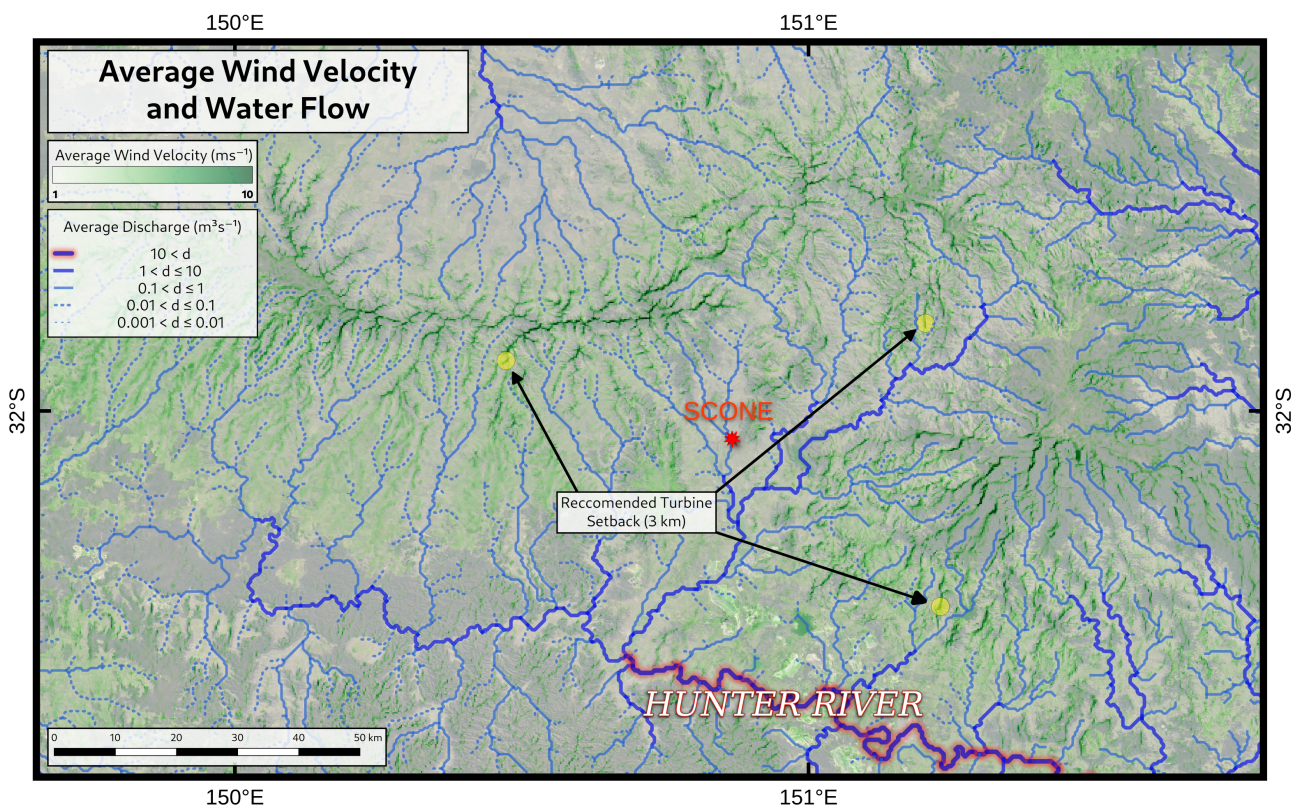


Figure 3.2: Average wind and water flows

Environmental

Expected emissions from the manufacturing of wind turbines is $34 \frac{g}{kWh} CO_2$ [30] [31]. The production of turbines occurs within Australia, centralised in Victoria. Hence, emission of $108 \frac{g}{Km} CO_2$ due to transportation is assumed [32].

A environmental drawback of wind turbines is the requirement of considerable land usage to ensure safe operation. Australian regulations require a set back of at least 3 km [33] from residential dwellings, although there have been isolated reports attributing adverse health impacts from large turbines at distance up to 5 km [34].

Another issue that turbines present is the danger they impose on local animal populations, due to the potentially required clearing of forest habitats and deaths due to impacting with

rotating blades. These concerns are impacting bird's and bat's habitats and resulting in reduced species diversity in the area [35].

Economic

The cost of the average wind turbine is 1.3 million $\frac{\$}{MW}$ [36] depreciating at 2.5% p.a. [37]. The operational and maintenance cost is between 42 000 $\frac{\$}{MW}$ and 48 000 $\frac{\$}{MW}$ during the first 10 years of use [36]. The salvage cost at the end of a turbine's 20-year life cycle is \$292 500 [36].

Social

Wind turbines are generally installed on raised elevations, such as hills, for power generation efficiency which can potential affect visual aesthetic. Another drawback of turbines is shadow flicker from the shadows cast by rotating turbine blades. These flickering shadows can be cast across considerable distances when the sun is low on the horizon and can create a strobe-like effect. This effect is a health concern for people with epilepsy, and depending on their proximity, they could exceed the recommended average exposure of 30 $\frac{Hr}{Yr}$ of shadow flicker [38].

3.2.3 Hydro

A preliminary study into the hydro energy generation potential Upper Hunter River catchment is already in place. From this, it was identified that stream power peaks generally occur at upstream and mid catchment positions [39]. In Figure 3.2 the average water flow and optimal area for a hydro dam is shown. Hydro energy generation was not considered in potential systems due to its potentially large impact on indigenous culture.

Environmental

Hydro dams produce enormous amounts of CO_2 during construction, mainly due to the substantial amount of concrete required [40]. Carbon emissions produced by this are dependent on the height and width of the dam, with the emission being a one-to-one ratio with the weight of concrete required.

The average emissions from the manufacture of hydro turbines is 11.2 $\frac{g\ CO_2}{kWh}$ [41]. The life cycle of a hydro dam is greater than 100 years, hence, at that mark they are automatically deemed a heritage-listed site [42]. Hence, they may be drained and abandoned, resulting in negligible disposal emissions. An example of this is the Mt Paris dam in Tasmania [43].

Economic

A 1 MW hydro dam costs, on average, \$2.8 million [44] with an estimated cost of 22 000 $\frac{\$}{MW}$ p.a. for operation and maintenance [45]. The depreciation of a dam is 1% p.a. due to the life expectancy of 100 years [46].

Social

Due to the large amounts of land consumed by the construction, there is potential risk of culturally significant artifacts being lost below the water level of the dam [47]. Another drawback

is the potential impact of people living upstream of the dam having to relocate[48].

3.2.4 Grid

Utilisation of the preexisting grid infrastructure in a potential system should only be seen as a short-to-medium term component if included in further studies. This is due to the projected replacement cycle and cost of coal fired power stations [4] causing instability with assumptions held over this study's 50-year period.

Environmental

The grid, consisting of 80% coal [49], 10% solar [50], 10% hydro [51], emits a total of 0.7275 $\frac{Kg\ CO_2}{kWh}$ (Table 3.1) during operation alone.

Emissions	Coal(g/Kwh)	Solar(g/Kwh)	Hydro(g/Kwh)	Weighting Total
Carbon dioxide	900	50	15	727.5
Particulate matter	76g	-	-	-
Sulfur dioxide	56	-	-	-
Nitrogen oxide	23.5	-	-	-

Table 3.1: Emissions in grams per kilowatt hour

While it is not the most environmentally-friendly option, using the grid as a short-term solution to ensure reliability of the potential system is the least harmful option.

Economic

Cost and sale-able energy price is listed and discussed in further detail in section 4.1.

3.2.5 Fossil-Fuel Generator

Preliminary research into fossil-fueled generators (FFG) was conducted, but shortened to keynotes for to aid future studies. This reduction was due to FFG's only necessity in incorporation being to assist potential systems ability to reliably meet load requirements. Fortunately, this was achieved through the incorporation of reliable methods of generation, storage and if necessary, the grid. While the grid isn't as environmentally friendly as most renewables, it is a preexisting infrastructure as opposed to FFGs and it allows for the selling back of excess energy generated.

Environmental

FFG's environmental impact can potentially be reduced in the future by using biodiesel blends derived from soy-oil waste [52]. In doing so, FFGs resulted in consistently lower emission concentration of harmful compounds, regardless of load, along with an increase in energy efficiency. This increase in efficiency can potentially offset the costly economic impact of biodiesel blending depending on when it is utilised [53].

Economic

The cost of fossil-based fuels is expected to rise in the future [54] as demand decreases with the emergence of alternative technologies. Biodiesel, comparatively, is expected to decrease in cost, hence the consideration of only diesel engines as they will be able to run on either pure biodiesel or a blending with minimal petroleum-based diesel. This would be engine model dependent. FFG's have a life cycle of 20 years with an assumed operation time of $50 \frac{H_r}{Y_r}$ to $100 \frac{H_r}{Y_r}$ [55].

Social

There are health concerns with the exposure to fossil-fuel based diesel exhaust . This can lead to serious health conditions like asthma and respiratory illnesses, especially in children and the elderly [56]. Figure 3.3 demonstrates the concentration of particulate matter released into the atmosphere by a typical commercial generator [57]. While biodiesel can reduce this, it is not currently economically viable to use as opposed to fossil-based fuel.

