THE UNIVERSITY OF QUEENSLAND

Paasifica Renewable Technology Analysis

Student Name: Tom Carruthers

Faculty of Engineering, Architecture and Information Technology

Course Code: MECH4501

Supervisor: Dr. Alexander Klimenko

Submission date: 30 May 2019

Acknowledgments

Firstly, I would like to thank my supervisor Dr. Alex Klimenko for his advice and guidance over the past year, I really appreciate it.

Secondly, I would like to thank Shane Ridley for allowing me to complete this analysis and for giving me as much help as he did. I can’t thank you enough, without you help and knowledge this project wouldn’t be were it is.

Abstract

Cryptocurrency and Renewable energy generation are both topics that are quickly gaining momentum and mainstream attention. This report aims to provide the reader with a brief introduction to both topics using a comprehensive critical literature review.

Paasifica is a Toowoomba based start-up that was founded in early 2018 by Shane Ridley, David McDonald, Roger House, Charles McDonald, and David Mactaggart. The company has the ambitious goal of creating a privately owned 'supercomputer' – a stacked array comprising of hundreds of high-end graphics processing units, or GPUs. The project aims to provide on demand processing power to consumers around the globe and will be publicly available from anywhere with an internet connection. The primary use of the hardware is planned to deliver the hashing power necessary for cryptocurrency mining, specifically Ethereum. The computer is designed to be run continuously for the lifespan of the project – 10 years.

The current proposed design has a system size of approximately 123.58kW, which equates to almost 3MWh per day. To achieve this goal in a profitable manner, electricity costs need to be kept as low as possible. Therefore, it is necessary to research not only the theory behind cryptocurrency mining, but also all possible renewable energy generation options in the South East Queensland area that could be used to offset the cost of grid electricity.

Australia, and specifically Queensland is incredibly lucky in that it has abundant supplies of natural resources, including those that are necessary for many of the main forms of renewable energy. These options were evaluated using a comprehensive criterion. It was found that the most feasible option, while staying within Paasifica's scope, was solar PV.

In order to explore all avenues, a feasibility analysis was conducted on three variations of the technology: solar PV alone, solar PV + lithium ion battery storage, and an alternative grid tariff option.

For solar PV with no storage, 3 different tracking options were examined over 6 different system sizes ranging from 100kW to 300kW. The 3 primary tracking options that were discussed are fixed axis tilt (FAT), single axis tracking (SAT), and dual axis tracking (DAT). Any excess power that was generated was sold back to the grid at a set solar feed in tariff. It was found that the 123.58kW (exactly matching the computer requirements) SAT solar PV array is the most viable option.

For solar PV + battery storage, 4 different grid offset amounts were investigated: full offset, ¾ offset, ½ offset, and ¼ offset. It was discovered that the ¼ offset amount was the most viable energy storage option.

An alternative grid tariff was also considered. Once all options were evaluated and compared, it was found that most feasible option is to implement the 123.58kW SAT solar PV array.

Table of Contents

1.0. Introduction

The world was first introduced to the concept of cryptocurrency and the blockchain on January 3rd, 2009 with the release of *Bitcoin*: a decentralized, peer-to-peer electronic cash system. Since then, cryptocurrencies have exploded in popularity, gaining mainstream attention. As of October 2018, there are over 1900 different cryptocurrencies, with the most popular by market capitalisation being Bitcoin, Ethereum, and Ripple (Coinlore, 2018).

The software allowing cryptocurrencies to operate in a secure and decentralized manner is called the Blockchain. It is an open-access digital ledger that constantly records and updates every transaction made with its associated cryptocurrency. The purpose of crypto-mining is two-fold: to update the blockchain ledger by verifying transactions, and to generate new currency. The process of verifying transactions is computationally difficult and requires state of the art software and hardware. In return for verifying 'blocks' of transactions, the miner is awarded with newly generated currency, providing the financial incentive to mine.

Paasifica is a Toowoomba based start-up founded in 2018 by *Shane Ridley, David McDonald, Roger House, Charles McDonald,* and *David Mactaggart*. The company's flagship project is to design and build a privately owned 'supercomputer' comprising of an array of hundreds of Graphics Processing Units (GPU's). The project aims to provide on demand processing power to consumers using a cloud-based token system – publicly available from anywhere with an internet connection. The primary use of the hardware will be to deliver the hashing power necessary for cryptocurrency mining, specifically Ethereum. However, it will also offer several other services such as artificial intelligence (AI) machine learning, rendering, and bulk data processing. Currently in the development stage, Paasifica plans to have the array operational by late 2019.

Besides the initial capital investment into the GPU rigs themselves, the biggest ongoing cost associated with running a processor bank is the cost of the electricity required to run and cool the GPU's. With Australia's energy costs rising annually with no end in sight, Paasifica is currently looking into ways to reduces this cost as much as possible, and whether the energy can be sourced in a renewable way.

This Thesis aims to investigate the theory behind the cryptocurrency blockchain, and the relationship between crypto-mining and the energy markets in Australia. This research will be utilized to develop an in-depth feasibility analysis on several renewable technology options available in Australia. The feasibility analysis will place emphasis on basic design, financials, and environmental impact.

2.0. Project Goals

The project has two well-defined goals which will be worked towards throughout the year, while remaining in close contact with Paasifica. The two primary goals have been split into manageable sections and sub goals.

It is necessary to have a full understanding of the problem, and the technologies behind it. Therefore, the first goal is to:

1. **Develop a comprehensive understanding of the theory and technologies behind the problem:**
    - Cryptocurrency, specifically Ethereum
    - Blockchain
    - Cryptocurrency mining

Once the mechanics behind the issue are fully understood, work can begin on the second goal of the project. It has been broken down into two phases, each with specific sub-goals:

2. **Research and propose a suitable renewable energy source capable of achieving all requirements set out by Paasficia:**
    - Phase 1 – Scoping and Identification:
        - Estimate full scale power consumption of the GPU rigs using real world data and appropriate scaling factors
        - Identify renewable technology options in Australia
        - Develop a criterion to evaluate technology options
    - Phase 2 – Evaluation and Analysis:
        - Evaluate feasibility of the different options
        - Identify most promising options to present to Paasifica

If both project goals are achieved, then it will be possible to provide Paasifica with an in-depth view into the different renewable technology options available to them. A comprehensive analysis into the most viable recommended options, and a set of recommendations outlining the findings of the feasibility study.

3.0. Critical Literature Review

3.1. Cryptocurrency

3.1.1. Ethereum

The idea of an online cryptographic payment system is not a new one. Anonymous and untraceable 'E-cash' payments were proposed by David Chaum in his 1983 paper 'Blind Signatures for Untraceable Payments' (Chaum, 1983). Over the decades several other cryptocurrency predecessors were proposed, although these largely failed to gain any traction. Until finally on October 31st, 2008 an individual (or group) under the alias Satoshi Nakamoto published the paper 'Bitcoin: A Peer to Peer Electronic Cash System' which outlined plans for a completely decentralized, anonymous cash transfer system (Nakamoto, 2008). The Bitcoin platform was launched in early January 2009.

Ethereum was first proposed in 2013 by Vitalik Buterin in his 'White Paper' post on the popular programming discussion site Github. In his paper Buterin outlined some of the underlying issues with Bitcoin technology and argued that the real value of the coin was in the Blockchain technology that underpinned its mechanics (Buterin, 2013). As such, Ethereum was developed as "an attempt to apply learnings from Bitcoin's decentralized, global cryptographic network to challenges beyond value exchange" (Coindesk, 2013).

Ethereum is an open-sourced, decentralized platform which utilizes blockchain technology as a foundation. It provides not only peer-to-peer transactions, but also facilitates 'smart contracts' which allow independent developers to create decentralized applications (Forbes, 2018). The project aims to solve the problem of intrinsic value within the cryptocurrency and

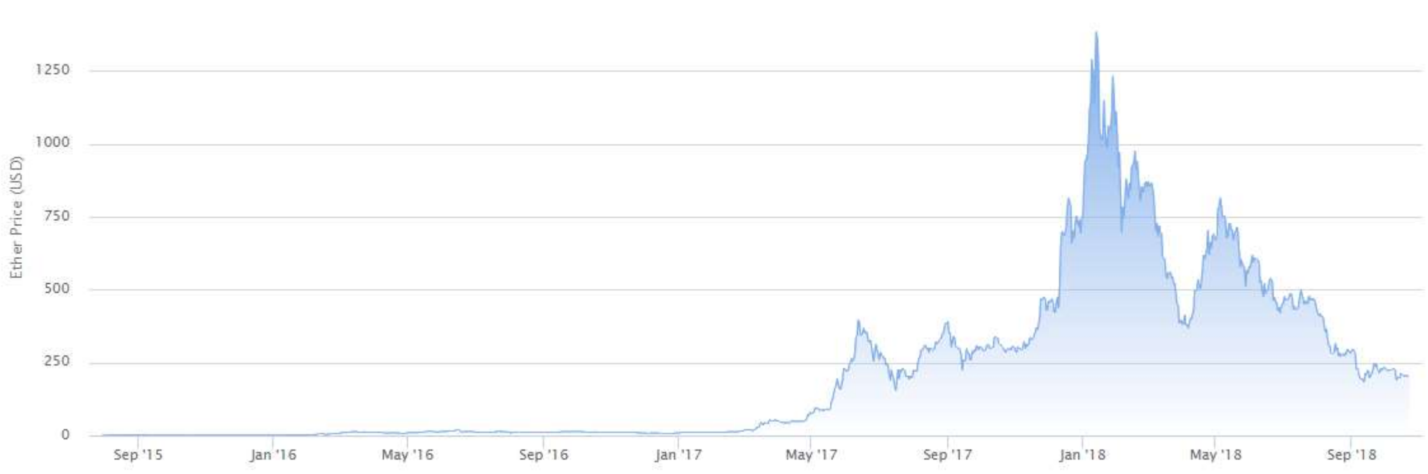


Figure 1: Historical Price of Ether (USD)

allows users much greater control over the platform. Ether (ETH, the cryptocurrency that uses the Ethereum blockchain) is currently the second largest cryptocurrency in circulation with a market capitalization of $21.06 Billion US, with one Ether token being valued at $204.98US ($289.33AUD) (BitinfoCharts, 2018). However, as can be seen in in *figure 1* above, ETH has experienced a rocky past, and the future value of the coin is unclear.

3.1.2. Blockchain technology

The development of blockchain technology is arguably one of the most important achievements of the 21st century to date. To quote co-founder and former CTO of Ethereum Dr. Gavin Wood, Blockchain is a “model that forms the backbone of not only Ethereum, but all decentralized consensus-based transaction systems to date” (Wood, 2017). On a fundamental level, the blockchain is an open access, consensus-based ledger. It consists of ‘blocks’, each of which contains a timestamp, cryptographic hash of the previous block, and a set of transactional data (Narayanan et al., 2016). It is the cryptographic hash which connects the blocks to form a ‘chain’, linking all the way back to the genesis block. All transactions that have ever taken place using a cryptocurrency are open and available to the public on its blockchain.

The exact method in which blockchains work is complex and outside the scope of this thesis. However, to understand how cryptocurrency mining works, two key elements are required (bitcoin is used as an example):

- **Transactions:** For one user to transfer bitcoin to another user, the blockchain must first confirm two things: 1. That user 1 has enough bitcoin in their wallet, and 2. That the user hasn’t already sent the coin. To confirm this information, the blockchain uses a combination of public and private keys – 34 and 64 strings of letters and numbers respectively. When a transaction is made, it is signed with User 1’s private key, the software then checks whether the transaction’s public key corresponds with the private key, and if so, validates the transaction (Coindesk, 2018).
- **Blocks:** once a transaction is confirmed it gets added to the ‘block’ of transactions. All information in the block is reduced through a cryptographic hash function to a very specific block header and ‘hash’ or string of 64 letters and numbers. This header contains the root of all previous blocks, a timestamp, a difficulty target, and

a ‘nonce’ number. One small deviation from the original data inputted to the hash will produce an entirely different combination, which is how blockchains make sure that no previous transactions are altered. (Blockgeeks, 2018).