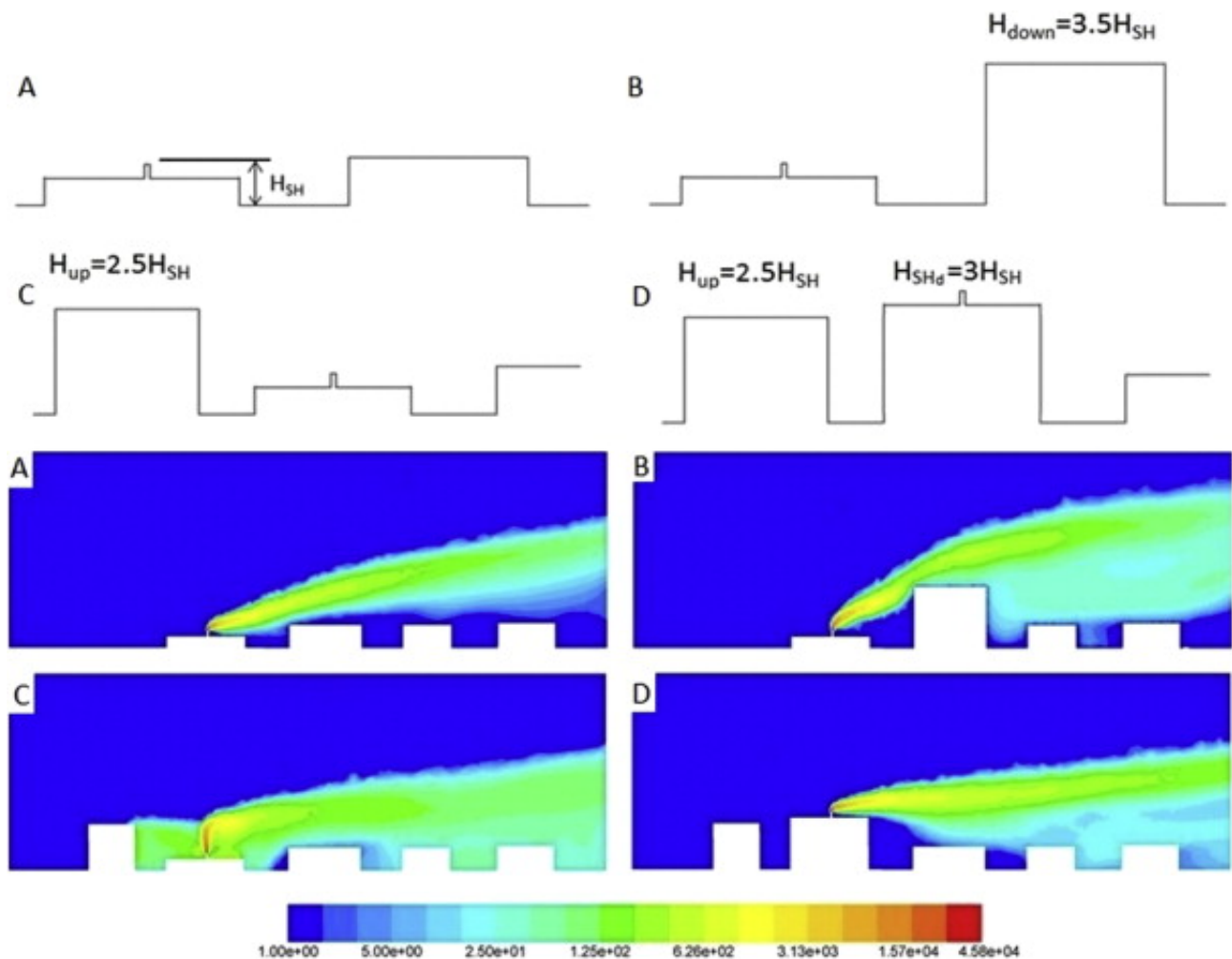


Figure 3.3: particulate matter emissions

3.3 Storage Potential

3.3.1 Pumped Hydro Energy Storage

Environmental

Pumped hydro energy storage (PHES) shares similar properties to hydro storage with the exception of lacking the requirement of being built in a mountain valley. CO_2 emissions due to construction are similarly dependent on the height and width of the dam wall. Manufacturing of pumps and turbines emits $24 \frac{g CO_2}{kWh}$ [58]. A drawback of PHES is the reduced ability to recharge a PHES system during drought periods, due to the lack of water in the rivers.

Economic

The cost of PHES [45] is

- 1.48 million $\frac{\$}{MW}$ for 6 hours of storage
- 1.7 million $\frac{\$}{MW}$ for 12 hours
- 2.11 million $\frac{\$}{MW}$ for 24 hours storage
- 2.75 million $\frac{\$}{MW}$ for 48 hours storage

The predicted operational maintenance cost is 45 000 $\frac{\$}{MW}$ p.a. [45]. PHES depreciation rate is 1% p.a., similarly to hydro [46].

Social

PHES has similar concerns as hydro power, which are addressed in section 3.2.3, but at a reduced scale for the scope of the Upper Hunter Shire.

3.3.2 Lithium Ion Batteries

Preliminary research into lithium batteries was conducted, but shortened to keynotes to aid future studies. This reduction was due to PHES covering all requirements of a storage method with reduced impacts when compared to lithium batteries.

Environmental

Manufacturing lithium battery produces $88 \frac{g CO_2}{Wh}$ of battery capacity [59]. The bulk of lithium battery manufacturing occurs in the region of China, with the transportation of batteries emitting $25 \frac{Kg CO_2}{kWh}$ [32].

Economic

The current price of lithium batteries is between 175 and 350 $\frac{\$}{kWh}$ [60] with a predicted price of installing batteries in 2030 is estimated to be 222 to 305 $\frac{\$}{kWh}$. The replacement cost is predicted to fall as much as 25% to 39% from 2030 to 2050 [61].

Social

Visual pollution from commercial battery storage has a potential social impact due to requirements of close proximity to residential areas for improved efficiency of power delivery. To assess this impact, analysis of the area for determination of the best site would be required to minimise the visual impact of commercial battery storage [62]. The materials that lithium batteries are composed of i.e. lithium, Cadmium and Cobalt are mainly located in developing countries. Ethically, issues arise around lack of labour policies in these countries, where child labour is commonly utilised for mineral extraction [63].

4 Energy Modelling

The HOMER Pro model was designed to supplement the analysis from earlier sections, with a particular focus on economic aspects of the system. The preliminary study determined that a combination of PV solar panels, 1.5 MW wind turbines, and PHES will provide an optimal system. Hence, the primary function of this section is to determine the optimal ratio of these components. The simulation runs over 50 years with a 30 minute time step.

4.1 Load And Grid Price

The grid connection is an essential aspect of the potential system, and is used to supply unmet load. The Upper Hunter Shire consumes $44 \frac{GWh}{Yr}$ of energy, distributed between residential, industrial, non-critical commercial, and critical commercial loads at a 40:30:20:10 ratio. The daily and yearly distribution of the loads are based on the default HOMER Pro configurations, with peak usage centered around January. These component loads are scaled and combined into a single resultant load.

We model the purchase price using AEMO 2019 NSW half-hourly purchase price data [64]. The highest resolution data available for wholesale sell-back price is a daily average. This is insufficient to properly model a complex system, particularly one which includes PHES. To mitigate this, a basic variable pricing model (Figure 4.1) is used. It fits the average daily average (2010-2020) to a cyclic function, such that power usage is at a maximum at 15:00 each day and a minimum each at 03:00 each night. To match the purchase price data, the model is half-hourly, with random variations of ± 5 at each time step.

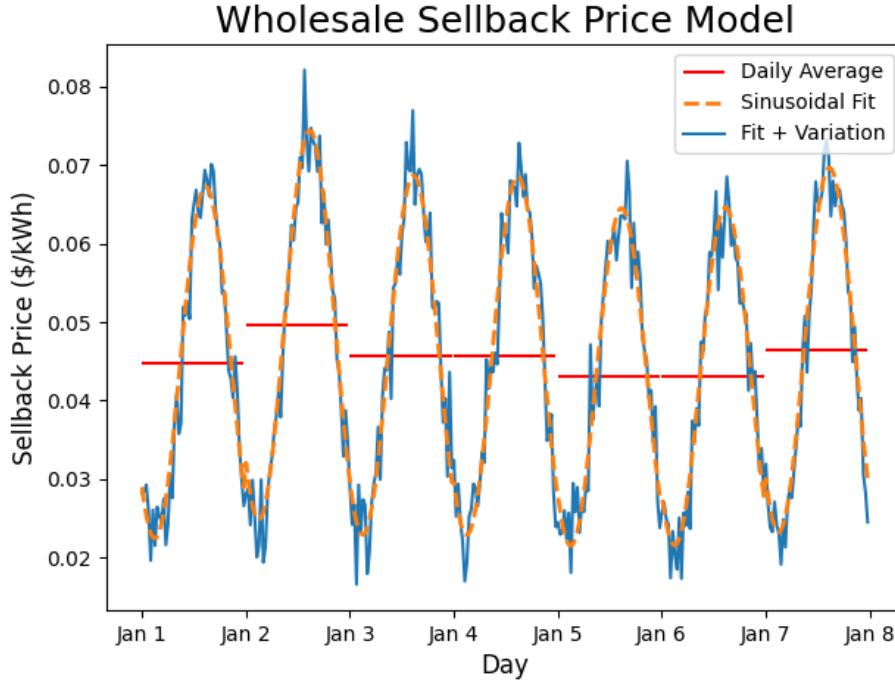


Figure 4.1: Wholesale sell-back price model optimisation

4.2 Dispatch And Pumped Hydro

The HOMER Pro simulation package does not include built-in dispatch methods optimised for PHES. To properly compare systems including this component, a custom algorithm was developed in MATLAB (Appendix 8.1) and integrated with HOMER Pro. The custom dispatch is integrated using the MATLAB Link (ML) module, and acts in place of a custom component, managing the charge/discharge logic of PHES with a 6 hour discharge period. The dispatch improves the net present cost by approximately 30% when compared to systems which use the built-in dispatch charge cycling (CC). All systems in the MCDA were modelled using ML.

The dispatch follows a basic structure: first, dispatch all available power i.e., currently generated solar and wind, to supply the requested load. If there is excess renewable supply, it is used to charge the PHES. If the supply cannot meet the full requested load, the additional unmet load is supplied using a mix of stored energy and the grid connection. This ratio is based on the following rules:

If battery charge is over 80%, supply full excess requested load with the battery. Otherwise, supply a fraction of the load with the battery:

$$f_b = \sin\left(\frac{c}{100} \times \frac{\pi}{2}\right); \{c : 0 \leq c \leq 100\} \quad (4.1)$$

where c is the state of charge of the battery in percent, and f_b is the fraction of the unmet load supplied by the battery. Thus, the fraction supplied by the grid, f_g , is simply:

$$f_g = 1 - f_b \quad (4.2)$$

This rule ensures the system discharges more quickly as it approaches storage capacity, increasing the overall flow of energy through the system. Optimising for greater utilization of PHES assets maximises their return, and maximises the overall magnitude of renewable energy supplied to the Upper Hunter region. Implementing this logic based on a sinusoidal function doubled performance of the ML algorithm when compared to a simple linear factor.

ML is also optimised to purchase electricity for storage when it is cheap. The PHES will purchase excess power as to meet the maximum charge rate when two conditions are met: (1) the battery is already charging at a rate ≥ 500 kW, and (2) the purchased power could be in the future sold at $0.05 \frac{\$}{\text{kWh}}$ and make a profit, after 20% efficiency losses.