3.1.3. Cryptocurrency mining

The ‘mining’ of cryptocurrencies is integral to the process of transaction verification and allows the blockchain to stay secure and decentralized. A crypto miner is an individual or organisation that takes part in the act of adding new blocks to the chain through the confirmation of transactions. In a blockchain system, a miner is considered one of many nodes (Tar, 2018).

Crypto mining is based off a “proof-of-work” (PoW) consensus algorithm. As previously mentioned, a block of transactions has a header with a unique hash code, which contains all the information about that block. A miner will pass the unique header through a hashing function, and the blockchain software checks if this new hash matches the unique block hash. If the hashes do not match, the miner changes the ‘nonce’ value in the header and tries again (Investopedia, 2018). Depending on how powerful the miner’s hardware set up is, this process can be repeated trillions of times per second.

Eventually a miner will find a matching hash, in this case the block is confirmed and added to the chain. Simultaneously, the blockchain sends out a signal that the current block has been completed, and to start work on the next block. For most cryptocurrencies, there is a reward for finding the correct hash and solving the block. Most miners are part of mining pools, which connects users through the internet to pool resources, allowing for a higher chance at mining a block, in which case the reward is split proportionally (Drake, 2018).

Another important aspect of mining cryptocurrency is the difficulty. Which is a function that is built into the unique header of each block to increase or decreases how much work is required to mine the block. If blocks are being mined too quickly, the difficulty will increase. This process ensures a constant output, and that opportunities are kept equal between miners (Cunningham, 2017).

3.2. Renewable energy technologies

3.2.1. Solar PV

Solar photovoltaic cells are one of the most popular and researched renewable technologies worldwide, with many believing that solar/battery combination arrays will one day become the dominant form of energy generation. Photoelectric cells directly convert irradiance into electricity on the atomic level, generally using single junction crystalline silicon cells, which are arranged into arrays (Knier, 2002). In recent years PV cells have experienced significant improvements in technology, efficiency, and price which has allowed for a massive increase in the global solar generating capacity (MIT, 2015).

According to the *Australian Renewable Energy Agency*, "Australia has the highest average solar radiation per square meter of any continent in the world", so it's understandable why the demand for solar PV has risen significantly in the last 8 years.

Figure 2: Australian PV installations: total capacity (kW)

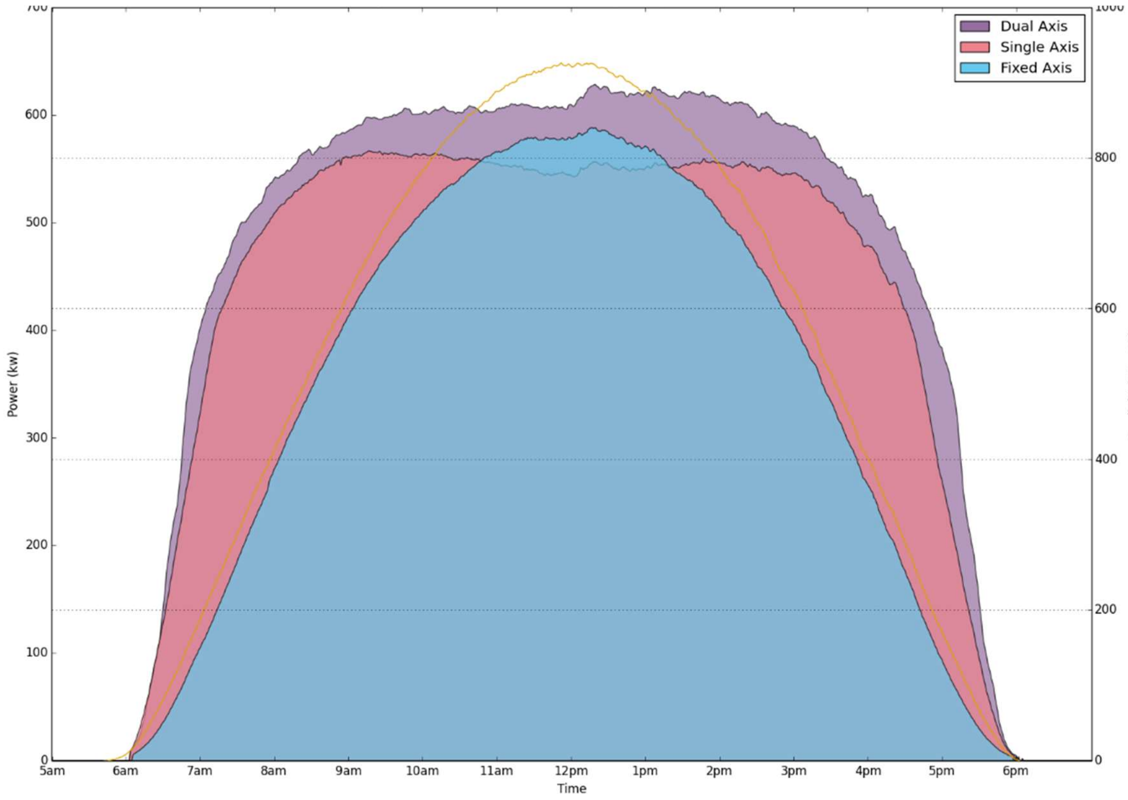
As can be seen in *figure 2* the installed capacity of solar PV has risen from 153MW in 2010, to 8.45GW in June of 2018, a 5400% increase (Australian PV Institute, 2018).

There are 3 different types of solar tracking that are typically used:

- Fixed axis tilt (FAT)
- Single axis tracking (SAT)
- Dual axis tracking (DAT)

Currently most traditional solar arrays are FAT. However, in an experiment conducted at the UQ Gatton Campus involving 630kW of each solar tracking array, it was found that SAT outperformed the FAT array, for only a small increment in cost as can be seen in *figure 3* and *appendix I*.

Figure 3: Gatton PV Pilot Plant Array Comparison 19-3-15

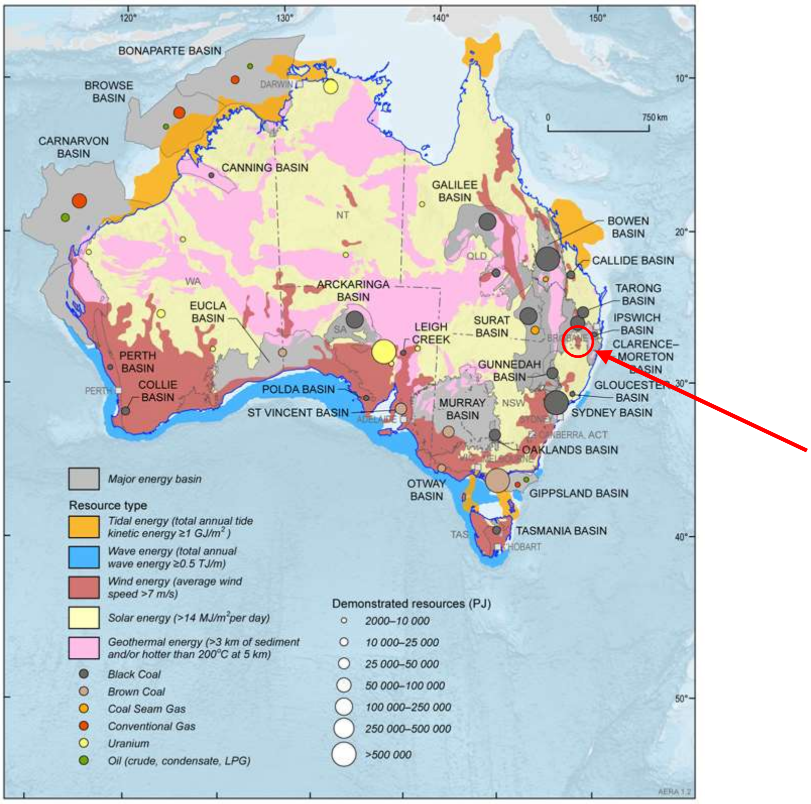


It can clearly be seen that the SAT and DAT arrays significantly outperform the standard FAT.

3.2.2. Wind power

Another popular choice of renewable electricity generation is the use of turbines to harness energy from the wind. Although slightly more controversial that solar PV, wind power is currently the cheapest source of large-scale renewable energy in Australia. In 2018 over 850MW of new wind energy was installed, which helped to produce 33.5% of Australia's clean energy, and 7.1% of its total electricity production (Clean Energy Council, 2018). Geoscience Australia indicates that effective wind generation occurs at consistent wind speeds of greater than 7m/s. Significant areas of the Southern and Western coastline of Australia fulfil this criterion as can be seen in *figure 4*. However, there are few areas with consistent conditions in QLD and NSW, the exceptions being a thin strip in the very centre of QLD and a small pocket South-West of Brisbane surrounding the town of Stanthorpe (Australian Government, 2014).

Figure 4: Australia's major energy resources



Pocket of suitable wind conditions around Stanthorpe

Currently there are three large scale wind farms being constructed in Queensland: Coopers Gap (453MW), Kennedy Energy Park (43MW + 2MW Battery), and Mt Emerald (180MW). There are also almost 11 others in various states of approval (Clarke, 2014). In addition, one of Australia's largest wind turbine producers *Goldwind Australia* has recently taken control of a major wind farm project in Dalveen, just near Stanthorpe (Stanthorpe Border Post, 2018).

Commercial wind turbines typically cost between $1 – 2 million per MW, with a 2MW turbine costing around $2.8 million (Rinkesh, 2018). This is primarily due to the difficult engineering challenge that accompanies constructing large, light-weight structures. Wind is a notoriously intermittent source of power, which is why it is not viable in many locations. Like solar PV, a battery or energy storage system can be implemented alongside the turbines to provide reliable electricity generation.

3.2.3. Biomass

Biomass is a mature and proven energy source which has been used throughout Australia for decades. It currently accounts for around 1% of Australia's total energy production, or 7% of the renewable electricity component (Australian Government, 2018). Biomass plants are incredibly versatile and can generate electricity in several different ways. Typically, biomass plants generate energy by burning living or recently dead natural material and green waste such as plants stalks, trees, leaves, and agricultural waste. However, they can also convert the biomass into biogas, or a liquid biofuel such as ethanol and biodiesel (Australian Government, 2018).

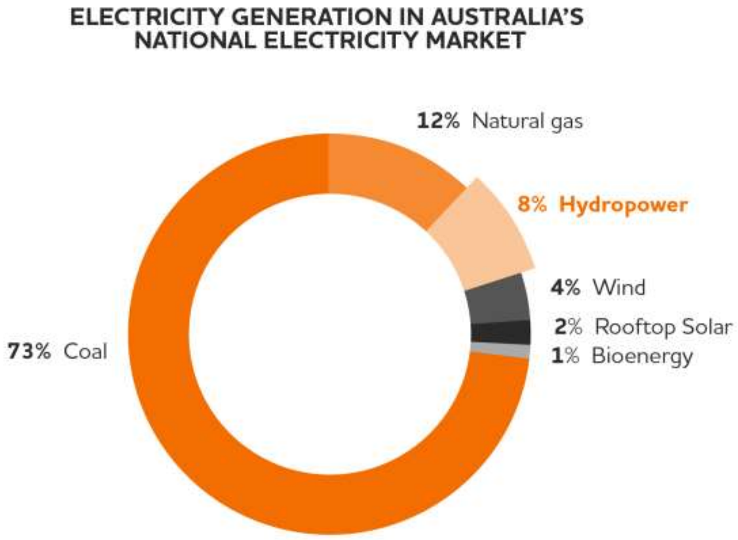
Queensland has a natural advantage when it comes to biomass energy production due to its extensive sugar cane plantations in the North. According to the Clean Energy Australia Report 2013, Queensland's power stations account for almost half of the country's bioenergy generation potential (Clean Energy Council, 2013).

Despite its versatility and wide usage throughout Australia, biomass is typically only feasible for large scale electricity generation, in the order of MWs. This is mainly because of the high demand for feedstock, large capital costs, and low small-scale efficiencies (National Geographic, 2019).

3.2.4. Hydroelectric

Hydroelectric power generation is a proven technology that has been used in Australia for decades. The Snowy mountains hydroelectric scheme was opened in 1972, and despite being only 1 out of over 100 hydro plants in Australia, provides roughly half of the countries total hydro output at 3800MW (Origin Energy, 2018). As can be seen in the following figure, hydroelectric power accounts for 8% of Australia's total energy generation.