5 MCDA

Following initial exploration and analysis covered throughout this report, the search space was limited to three dimensions: PV Solar, 1.5 MW wind turbines, and PHES capacity. HOMER Pro Optimiser [65] was initially used to determine an approximate optimal system, and of this approximation nine options were chosen to undergo a more thorough analysis of system performance and other related aspects. These systems were chosen as approximately representative of this search space.

System Number	Photovoltaic Solar (kW)	Wind Turbines (kW)	PHES (MWh)
1 (control)	0	0	0
2	50 000	0	0
3	100 000	0	0
4	0	15 000	45
5	50 000	15 000	45
6	100 000	15 000	45
7	0	37 500	225
8	50 000	37 500	225
9	100 000	37 500	225

5.1 Sensitivity Analysis

Four systems assumptions are tested through sensitivity analysis. For each parameter, the orange value is the default and to be assumed unless otherwise stated: for example, the project lifetime is assumed to be 50 years in all simulations except the 75 year (green) and 25 year (blue) columns of Figure 5.1. A multivariate sensitivity analysis would cause unwieldy complexity for this preliminary study, therefore it is recommended as a point of investigation for later study. This section includes a brief outline of how changes along each sensitivity axis affected the MCDA score of each potential system.

5.1.1 Project Lifetime

Most systems behave predictably, and see an increase in net present cost (NPC) and a decrease in cost of energy (COE) as the project ages. Notably, the NPC of system (6) decreases as its operating lifespan increases. This highlights profitability of the system, although the benefit is small relative to the large uncertainty of predictions past the 50 year point. Note that systems in the energy sold and renewable fraction graphs remain static, as they represent the yearly averages of the system, which does not change with lifespan.

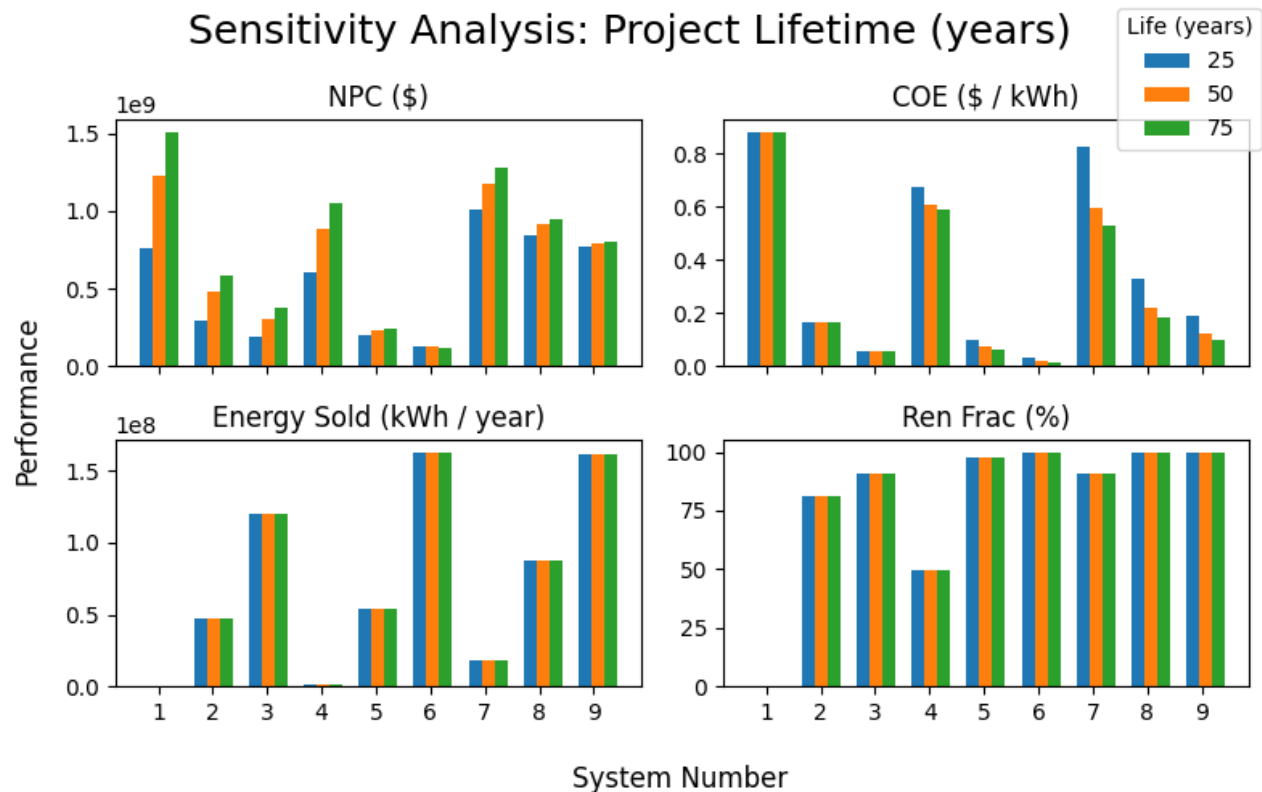


Figure 5.1: Sensitivity analysis: Project Lifetime

5.1.2 Expected Inflation Rate

Most systems see an increase in NPC as the expected inflation rate (EIR) increases, however systems (6) and (9) see a decrease. System (6) returns a negative NPC when the EIR is at 6%, with a COE at almost $0 \frac{\$}{kWh}$. The energy sold and renewable fraction graphs once again remain static as EIR changes (as it is purely an economic indicator). The effect of EIR on COE is higher in systems with a large amount of pumped hydro, and is almost negligible when none is present, as seen in systems (1) to (3).

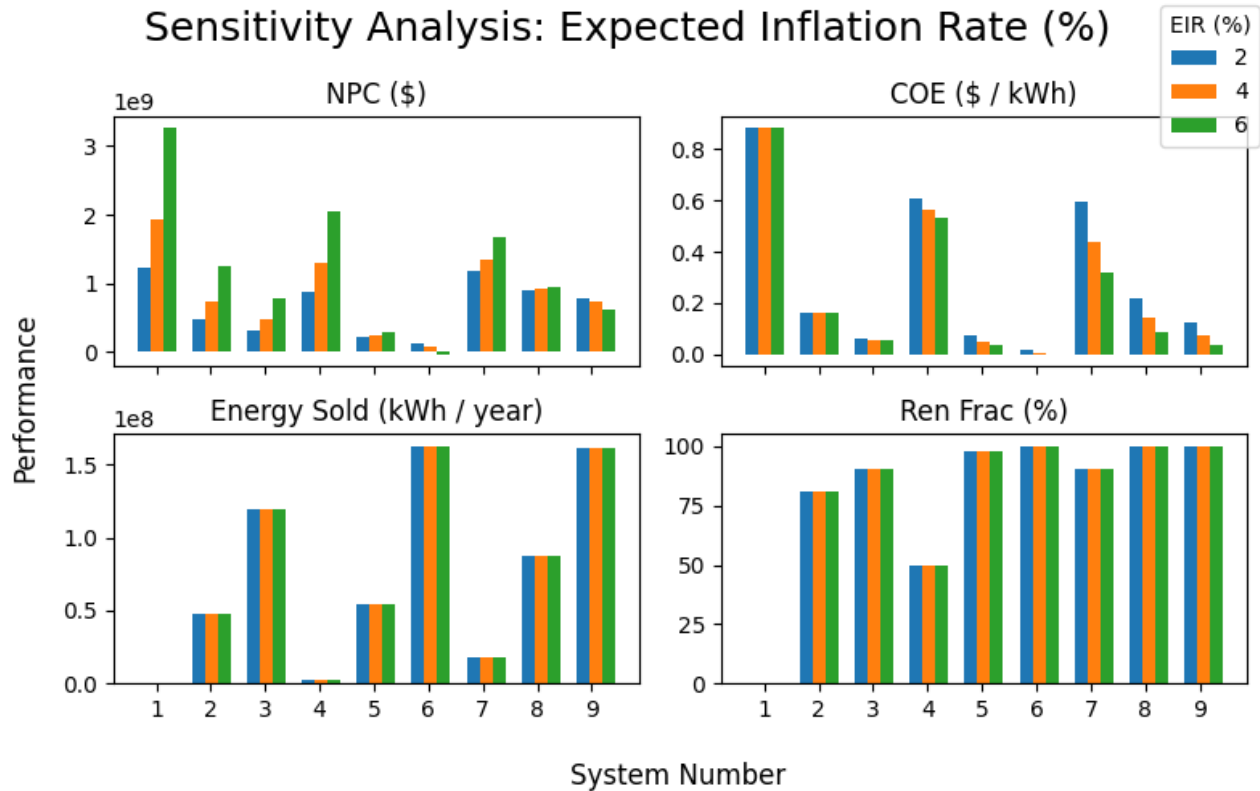


Figure 5.2: Sensitivity analysis: Expected Inflation Rate

5.1.3 Nominal Discount Rate

The nominal discount rate (NDR) affects the system in the opposite manner to EIR: as NDR increases, the NPC decreases in all systems except (6) and (9), which see an increase. Once again, only systems with PHES are significantly affected by changes in the NDR.