Figure 5: Australia's energy generation spread



Hydroelectricity is completely dispatchable renewable source that can provide base load and peak load electricity and can produce maximum power within 90 seconds (Clean Energy

Council, 2018). However, since Australia is the driest inhabited continent on earth, almost all of its economically feasible hydro energy resources are already being used (Geoscience Australia, 2019). This leaves practically no room for any private hydroelectric development.

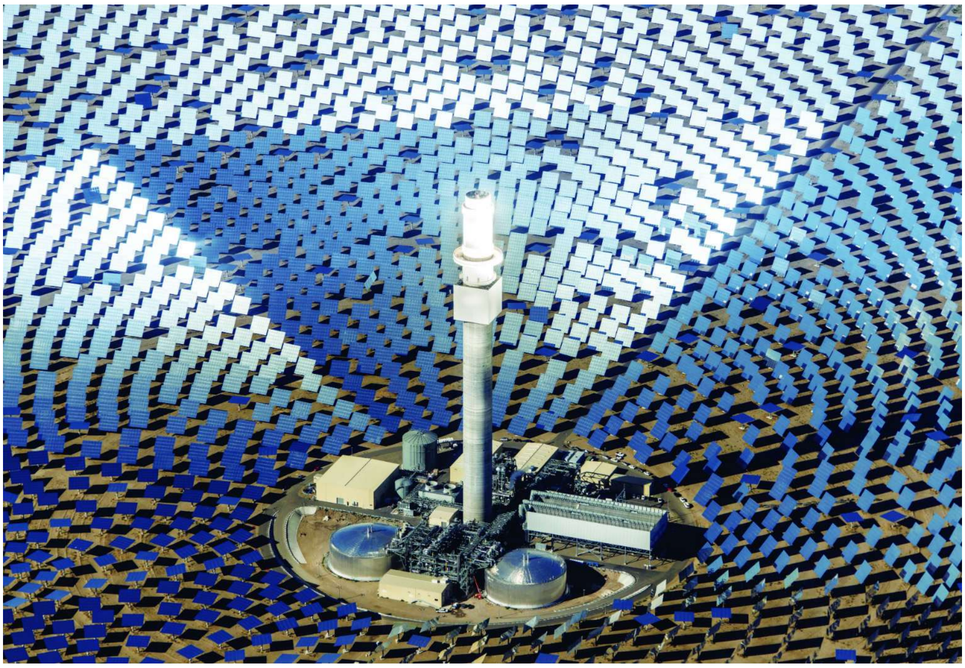
3.2.5. Solar Thermal

Concentrating solar thermal (CST) is an emerging technology that uses large arrays of focused mirrors to a central locus. This generates large amounts of heat, which is typically transferred to some working fluid. According to the Clean Energy Council in 2018, there are 4 main technology types:

- Linear Fresnel – single axis tracking mirrors that focus on linear receivers mounted above them.
- Tower – large array of dual axis tracking mirrors that focus on a receiver at the top of a central tower.
- Dish – parabolic dish that focuses light to a single receiver
- Trough – parabolic mirrors to track the sun across the sky.

CST can also store heat in the form of molten salt, which can then be used later. This essentially means that it has the potential to deliver dispatchable energy while still being renewable (ARENA, n.d.). Figure X shows Australia's largest CST power station (150MW) in Port Augusta:

Figure 6: 150MW CST Tower in Port Augusta, SA



However, it is still a new technology, and is not currently economically viable due to huge capital expenses and operating costs (ARENA, n.d.)

3.3. Energy storage technologies

3.3.1. Lithium ion batteries

The yearly drop in price and increase in efficiency seen in PV cells have been mirrored in the battery storage industry. Just as Australia has seen a significant upwards trend in solar uptake, a report published by the Climate Council in 2018 estimates that new home battery installations almost tripled between the years of 2016 – 2017 (Vorrath, 2018). In addition, the cost of lithium-ion batteries has fallen significantly in the past 8 years, all the while increasing energy density. Additionally, large scale battery storage is now a proven technology in Australia after the installation of a 100MW Tesla 'mega battery' near Jamestown in SA.

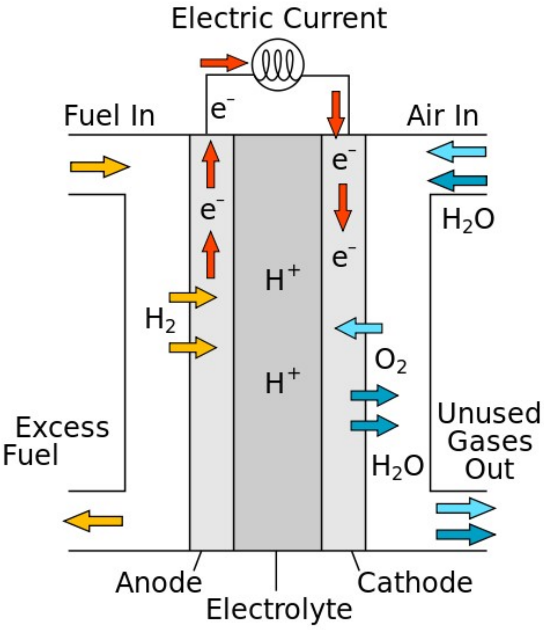
Figure 7: 100MW Tesla Battery Pack in SA

This simultaneous drop in price may allow for the combined installation of the two technologies, with battery storage being able to offset the intermittent nature of solar PV.

3.3.2. Hydrogen fuel cells

Hydrogen fuel cells are a promising emerging technology that function similarly to traditional batteries in that a chemical reaction is used to create electricity. However, in this case hydrogen and oxygen are inputted into the cell as 'fuel', which then react with the anode and cathode to produce electricity, heat and water as biproducts (Renewable Energy World, n.d.).