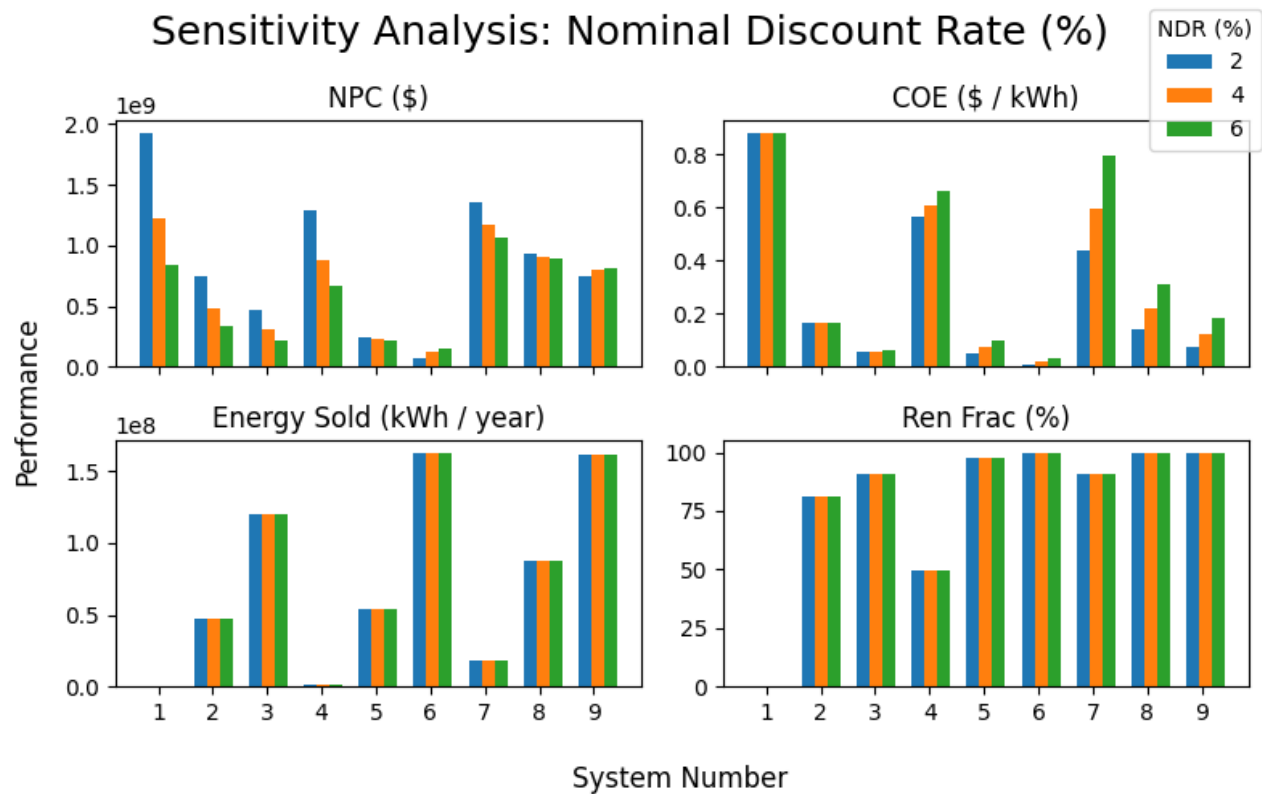


Figure 5.3: Sensitivity analysis: Nominal Discount Rate

5.1.4 Scaled Average Daily Load

The effect of change to the average daily load is predictable. Larger loads are more expensive to meet, and result in less renewable energy sold back to the grid. Systems (8) and (9) achieve 100% renewable utilization under all conditions. System (6) could achieve 100% should the average daily load fall from the current $120\,000 \frac{kWh}{Day}$ to $90\,000 \frac{kWh}{Day}$. A decrease of this kind may be possible if current trends in residential solar uptake continue, however industrial demand is likely to increase and offset or eclipse the decrease from residential solar.

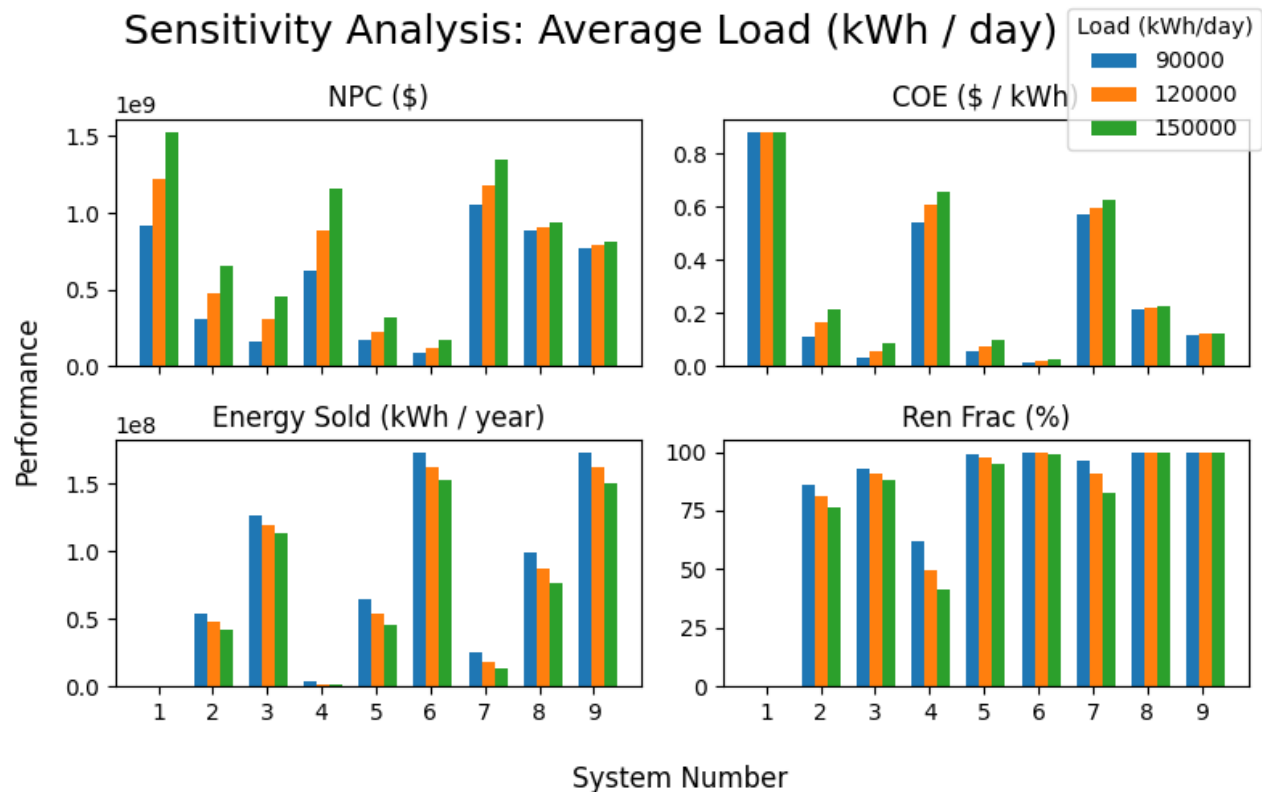


Figure 5.4: Sensitivity analysis: Scaled Average Daily Load

5.2 System Scoring

Systems are scored along 4 axes: economic, environmental, political, and social. Political and social scores are based primarily off (whatever sections research this). Environmental scores account for considerations from earlier sections, and results from the HOMER Pro simulation and sensitivity analysis. Economic scores are based entirely on the HOMER Pro simulation.

A risk unaware (linear) utility function is used. While the financial risks of large wind and hydro projects are non-negligible, these projects would inherently require financial support from commercial and government sources, that would normalise risk for the Upper Hunter Shire council. This assumption may be investigated further in later studies.

System Number	Economic	Environmental	Political	Social	Score (/36)
1 (control)	1	1	5	6	13
2	6	5	7	8	27
3	7	6	7	8	28
4	4	4	3	6	18
5	8	8	5	6	27
6	9	8	7	6	30
7	5	5	1	4	16
8	4	9	2	4	19
9	5	9	4	4	22

Under all conditions, system (6) is the most affordable system, providing the lowest cost electricity, and supplying more than 95% renewable-based power. Environmentally, systems (8) and (9) are ranked marginally higher. While large hydro infrastructure presents a risk to the local environment, this is outweighed by the potential benefits of high capacity storage as a whole such as supporting the transition of more than 1 million homes to renewables.

In section 2.1 it is noted that generating social and political support for systems which are not economically competitive is not feasible. System (6) is economically competitive while also providing an exceptional renewable fraction. Systems (2) and (3) are composed of only PV solar arrays, with no wind turbines or PHES, which in turn reduces the political risk of these systems. PHES and large wind turbines encourage greater controversy and NIMBYism, therefore PV solar arrays are politically simpler than more complex systems. For the same reasons, these systems rank highly in their social score, and more complex systems receive lower scores.

5.2.1 Optimal System

System (6) is the highest scoring system on the whole. It out competes all other systems in economic score, and provides close to optimal environmental performance at a much greater efficiency. These results are the most desirable, and in turn, influence the system's political and social scores positively. System (2), (3), and (5) follow closely in score, and would each be attractive projects for further study. System (9), while exceptional in some areas, under performs in others.

The scale of systems (7) - (9) hinder their ability to be considered by a single LGA. These systems could be a point of further investigation in conjunction with the proposed unification of community renewable energy of multiple LGA's, as noted in section 2.1, as a major PHES system

Potential Optimisations

The Brokenback range significantly affects the global horizontal irradiance (GHI) of the Upper Hunter region. To the north of the range, GHI values are 15% higher, resulting in an increase of yearly generation potential to 170 GWh from the 145 GWh produced in the Upper Hunter Valley. This increase in efficiency is visualised in (Figure 5.5), with data sourced from the Global Solar Atlas[66]. It would be highly recommended to consult with the Liverpool Plains Shire council regarding the construction of solar facilities in their region.