Figure 8: A Hydrogen Fuel Cell



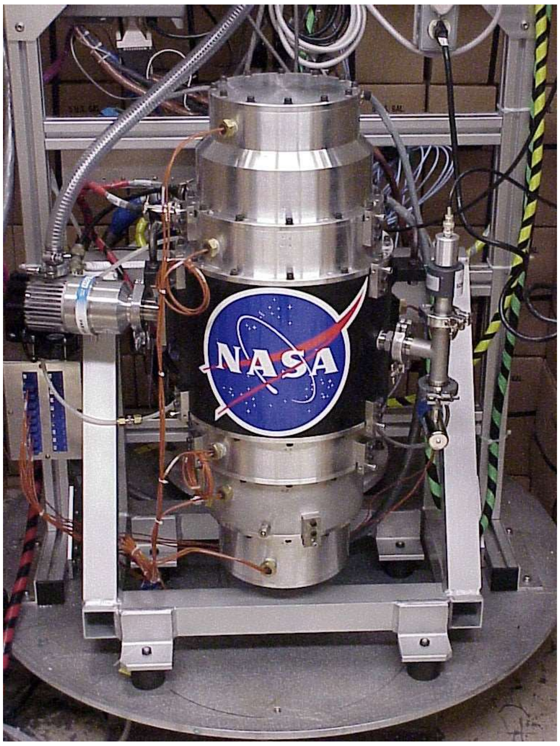
Despite the fact that hydrogen is the most abundant element in the universe, there are practically no free deposits of hydrogen on earth. Most hydrogen is produced through an energy intensive process involving fossil fuels called steam methane reformation (Wise, 2006). Therefore, while there is huge potential in hydrogen energy, both production and storage, further development of the hydrogen refinement process is required.

3.3.3. Kinetic energy storage

Otherwise known as flywheel energy storage (FES), this emerging technology operates by accelerating a flywheel or rotor to very high speeds (up to 60,000 RPM), where energy is stored as rotational energy. When electricity is required, the flywheel is slowed down and energy is transferred out of the system as a consequence of the principle of conservation of energy (Energy Storage Association, n.d.).

Figure 9 below shows NASA's FES system:

Figure 9: NASA Flywheel Energy Storage



The rotor sits on near frictionless magnetic bearings inside a vacuum enclosure in order to minimize friction as much as possible. Spinning at 60,000RPM means the rotor is travelling almost 2.5 times the speed of sound (Greenage, 2016). While still in its infancy, with no practical large-scale energy storage options, FES has huge potential.

4.0. Methodology

4.1. Phase 1 – Scoping and identification

4.1.1. Current Stage

The project is currently in the developmental stage, where a number of tests are being run to determine the large-scale feasibility of the project. A small-scale GPU array was constructed in early 2018 to gauge the potential costs, difficulties, and energy usage that would accompany a large-scale supercomputer. The set-up consists of 7 'rigs' – a colloquial term for a cryptocurrency mining computer. Each rig is a self-contained, open-air aluminium frame that houses the following hardware components:

Table 1: Rig Components List

Hardware:	Component:	Number:	RRP:
GPU	Gigabyte GeForce GTX 1070	8	$652.92
Motherboard	ASUS Z270 Prime A	1	$318.02
CPU	Intel i3 8100	1	$205.00
RAM	Corsaire Vengence 4GB DDR4	1	$38.62
Hardrive	Sandisk SSD120GB	1	$31.63
Power Supply Unit	EVGA Supernova 1200W PSU	1	$365
Riser Card	Onvian 16x PCI 6pin Riser	1	$24.54
Cooling fan	Be Quite! Pure wings 2 120mm	4	$15
		Total (per rig):	$6266.17

The setup currently consists of 7 rigs which stack within a metal racking system that allows for easy expansion. A test run was conducted in which the experimental computer mined Ethereum cryptocurrency 24/7 for approximately 1 month to gather data about its operation. From these tests, total amount of processing power the computer can output is summarized in the following table:

Table 2: Test setup performance values

Property:	Value:
Total number of GPUs	56
CPU architecture	32bit
Average hash rate per GPU	40Mh/s
Average FLOPs per GPU	6.5 TFLOPs
Total potential hash rate	1680Mh/s
Total potential FLOPs	364 TFLOPs

The test also gathered data on the array's power consumption. The power requirements of the GPUs are considered stable, and typically vary by less than 1-2W at any given moment. However, it should be noted that this test was conducted in Autumn 2018 where air temperatures were still high on average. This means that ambient cooling was not a factor, and that cooling fans were run 100% of the time.

Table 3: Test setup electricity usage

Property:	Value:
Avg. electricity draw per GPU:	120W
Avg. electricity draw per rig:	960W
Total avg. electricity draw:	6720W (6.72kW)
Avg. daily electricity usage:	161.28kWh

According to Canstar Blue, the average electricity rate in Queensland is 27.6256c/kWh. However, this does not take into a the 'supply charge' which is a daily fee that applies for being simply connected to the grid (O'Neill, 2018). However, according to Shane the actual average daily electricity cost is closer to 35c/kWh on their current energy plan. Therefore, the estimated daily cost of the computer can be calculated. Note these values do not consider the capital cost of the rigs, or the potential revenue generated from mining ETH.

Table 4: Test set up cost estimates

Property:	Value:
Avg. cost per kWh:	$0.35
Cost per rig per day:	$8.06
Estimated daily electricity cost:	$56.448
Estimated yearly electricity cost:	$20603.52

4.1.2. Next stage

The next stage in the project is a large increase in the number of rigs from 7 to 128 which will significantly increase their processing power and mining potential. Extrapolating the data from the small-scale test, it is possible to estimate the total processing power and energy consumption of the full-size supercomputer. This next stage of the project has a predicted lifespan of 10 years, in which the supercomputer will not be shutoff unless it is deems absolutely necessary. Due to the modular nature of the rig system, any required maintenance can be conducted without disrupting the operations of the remaining system. Therefore, for calculating electricity usage values it is assumed that the supercomputer operates 24/7/365.

Under general operating conditions, the GPU cores are at practically 100% utilization and can run quite hot in enclosed areas (approx. 81°C). Scaling up requires additional cooling, especially since the array will be kept indoors.

Table 5: Supercomputer processing power and electricity usage

Property:	**Value:**
Total number of GPUs:	1024
Total potential hash rate	40.96GH/s
Total potential FLOPs	6.656PFLOPs
Estimated rig electricity draw:	122.88kW
Estimated additional cooling	700W
Total system draw:	**123.58kW**
Estimated electricity usage per day:	**2965.92kWh** (2.97MWh)
Estimated electricity usage per year:	1082.56MWh
Estimated electricity usage over lifespan:	10825.6MWh (10.8GWh)

In a similar fashion to the small-scale setup, the estimated costs of the stage 2 supercomputer can be calculated using the same average cost of electricity at $0.35/kWh:

Table 6: Supercomputer base electricity costs

Property:	**Value:**
Electricity cost per day:	$1038.072
Electricity cost per year:	$378896.28 (approx. $380,000)
Lifetime electricity costs:	$3788962.8 (approx. $3.8million)

As can be seen above, besides the initial capital investment the electricity cost, the largest on-going cost of the project is electricity.

4.1.3. Research into technology options

It is clear that besides the initial capital investment into the hardware and installation costs, by far the largest on-going cost is the electricity usage charges. In addition to estimating the large-scale power requirements of the proposed array, significant research was done into different power generation options in the South East Queensland/Toowoomba region. This was primarily achieved through two avenues:

1. Personal research into the topic, much of which is summarized in the critical literature review
2. Contact with experts within the renewable energy field.

The energy generation options that were considered vary from mature, proven technologies, to options that are not currently possible. However, many are not within the scope of this thesis or do not align with Paasificas requirements. The following table outlines technology options that were and were not included:

Table 7: Scope of technology options

In scope:	Out of scope:
Solar PV	Nuclear power
Wind power	Hydrogen and fuel cells
Hydroelectric	Geothermal power
Biomass	Fusion
Solar Thermal	

4.2. Phase 2 – Evaluation and analysis

4.2.1. Evaluation criterion

The second phase of the project involved narrowing down potential energy generation options. This was achieved by developing a comprehensive evaluation criterion by which to examine the feasibility of each technology option. Strong emphasis was placed on aligning with Paasfica's goals and requirements. The criterion can be divided into 4 parts: cost, pollution, risk, and difficulty. Each part consists of its own sub-categories and weighting factor. The weighting factors range from 1 – 5 with 1 being least applicable to the project, and 5 being most applicable.

Estimating the actual values required to evaluate cost, pollution, risk, and difficult for each energy generation technology are complex and multi-faceted calculations that are out of scope for this section. Therefore, value rankings are based off initial research into the options. The following table contains the different sub-categories, and justifications for their chosen weighting factor:

Table 8: Evaluation Criterion Explanation

Criterion		Weighting factor	Justification
Cost	Capital	5	The total cost of a technology is perhaps the largest effector on the success of the project. Capital investments provide the driving force behind the project, allowing Paasifica to transition from an experiment into a business. Therefore, capital has the largest weighting factor, which is appropriate considering the company is privately funded. Operating and maintenance costs are also important as they can greatly drive the price of a technology up over its lifespan. This criterion is scored from 1 – 5, where 1 is the least expensive and 5 is the most expensive.
	Operating	3	
	Maintenance	3	
Pollution	Emissions	4	Paasifica is a progressive and environmentally conscious company that is all too aware of the global warming threat. Therefore, the sustainability of a technology option is considered an important part of its selection. The equivalent CO2 emissions of an energy generation technology, whether it's embodied energy or direct emission, are important to the company and carry a large weighting factor. The outputted noise of an option also needs to be taken into consideration due to the location of the company. The look of the technology is less important. This criterion is scored from 1 – 5, where 1 is the least pollution, and 5 is the most pollution.
	Aesthetic	1	
	Noise	3	
Risk	Environmental	3	All new technology options are accompanied by some degree of risk. In aligning with Paasifica's aims, the capital risk of an option carries the highest weighting. However, environmental and operating risks cannot be neglected. All associated risks will need to be managed properly, but these can be offset in advance by selecting a low risk energy generation choice. This criterion is scored from 1 – 5, where 1 is the least risk, and 5 is the most risk.
	Capital	5	
	Operating	4	
Difficulty	Maturity	5	Another important part in selecting a technology option is its associated difficulty. Immature technologies come with many variables and unknowns, and it can be difficult to predict how much of a challenge they will be to manage. Due to the current small size of the company, it aligns with their aims to choose a proven technology with less installation and operating hassles. This criterion is scored from 1 – 5, where 1 is least difficult and 5 is the most difficult.
	Installation	4	
	Operating	3	

4.2.2. Feasibility analysis

Once the relevant technology options were evaluated from the criterion, a detailed feasibility analysis was conducted for the best choice. It was decided to focus on Solar PV alone as an energy generation technology, in order to include an evaluation of all alternative options, 2 variations of this technology were also investigated, as well as an alternative grid option:

- Solar PV
- Solar PV + energy storage
- Alternative grid electricity tariff

Research into the current state of energy storage options in Australia indicated that the only commercially viable option for large scale storage was lithium ion batteries.

An analysis was done for each technology, which was broken down into 3 key segments:

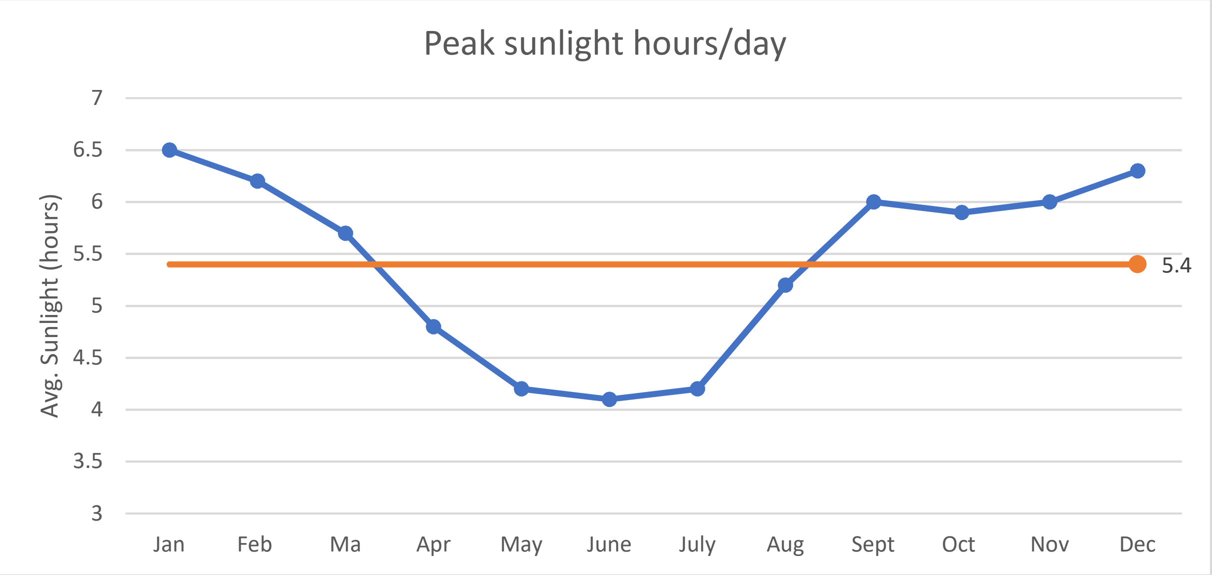
- Basic design
- Cost analysis
- Emissions and environmental impact