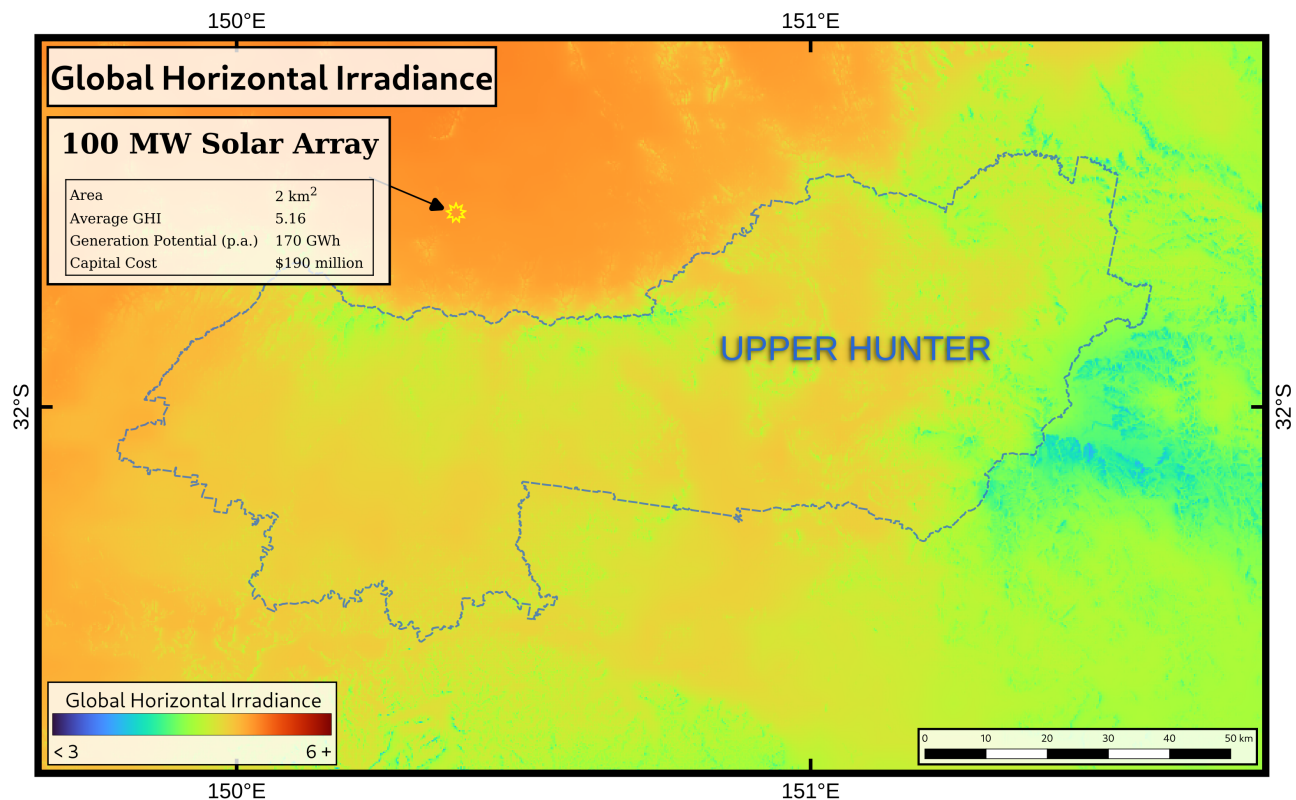


Figure 5.5: Wholesale sell-back price model optimisation

Further research is recommended into a more optimised dispatch methods for PHES. The included dispatch, while effective, has large headroom for optimizations, particularly for applications involving grid stabilization and load smoothing, which are beyond the scope of the HOMER Pro simulation and this report.

6 Conclusion

Following our review of Australian energy policy, trends, and simulations, we recommend that the Upper Hunter Shire council invest in a medium scale renewable energy project, consisting of:

- 100 MW Solar PV generation
- 37.5 MW wind generation over 25 wind turbines
- 45 MWh of PHES
- Net present cost of \$91 million

From in-depth analysis this system was found to have the highest economic rating, optimal environmental performance at a much greater efficiency comparatively to other systems. This then results in high political and social scores.

There is a high likelihood that this system remains optimal, even with the decoherence of our initial assumptions. It is recommended that the council remain aware of state and federal energy policy and commercial investments, and to prepare for the possibility of larger joint projects with these entities.

7 Bibliography

- [1] “The future of coal and renewable power generation in australia: A review of market trends,” *Economic Analysis and Policy*, vol. 68, pp. 363–378, Dec. 1, 2020, ISSN: 0313-5926. DOI: 10.1016/j.eap.2020.10.003. [Online]. Available: <https://www.sciencedirect.com/ezproxy.newcastle.edu.au/science/article/pii/S0313592620304318> (visited on 11/01/2021).
- [2] K. L. Phillips, D. W. Hine, and W. J. Phillips, “How projected electricity price and personal values influence support for a 50% renewable energy target in australia,” *Energy Policy*, vol. 129, pp. 853–860, Jun. 1, 2019, ISSN: 0301-4215. DOI: 10.1016/j.enpol.2019.02.064. [Online]. Available: <https://www.sciencedirect.com/science/article/pii/S0301421519301545> (visited on 11/01/2021).
- [3] (). “Welcome to HOMER,” [Online]. Available: <https://www.homerenergy.com/products/pro/docs/latest/index.html> (visited on 11/01/2021).
- [4] B. Elliston, I. MacGill, and M. Diesendorf, “Least cost 100% renewable electricity scenarios in the australian national electricity market,” *Energy Policy*, vol. 59, pp. 270–282, Aug. 1, 2013, ISSN: 0301-4215. DOI: 10.1016/j.enpol.2013.03.038. [Online]. Available: <https://www.sciencedirect.com/science/article/pii/S0301421513002164> (visited on 11/01/2021).

- [5] (). "2021 planning and forecasting consultation on inputs assumptions and scenarios," [Online]. Available: <https://aemo.com.au/consultations/current-and-closed-consultations/2021-planning-and-forecasting-consultation-on-inputs-assumptions-and-scenarios> (visited on 11/01/2021).
- [6] S. Department of Industry. (Dec. 9, 2020). "Australia's climate change strategies," Department of Industry, Science, Energy and Resources, [Online]. Available: <https://www.industry.gov.au/policies-and-initiatives/australias-climate-change-strategies> (visited on 11/01/2021).
- [7] (). "2021 australian energy statistics — energy.gov.au," [Online]. Available: <https://www.energy.gov.au/news-media/news/2021-australian-energy-statistics> (visited on 11/01/2021).
- [8] F. Keck, M. Lenzen, A. Vassallo, and M. Li, "The impact of battery energy storage for renewable energy power grids in australia," *Energy*, vol. 173, pp. 647–657, Apr. 15, 2019, ISSN: 0360-5442. DOI: 10.1016/j.energy.2019.02.053. [Online]. Available: <https://www.sciencedirect.com/science/article/pii/S0360544219302427> (visited on 11/01/2021).
- [9] (). "About snowy 2.0," Snowy Hydro, [Online]. Available: <https://www.snowyhydro.com.au/snowy-20/about/> (visited on 11/01/2021).
- [10] F. Mey, M. Diesendorf, and I. MacGill, "Can local government play a greater role for community renewable energy? a case study from australia," *Energy Research & Social Science*, vol. 21, pp. 33–43, Nov. 1, 2016, ISSN: 2214-6296. DOI: 10.1016/j.erss.2016.06.019. [Online]. Available: <https://www.sciencedirect.com/science/article/pii/S2214629616301487> (visited on 11/01/2021).
- [11] (). "Upper hunter shire council," Cities Power Partnership, [Online]. Available: <https://citiespowerpartnership.org.au/partners/upper-hunter-shire-council/> (visited on 11/01/2021).
- [12] C. corporateName=Commonwealth Parliament; address=Parliament House. (). "Jobs for the future in regional areas," [Online]. Available: https://www.aph.gov.au/Parliamentary_Business/Committees/Senate/Jobs_for_the_Future_in_Regional_Areas/JobsRegionalAreas/Report (visited on 11/01/2021).
- [13] QGIS Development Team, *Qgis geographic information system*, Open Source Geospatial Foundation, 2009. [Online]. Available: <http://qgis.osgeo.org>.
- [14] *Australian population grid, 2011*, <https://www.abs.gov.au/ausstats/abs@.nsf/mf/1270.0.55.007>, Accessed: 2021-11-01.
- [15] *Collaborative australian protected areas database*, <https://www.environment.gov.au/fed/catalog/search/resource/details.page?uuid=%7B4448CADC-9DA8-43D1-A48F-48149FD5FCFD%7D>, Accessed: 2021-11-01.
- [16] (). "Solar energy for net zero energy buildings – a comparison between solar thermal, pv and photovoltaic-thermal (pv/t) systems," [Online]. Available: <https://www.sciencedirect.com/science/article/pii/S0038092X15005460> (visited on 01/01/2021).

- [17] (). "Assessing the lifecycle greenhouse gas emissions from solar pv and wind energy: A critical meta-survey," [Online]. Available: <https://reader.elsevier.com/reader/sd/pii/S0301421513010719?token=AF0B451D0B91E7EE5C8B0DDCAEAAC8ED06D3D70AF04FC78465A8D4E0CD7&originRegion=us-east-1&originCreation=20211101072505> (visited on 11/01/2021).
- [18] (). "How much do solar panels cost?" [Online]. Available: <https://homeguide.com/costs/solar-panel-cost> (visited on 11/01/2021).
- [19] (). "A to depreciation rates 2021," [Online]. Available: <https://www.depreciationrates.net.au/solar> (visited on 11/01/2021).
- [20] (). "Solar photovoltaic plant operating and maintenance costs," [Online]. Available: <https://www.scottmadden.com/insight/solar-photovoltaic-plant-operating-and-maintenance-costs/> (visited on 11/01/2021).
- [21] (). "Reliability factors for salvage value of photovoltaics," [Online]. Available: https://www1.eere.energy.gov/solar/pdfs/pvmrw2011_p47_csi_mccabe.pdf (visited on 11/01/2021).
- [22] (). "The visual impact of solar panels on neighborhood roofs," [Online]. Available: <https://renewableenergysolar.net/the-visual-impact-of-solar-panels-on-neighborhood-roofs/#:~:text=%5C%20The%5C%20visual%5C%20impact%5C%20of%5C%20Solar%5C%20Panels%5C%20on,stands%5C%20for%5C%20more%5C%20than%5C%20just%5C%20slashing...%5C%20More%5C%20> (visited on 08/01/2021).
- [23] (). "Social acceptance of solar energy technologies in china—end users' perspective," [Online]. Available: <https://www-sciencedirect-com.ezproxy.newcastle.edu.au/science/article/pii/S0301421511000139?via%5C%3Dihub> (visited on 08/01/2021).
- [24] (). "The plan to deliver net zero," [Online]. Available: <https://www.industry.gov.au/sites/default/files/October%5C%202021/document/the-plan-to-deliver-net-zero-the-australian-way.pdf> (visited on 08/01/2021).
- [25] (). "Australia's long-term emissions reduction plan," [Online]. Available: <https://www.industry.gov.au/sites/default/files/October%5C%202021/document/australias-long-term-emissions-reduction-plan.pdf> (visited on 08/01/2021).
- [26] (). "Solar energy isn't always as green as you think," [Online]. Available: <https://spectrum.ieee.org/solar-energy-isnt-always-as-green-as-you-think> (visited on 08/01/2021).
- [27] *Australia climate averages*, http://www.bom.gov.au/jsp/ncc/climate_averages/wind-velocity/index.jsp, Accessed: 2021-11-01.
- [28] (). "Upperhunter energy park approval," [Online]. Available: <https://upperhunterenergypark.com.au/wp-content/uploads/2021/02/Ministers-Conditions-of-Approval.pdf> (visited on 01/31/2010).
- [29] (). "Liverpool range wind farm," [Online]. Available: <https://www.tiltrenewables.com/assets-and-projects/liverpool-range-wind-farm/> (visited on 01/01/2021).
- [30] (). "Assessing the lifecycle greenhouse gas emissions from solar pv and wind energy: A critical meta-survey," [Online]. Available: <https://www.sciencedirect.com/science/article/pii/S0301421513010719> (visited on 01/01/2021).

- [31] (). "Life cycle greenhouse gas emission from wind farms in reference to turbine sizes and capacity factors," [Online]. Available: <https://www.sciencedirect.com/science/article/pii/S0959652620334302> (visited on 01/01/2021).
- [32] (). "Real-world fuel economy of heavy trucks," [Online]. Available: <https://www.knowledgehub.transport.govt.nz/assets/TKH-Uploads/TKC-2019/Real-world-fuel-economy-of-heavy-trucks.pdf> (visited on 01/01/2021).
- [33] (). "Nsw legislation," [Online]. Available: <https://legislation.nsw.gov.au/view/whole/html/inforce/current/epi-2020-0545> (visited on 01/01/2021).
- [34] (). "Nsw planning guide for wind farms," [Online]. Available: <https://www.planning.nsw.gov.au/~media/Files/DPE/Guidelines/draft-nsw-planning-guidelines-wind-farms-a-resource-for-the-community-applicants-and-consent-2011-12.ashx> (visited on 11/01/2021).
- [35] (). "Ethical issues and controversies," [Online]. Available: <https://sites.google.com/site/enviroethenergysources/ethical-issues> (visited on 01/01/2021).
- [36] (). "Commercial wind turbine cost (\$1 million cost breakdown)," [Online]. Available: <https://climatebiz.com/commercial-wind-turbine-cost/#whatand8217-s-the-cost-of-a-wind-turbine> (visited on 01/01/2021).
- [37] (). "Depreciation," [Online]. Available: <https://energyeducation.ca/encyclopedia/Depreciation> (visited on 01/01/2021).
- [38] (). "Wind energy, climate and health: Evidence for the impacts of wind generated energy in australia," [Online]. Available: <https://australiainstitute.org.au/wp-content/uploads/2020/12/WEB-Wind-energy-climate-and-health.pdf> (visited on 01/01/2021).
- [39] (). "Comparative assessment of three approaches for deriving stream power plots along long profiles in the upper hunter river catchment, new south wales, australia," [Online]. Available: <https://www.sciencedirect-com.ezproxy.newcastle.edu.au/science/article/pii/S0169555X0500276X> (visited on 01/01/2021).
- [40] (). "Life-cycle impact assessment of renewable electricity generation systems in the united states," [Online]. Available: <https://www.sciencedirect.com/science/article/pii/S0960148119317835> (visited on 01/01/2021).
- [41] (). "Life cycle greenhouse gas (ghg) emissions from the generation of wind and hydro power," [Online]. Available: <https://www.sciencedirect.com/science/article/pii/S1364032111001924> (visited on 01/01/2021).
- [42] (). "Nsw government - heritage nsw home page state heritage inventory," [Online]. Available: <https://www.hms.heritage.nsw.gov.au/App/Item/SearchHeritageItems#> (visited on 01/01/2021).
- [43] (). "Abandoned mt paris dam, tasmania," [Online]. Available: https://tassie4kids.com.au/uploads/blog/_1200x630_crop_center-center_82_none/IMG_6895.JPG?mtime=1537325844 (visited on 01/01/2021).
- [44] (). "How much does it cost to build a hydropower dam?" [Online]. Available: <https://www.constructorasenqueretaro.com/how-to-build/how-much-does-it-cost-to-build-a-hydropower-dam.html> (visited on 01/01/2021).

- [45] (). "Pumped hydro cost modelling," [Online]. Available: <https://www.constructorasenqueretaro.com/how-to-build/how-much-does-it-cost-to-build-a-hydropower-dam.html> (visited on 12/07/2018).
- [46] (). "Ato depreciation rates 2021," [Online]. Available: <https://www.depreciationrates.net.au/dam> (visited on 12/07/2018).
- [47] (). "Environmental impact assessment of dam: Durgawati reservoir project," [Online]. Available: https://www.researchgate.net/publication/322078280_Environmental_Impact_Assessment_of_Dam_Durgawati_Reservoir_Project (visited on 11/01/2021).
- [48] (). "Environmental issues of hydropower," [Online]. Available: <https://followgreenliving.com/environmental-issues-hydropower/> (visited on 11/01/2021).
- [49] M. Garg, J. D. Silver, R. Schofield, and R. G. Ryan. (2021). "Hourly emission inventories for air toxic emissions for eastern australian electricity generators derived from energy distribution data," [Online]. Available: <https://link-springer-com.ezproxy.newcastle.edu.au/article/10.1007/s13762-021-03429-5/tables/7>.
- [50] K. Burkart. (2020). "How much co2 does one solar panel create," [Online]. Available: <https://www.treehugger.com/how-much-co-does-one-solar-panel-create-4868753>.
- [51] L. Gagnon and J. F. de Vate. (2020). "Greenhouse gas emissions from hydropower: The state of research in 1996," [Online]. Available: <https://www-sciencedirect-com.ezproxy.newcastle.edu.au/science/article/pii/S0301421596001255>.
- [52] (). "Biodiesel production from waste soybean oil biomass as renewable energy and environmental recycled process," [Online]. Available: <https://www.ajol.info/index.php/ajb/article/view/82635> (visited on 11/01/2021).
- [53] (). "Pm, carbon, and pah emissions from a diesel generator fuelled with soy-biodiesel blends," [Online]. Available: <https://www.sciencedirect.com/science/article/pii/S0304389410002992> (visited on 11/01/2021).
- [54] (). "Gas price projections for the 2021 gs00," [Online]. Available: https://aemo.com.au/-/media/files/electricity/nem/planning_and_forecasting/inputs-assumptions-methodologies/2021/gas-price-projections-for-the-2021-gs00-public-final-13-12-20.pdf?la=en (visited on 11/01/2021).
- [55] (). "Life cycle energy assessment of a standby diesel generator set," [Online]. Available: <https://www.sciencedirect.com/science/article/pii/S0959652617302962> (visited on 11/01/2021).
- [56] (). "Learn about impacts of diesel exhaust and the diesel emissions reduction act (dera)," [Online]. Available: <https://www.epa.gov/dera/learn-about-impacts-diesel-exhaust-and-diesel-emissions-reduction-act-dera> (visited on 11/01/2021).
- [57] (). "Energy and the environment," [Online]. Available: <https://energy.mae.cornell.edu/research-2/micro-environmental-air-quality/distributed-generation/diesel-bugs/> (visited on 11/01/2021).
- [58] (). "Hydropower's carbon footprint," [Online]. Available: <https://www.hydropower.org/factsheets/greenhouse-gas-emissions> (visited on 11/01/2021).

- [59] (). "1kw portable off grid solar and lithium battery system 1100wh," [Online]. Available: <https://greenenergylimited.com/product/portable-off-grid-solar-and-lithium-battery-system/> (visited on 11/01/2021).
- [60] (). "Prospective improvements in cost and cycle life of off-grid lithium-ion battery packs: An analysis informed by expert elicitations," [Online]. Available: <https://www.sciencedirect.com/science/article/pii/S0301421517308595> (visited on 11/01/2021).
- [61] (). "Cost projections for utility-scale battery storage," [Online]. Available: <https://www.nrel.gov/docs/fy19osti/73222.pdf> (visited on 11/01/2021).
- [62] (). "Hume battery energy storage system project visual impact assessment," [Online]. Available: <https://majorprojects.planningportal.nsw.gov.au/prweb/PRRestService/mp/01/getContent?AttachRef=SSD-10460%5C%2120200731T062125.543%5C%20GMT> (visited on 11/01/2021).
- [63] (). "Industry giants fail to tackle child labour allegations in cobalt battery supply chains," [Online]. Available: <https://www.amnesty.org/en/latest/press-release/2017/11/industry-giants-fail-to-tackle-child-labour-allegations-in-cobalt-battery-supply-chains/> (visited on 11/01/2021).
- [64] *Aemo dashboard*, <https://aemo.com.au/en/energy-systems/electricity/national-electricity-market-nem/data-nem/data-dashboard-nem>, Accessed: 2021-11-01.
- [65] (). "Homerpro optimization," [Online]. Available: <https://www.homerenergy.com/products/pro/docs/latest/optimization.html> (visited on 11/01/2021).
- [66] *Global solar atlas*, <https://globalsolaratlas.info/download/world>, Accessed: 2021-11-01.

8 Appendices

8.1 MATLAB Code

8.1.1 Start Simulation (MatlabStartSimulation.m)

```
function [myErr, matlab_simulation_variables] =
    MatlabStartSimulation(simulation_parameters)
myErr.error_description = '';
myErr.severity_code = '';

%Initialize user-defined simulation variables. We can use these
    throughout the simulation
%for dispatch decisions or to generate errors at the end of the
    simulation.
%matlab_simulation_variables.total_energy_test = 0;
%matlab_simulation_variables.gen1_CO = 0;
%matlab_simulation_variables.SoC_PH_old = 50.0;
%matlab_simulation_variables.SoC_PH_new = 50.0;
%matlab_simulation_variables.array = zeros(1,35136);
```

```
matlab_simulation_variables.array = zeros(1,35136);
```

```
end
```

8.1.2 Dispatch (MatlabDispatch.m)

```
function [simulation_state, matlab_simulation_variables] =
    MatlabDispatch(simulation_parameters, simulation_state,
    matlab_simulation_variables)
    % Dispatch requires PV, converter, and a battery bank
    if (simulation_parameters.has_pv || simulation_parameters.
        has_wind_turbine) && (simulation_parameters.has_converter &&
        simulation_parameters.has_battery)
        % Some helpful variables for calculations / reduced typing
        battery_capacity = simulation_parameters.batteries.
            battery_bank_maximum_absolute_soc;
        discharge_time = 6;
        MAX_HYDRO_CHARGE = battery_capacity / discharge_time;
        MAX_HYDRO_DISCHARGE = battery_capacity / discharge_time;

        % Sum of all renewable power generated this tick
        generated_power = 0;

        % Add PV to sum of all renewable power
        if simulation_parameters.has_pv
            simulation_state.pvs(1).power_setpoint =
                simulation_state.pvs(1).power_available;
            generated_power = generated_power + simulation_state.pvs
                (1).power_setpoint;
        end

        % Add turbines to sum of all renewable power
        if simulation_parameters.has_wind_turbine
            simulation_state.wind_turbines(1).power_setpoint =
                simulation_state.wind_turbines(1).power_available;
            generated_power = generated_power + simulation_state.
                wind_turbines(1).power_setpoint;
        end

        % If there is excess renewable energy generated this tick
        if (generated_power > simulation_state.ac_bus.load_requested
        )
            excess_renewable = generated_power - simulation_state.
                ac_bus.load_requested;
```

```

% Available space in battery
battery_additional_capacity = simulation_parameters.
    batteries.battery_bank_maximum_absolute_soc -
    simulation_state.batteries(1).state_of_charge_kwh;

% Reduce charge rate if battery is near capacity
if simulation_state.batteries(1).state_of_charge_percent
    > 70
    n_soc = simulation_state.batteries(1).
        state_of_charge_percent - 70;
    multiplier = -1 * sin(((3 * pi)/2) + ((n_soc * pi) /
        60));
    battery_additional_capacity =
        battery_additional_capacity * multiplier;
end

% Max possible charge rate. Cannot charge more than
    there is
% empty space in the battery.
battery_possible_charge_power = min(
    battery_additional_capacity, MAXHYDROCHARGE);

% If all excess renewable can be used to charge the
    battery, do
% so
if battery_possible_charge_power >= excess_renewable
    simulation_state.batteries(1).power_setpoint =
        excess_renewable;
% Otherwise, charge battery as much as possible and sell
    the
% rest
elseif battery_possible_charge_power < excess_renewable
    simulation_state.batteries(1).power_setpoint =
        battery_possible_charge_power;
    excess_excess = excess_renewable -
        battery_possible_charge_power;
    simulation_state.grids(1).grid_sales =
        simulation_state.grids(1).grid_sales +
        excess_excess;
end

% If the generated renewable power is insufficient to supply
    the load
elseif (generated_power < simulation_state.ac_bus.
    load_requested)
    energy_deficit = simulation_state.ac_bus.load_requested -
        generated_power;

```

```

% If battery charge is very high, discharge quickly
if simulation_state.batteries(1).state_of_charge_percent
    > 80
    renew_frac = 1;
% Otherwise, discharge speed is a sinusoidal function of
    charge percent
else
    renew_frac = sin((simulation_state.batteries(1).
        state_of_charge_percent / 100) * (pi/2));
end

% Fraction of energy deficit renew/grid
part_renew = energy_defict * renew_frac;
part_grid = energy_defict * (1-renew_frac);

% Ensure batteries have capacity to supply load and
    losses
if part_renew < simulation_state.batteries(1).
    state_of_charge_kwh * 0.8
    simulation_state.batteries(1).power_setpoint = -1 *
        part_renew;
    simulation_state.grids(1).grid_purchases = part_grid
        ;
else
    simulation_state.grids(1).grid_purchases =
        energy_defict;
end

% If renewable power generated and load in perfect balance
else
    simulation_state.batteries(1).power_setpoint = 0;
    simulation_state.grids(1).grid_purchases = 0;
    simulation_state.grids(1).grid_sales = 0;
end

if simulation_state.batteries(1).power_setpoint > 500 &&
    simulation_state.grids(1).power_price * 0.8 < 0.05
    battery_additional_capacity = battery_capacity -
        simulation_state.batteries(1).state_of_charge_kwh;
    battery_possible_charge_power = min(
        battery_additional_capacity , MAXHYDRO_CHARGE);

    additional_power = battery_possible_charge_power;

    simulation_state.batteries(1).power_setpoint =
        simulation_state.batteries(1).power_setpoint +

```

```

        additional_power;
simulation_state.grids(1).grid_purchases =
    simulation_state.grids(1).grid_purchases +
    additional_power;
end

% serve the load
simulation_state.ac_bus.load_served = simulation_state.
    ac_bus.load_requested;
simulation_state.primary_loads(1).load_served =
    simulation_state.ac_bus.load_requested;

% serve operating capacity
simulation_state.ac_bus.operating_capacity_served =
    simulation_state.ac_bus.load_served;
simulation_state.dc_bus.operating_capacity_served = 0;

% set capacity shortage
simulation_state.ac_bus.capacity_shortage=simulation_state.
    ac_bus.operating_capacity_requested - simulation_state.
    ac_bus.operating_capacity_served;
simulation_state.dc_bus.capacity_shortage=0;

% set the unmet load
simulation_state.dc_bus.unmet_load = 0;
simulation_state.ac_bus.unmet_load = 0;

% set excess electricity
simulation_state.ac_bus.excess_electricity =
    simulation_state.ac_bus.load_served - simulation_state.
    ac_bus.load_requested;
simulation_state.dc_bus.excess_electricity = 0;
end

```

8.1.3 End Simulation (MatlabEndSimulation.m)

```

function myErrs = MatlabEndSimulation(simulation_parameters ,
    matlab_simulation_variables)
myErrs.simulation_errors = {};
myErrs.simulation_warnings = {'This is a MATLAB test warning.'};

% if matlab_simulation_variables.total_energy_test < 1e4
%     myErrs.simulation_warnings = [myErrs.simulation_warnings {'Not
%         very much energy.'}];
% end

% if simulation_parameters.emissions.use_max_emissions_CO2

```

```

    matlab_simulation_variables.gen1_CO > simulation_parameters.
    emissions.max_emissions_CO
%     myErrs.simulation_errors = [myErrs.simulation_errors {'Too
    much carbon monoxide from generator 1.'}];
% end
end

```

8.2 Python Code

8.2.1 Graph Generation Tools (main.py)

```
import datetime
import pandas as pd
import numpy as np
import matplotlib.pyplot as plt
import matplotlib.dates as mdates
import os
from matplotlib import ticker

def generate_price_load_data(sell_override='a'):
    data = []

    for month_file in os.listdir('data/'):
        data.append(pd.read_csv('data/{0}'.format(month_file)))

    data = pd.concat(data)

    data['time'] = pd.to_datetime(data['SETTLEMENTDATE'])
    data[data['RRP'] > 500] = data['RRP'].mean()
    data = data[:17520]

    data['buy_price'] = data['RRP']
    sell_price = []

    for time in data['time']:
        if type(time) == type(data['time'].iloc[0]):
            if 15 <= time.hour <= 21:
                sell_price.append(0.10)
            else:
                sell_price.append(0.03)
        else:
            sell_price.append(0.03)

    data['sell_price'] = sell_price

    x = data['buy_price'] / 100
    y = data['sell_price']

    if sell_price != 'a':
        y = sell_override

    with open('grid_price.txt', 'w') as f:
```

```

        for buy_price, sell_price in zip(x, y):
            f.write('{}{}\n'.format(round(buy_price, 2), round(
                sell_price, 4)))

# Load default values

with open('industrial-none.dmd', 'r') as f:
    industrial = np.array([float(x[:-1]) for x in f.readlines()
        ])

with open('commercial-none.dmd', 'r') as f:
    commercial = np.array([float(x[:-1]) for x in f.readlines()
        ])

with open('residential-jan.dmd', 'r') as f:
    residential = np.array([float(x[:-1]) for x in f.readlines()
        ])

# Normalise to 1 kWh / day

industrial = industrial / (sum(industrial) / 365)
commercial = commercial / (sum(commercial) / 365)
residential = residential / (sum(residential) / 365)

# Scale to correct values

total = 44000000000 / 365

industrial = industrial * total * 0.3
commercial = commercial * total * 0.3
residential = residential * total * 0.4

load = industrial + commercial + residential

# convert W to kWh
load = load / 1000

with open('final_load.txt', 'w') as f:
    for hour in load:
        f.write('{}\n'.format(hour))

return

def get_month_price_data(year, month, regionid='all'):
    # Month number must have a leading zero if single digit. Eg 4

```



```

    —> 04
    if len(str(month)) == 1:
        month = '0' + str(month)

    month_data_url = f'https://visualisations.aemo.com.au/aemo/data/
        nem/averageprices/WEB_AVERAGE_PRICE_DAY_{year}{month}.csv'
    month_data = pd.read_csv(month_data_url)

    #Remove unwanted regions
    if regionid != 'all':
        month_data = month_data[month_data['REGIONID'] == regionid]

    #Convert $/MWh to $/KWh
    month_data['AVGRRP'] /= 1000
    month_data['PEAKRRP'] /= 1000

    #Convert to to datetime object
    month_data['day'] = pd.to_datetime(month_data['SETTLEMENTDATE'])

    return month_data

def get_year_price_data(year, regionid='all'):
    year_data = []
    for month_n in range(1, 13):
        try:
            year_data.append(get_month_price_data(year, month_n,
                regionid=regionid))
        except:
            break

    combined_data = pd.concat(year_data)

    avg_avgrrp = np.average(combined_data['AVGRRP'])
    new_combined = np.array(combined_data['AVGRRP'])

    new_combined[new_combined > 0.15] = avg_avgrrp
    combined_data['AVGRRP'] = new_combined

    return combined_data[:365]

def get_historical_data(years, regionid='NSW1'):
    return {year: get_year_price_data(year, regionid=regionid) for
        year in years}

```

```

def calculate_average_rrp(historical_data , years):
    average_rrp = np.zeros(365)
    peak_rrp = np.zeros(365)

    for year in years:
        if year != 2021:
            average_rrp = average_rrp + np.array(historical_data[
                year][ 'AVGRRP' ][:365].values)
            peak_rrp = peak_rrp + np.array(historical_data[year][ '
                PEAKRRP' ][:365].values)

    average_rrp /= len(years)
    peak_rrp /= len(years)

    return average_rrp

def sinify_daily_data(daily_data , intervals_in_day=48,
    random_variability=0.075):
    global graph_data

    intervals = np.linspace(0, 2 * np.pi, intervals_in_day)
    energy_use_scaling = (np.sin(intervals - ((3 * np.pi) / 4))+ 2)
        / 2

    scaled_daily_data = []
    for day in daily_data:
        day = np.repeat(day, intervals_in_day)
        scaled_day = energy_use_scaling * day

        if random_variability > 0:
            variable_range = day * random_variability
            variable_scales = np.random.randn(intervals_in_day)

            scaled_day = scaled_day + (variable_scales *
                variable_range)

        scaled_daily_data.append(scaled_day)

    return np.concatenate(scaled_daily_data)

def generate_sellback_price_plot():
    years = [2018, 2019, 2020]
    #years = [2010, 2011, 2012, 2013, 2014, 2015, 2016, 2017, 2018,
        2019, 2020, 2021]

    historical_data = get_historical_data(years)

```

```

average_rrp = calculate_average_rrp(historical_data)

graph_data = []

v = sinify_daily_data(average_rrp)
nv = sinify_daily_data(average_rrp, random_variability=0)

days = 7
intervals = days * 48

x = historical_data[2019]['day'].values[:days]

real_x = np.concatenate([[midnight] + [np.nan for x in range(47)
] for midnight in x])
real_x = pd.DataFrame(real_x).interpolate(method='ffill')
timedelta_mask = [datetime.timedelta(minutes=30*n) for n in
range(48)]

real_x = [real_x.iloc[v] + timedelta_mask[v%48] for v in range(
intervals)]

fig, ax = plt.subplots(figsize=(7,5))

for n, day in enumerate(average_rrp[:days]):
    plt.hlines(day, real_x[n*48], real_x[((n+1)*48)-1], color='
red', label='Daily Average')

plt.plot(real_x, v[:intervals], label='Fit + Variation')
plt.plot(real_x, nv[:intervals], linestyle='dashed', label='
Sinusoidal Fit', linewidth=2)

handles, labels = plt.gca().get_legend_handles_labels()
by_label = dict(zip(labels[:: -1], handles[:: -1]))
plt.legend(by_label.values(), by_label.keys())

fmt_day = mdates.DayLocator()
ax.xaxis.set_major_locator(fmt_day)

#fmt_month = mdates.MonthLocator()
#ax.xaxis.set_minor_locator(fmt_month)

# Text in the x axis will be displayed in 'YYYY-mm' format.
ax.xaxis.set_major_formatter(mdates.DateFormatter('%b-%d'))

plt.title('Wholesale Sellback Price Model', fontsize=18)

```

```
plt.xlabel('Day', fontsize=12)
plt.ylabel('Sellback_Price_($/kWh)', fontsize=12)

plt.show()
```

```
system_definitions = {
    1 :
        {
            'Architecture/PV_(kW)' : 0,
            'Architecture/G1500' : 0,
            'Architecture/PHES' : 0},
    2:
        {
            'Architecture/PV_(kW)' : 50000,
            'Architecture/G1500' : 0,
            'Architecture/PHES' : 0},
    3:
        {
            'Architecture/PV_(kW)' : 100000,
            'Architecture/G1500' : 0,
            'Architecture/PHES' : 0},
    4:
        {
            'Architecture/PV_(kW)' : 0,
            'Architecture/G1500' : 10,
            'Architecture/PHES' : 200},
    5:
        {
            'Architecture/PV_(kW)' : 50000,
            'Architecture/G1500' : 10,
            'Architecture/PHES' : 200},
    6:
        {
            'Architecture/PV_(kW)' : 100000,
            'Architecture/G1500' : 25,
            'Architecture/PHES' : 200},
    7:
        {
            'Architecture/PV_(kW)' : 0,
            'Architecture/G1500' : 25,
            'Architecture/PHES' : 1000},
    8:
        {
            'Architecture/PV_(kW)' : 50000,
            'Architecture/G1500' : 25,
            'Architecture/PHES' : 1000},
```

```

9:
    {
        'Architecture/PV_(kW) ': 100000,
        'Architecture/G1500 ': 25,
        'Architecture/PHES ': 1000}
}

def determine_system_number(data, system_definitions):
    systems = {n: [] for n in system_definitions.keys()}

    for system_n in system_definitions.keys():
        sub_systems = data.copy()
        for comp in system_definitions[system_n].keys():
            if system_definitions[system_n][comp] == 0:
                sub_systems = sub_systems[np.isnan(sub_systems[comp])
                ]
            else:
                sub_systems = sub_systems[sub_systems[comp] ==
                system_definitions[system_n][comp]]

        sub_systems['System_Number'] = system_n

        #replacement = sub_systems['Sensitivity/Electric Load #1
        Scaled Average (kWh/d) '].copy()
        #replacement = 120000
        #sub_systems['Sensitivity/Electric Load #1 Scaled Average (
        kWh/d) '] = replacement

        systems[system_n] = sub_systems
        print(len(sub_systems))

    allsystems = [systems[k] for k in systems.keys()]
    allsystems = pd.concat(allsystems)

    return allsystems

def generate_normalised_system_performance_graph():
    system_data.sort_values(by='System_Number', inplace=True)
    system_data.reset_index(inplace=True, drop=True)

    normal_systems = system_data.select_dtypes([np.number])
    normal_systems = (normal_systems - normal_systems.min()) / (
        normal_systems.max() - normal_systems.min())
    normal_systems['System_Number'] = np.array(normal_systems.index)
    + 1

```

```

fig, ax = plt.subplots(2, 2, sharex='all', sharey='row', figsize
    =(8, 5))

normal_systems['N_NPC'] = 1 - normal_systems['Cost/NPC_($)']
normal_systems['N_CAP'] = 1 - normal_systems['Cost/Initial_
    capital_($)']

normal_systems.plot.bar('System_Number', 'N_NPC', ax=ax[0][0],
    color='red')
normal_systems.plot.bar('System_Number', 'N_CAP', ax=ax[0][1],
    color='purple')
normal_systems.plot.bar('System_Number', 'Grid/Energy_Sold_(kWh)
    ', ax=ax[1][0])
normal_systems.plot.bar('System_Number', 'System/Ren_Frac_(%)',
    ax=ax[1][1], color='green')

fig.supxlabel('System_Number', fontsize=12)
fig.supylabel('Normalised_Performance', fontsize=12)
fig.suptitle('Normalised_System_Performance_(higher_is_better)',
    fontsize=18)

ax[1][0].title.set_text('Energy_Sold')
ax[1][1].title.set_text('Renewable_Fraction')
ax[0][1].title.set_text('Initial_Capital')
ax[0][0].title.set_text('NPC')

ax[1][0].set_xlabel('')
ax[1][1].set_xlabel('')

#ax[1][0].set_yticks([])#[0, 1])
#ax[0][0].set_yticks([])#[0, 1])

ax[1][1].set_xticklabels(labels=[x for x in range(1, 10)],
    rotation=0)
ax[1][0].set_xticklabels(labels=[x for x in range(1, 10)],
    rotation=0)

ax[1][0].get_legend().remove()
ax[0][1].get_legend().remove()
ax[1][1].get_legend().remove()
ax[0][0].get_legend().remove()

ax[0][0].tick_params(
    axis='y',          # changes apply to the x-axis
    which='both',      # both major and minor ticks are affected
    bottom=False,      # ticks along the bottom edge are off

```

```

        top=False,          # ticks along the top edge are off
        labelbottom=False)

plt.tight_layout()
plt.show()

def compare_sensitivity(data, sensitivity_variable,
    performance_variable, ax):
    system_numbers = data['System_Number'].unique()
    sensitivity_values = sorted(data[sensitivity_variable].unique())
    category_values = []

    for system_n in system_numbers:
        cat = []
        for n, sen_n in enumerate(sensitivity_values):
            relevant_rows = data[data['System_Number'] == system_n]
            sen_variables = ['Sensitivity/NominalDiscountRate_(%)',
                'Sensitivity/Electric_Load_#1_Scaled_Average_(kWh/d)',
                'Sensitivity/ExpectedInflationRate_(%)',
                'Sensitivity/Project_Lifetime_(years)']
            sen_defaults = [4, 120000, 2, 50]

            for s, d in zip(sen_variables, sen_defaults):
                if s != sensitivity_variable:
                    relevant_rows = relevant_rows[relevant_rows[s]
                        == d]

            value = relevant_rows.iloc[n][performance_variable]
            cat.append(value)
        truecat = [cat[2], cat[0], cat[1]]
        category_values.append(truecat)

    category_values = list(np.array(category_values).T)

    x = np.arange(len(system_numbers))
    default_width = 0.7
    n_cols = len(category_values)
    width = default_width / n_cols

    for n, data in enumerate(category_values):
        if sensitivity_values[n] == 120547.944:
            sensitivity_values[n] = 120000
        ax.bar(x-(width*(n_cols-n)), data, width, label=int(
            sensitivity_values[n]))

    ticks = [(default_width * n) - (width * (n_cols-(n+1))) +

```

```

        0.0575*n for n in range(len(system_numbers))]
ax.set_xticks(ticks)
ax.set_xticklabels(system_numbers)

if performance_variable == 'Grid/Energy_Sold_(kWh)':
    ax.title.set_text('Energy_Sold_(kWh_/_year)')
elif performance_variable == 'Cost/COE_($)':
    ax.title.set_text('COE_($/_kWh)')
else:
    ax.title.set_text(performance_variable.split('/')[-1])

system_data = pd.read_csv('exportall.csv')

x = determine_system_number(system_data, system_definitions)

#a = x[x['System Number'].isin([4, 5, 6, 8, 9])]
a = x

fig, ax = plt.subplots(2, 2, figsize=(8, 5), sharex='all')

s = 'Sensitivity/Electric_Load_#1_Scaled_Average_(kWh/d)'

compare_sensitivity(a, s, 'Cost/NPC_($)', ax=ax[0][0])
compare_sensitivity(a, s, 'Cost/COE_($)', ax=ax[0][1])
compare_sensitivity(a, s, 'Grid/Energy_Sold_(kWh)', ax=ax[1][0])
compare_sensitivity(a, s, 'System/Ren_Frac_(%)', ax=ax[1][1])

lines_labels = [ax.get_legend_handles_labels() for ax in fig.axes]
lines, labels = [sum(lol, []) for lol in zip(*lines_labels)]
fig.legend(lines[:3], labels[:3], title='Load_(kWh/day)')

plt.suptitle('Sensitivity_Analysis:_Average_Load_(kWh_/_day)_____',
             fontsize=18)

fig.supxlabel(str('_' * 12) + 'System_Number') #add space to center
properly due to ylabel width
fig.supylabel('Performance')

plt.tight_layout()

plt.show()

```