This analysis created a basis from which options could be compared at a much more detailed level, and the results of this section ultimately lead to the final conclusions and recommendations for this report.

4.2.3. Average peak sunlight hours – Brisbane

Data regarding the peak sunlight hours over a year in Brisbane was gathered from the Australian Solar Energy Society in 2006 and displayed in figure 10 below:

Figure 10: Average peak sunlight hours for Brisbane



This data is crucial to the rest of the thesis since it provides the basis for most solar PV calculations. Based of the plot Brisbane receives 5.4 hours of sunlight per day on average across a year.

4.2.4. Solar PV – basic design

To cover all bases, solar PV arrays ranging in size from 100kW to 300kW were compared to find the most viable combination. Since the supercomputer will only ever draw 123.58kW, any excess power that is generated throughout the day will be sold back to the grid using a commercial solar feed in tariff. This segment dealt with potential design decisions that would be encountered if the technology was built. Focus was placed on the following properties of the design:

4.2.4.1. Product choice

It was important to choose the best/most applicable solar PV products. For solar PV alone, the three main components that were examined were:

- Panel choice
- Tracking options
- Inverters

After considerable research into the topic, it was decided that the following products would be used for the basic design of the solar PV array:

4.2.4.2. Panel choice

LG NeON R (LG370Q1C)

The following table provides all required information about the selected module including electrical and mechanical properties, cost and warranty:

Table 9: LG Neon R module information

Electrical properties	
Maximum power Pmax (W)	370
MMP Voltage Vmmp (V)	37.0
MMP Current Immp (A)	10.01
Open circuit Voltage Voc (V)	42.8
Short circuit current Isc (A)	10.82

Module efficiency (%)	21.4
Mechanical properties	
Cells	6 x 10
Cell type	Monocrystalline N-type
Cell dimensions	161.7 x 161.7mm
Module dimensions	1700 x 1016 x 40mm
Weight	17.5kg
Cost and Warranty	
Cost $/W	1.10
Product warranty	25 Years
Output warranty of Pmax	Linear warranty: • 98% after first year • After 2nd year: 0.3%annual degradation • 90.8% after 25 years

The modules I-V curve can be found in appendix II. All data was sourced from LG, 2019.

4.2.4.3. Solar tracking

Table 10 demonstrates the main differences between the different tracking options:

Table 10: Solar tracking comparison table

	FAT	SAT	DAT
Estimated avg. increase in produced kWh/year (Brisbane):	NA	21%	25%
Avg. peak hours per day (Brisbane):	5.4	6.534	6.75
Estimated cost increase multiplier	1	1.57	2
O&M Costs ($/kW/year)	25	30	39

(Values sourced from: Solarchoice, 2010., Peterson, 2018.)

- **Single axis tracker – NEXTracker NX Horizon**

Table 11: NEXTracker NX Horizon system information

Property:	Value:
Tracking range:	120° (± 60°) horizontal
Drive system:	Slew gear, 24VDC motor and self-powered controller
Power consumption	No grid connection necessary – self powered
Typical dimensions:	1.4m x 2m x 85m
Solar tracking method:	Astronomical GPS based algorithm
Cost:	$0.14US/W ~ $0.2AUS/W ($200/kW)
Installation method:	Pre-manufactured components
Scheduled maintenance:	Annually
Warranty:	10 years on structural components; 5 years on drive and control systems

(All values retrieved from NEXTracker, 2019.)

- **Dual axis tracker – DEGERtraker 5000HD**

Table 12: DEGERtraker 5000HD DAT system information

Property:	Value:
Tracking range:	300° East to West 20° to 90° rotating angle elevation
Module surface area:	40m^2 (8.3m x 5.3m)
Drive system	East West: Gear in drive head Elevation: 1,100mm stroke
Power consumption:	Control mode – 1W Drive mode – approx. 15W
Yearly internal energy consumption:	Approx. 8kWh
Cost:	~$0.45/W ($454/kW)
Warranty:	Per request

(All values retrieved from DEGER ENERGIE, 2019.)

4.2.4.4. Inverter

Fronius Eco 25.0-3-S

Table 13: Fronius Eco 25kW Inverter system information

Property:	Value:
DC input voltage range:	580 – 1000V
Usable MPP voltage range:	580 – 850V
Max PV generator power input (Pmax)	37.8kWp
AC nominal output:	25kW
AC voltage range:	150 – 275V
Dimensions:	725 x 510 x 225mm – 35.7kg
Max efficiency PV to grid	98.2%
Protection devices:	Overload power limitation, DC disconnector, integrated string fuse holder.
Cost:	$240.56/kW (Ecoelectric, 2019)
Warranty:	Per request

(All values retrieved from Fronius, 2019.)

4.2.4.5. Capacity factors (CF)

An important measurement in calculating the power output of renewable technologies is the capacity factor of a system. The U.S. Nuclear Regulatory Commission defines capacity factor as “the ratio of the net electricity generated, for the time considered, to the energy that could have been generated at continuous full-power operation during the same period” (U.S.NRC, 2019). It is a good metric to calculate the actual performance of a proposed renewable system.

Typically, capacity factors are calculated once a system has already been installed. However, it is possible to estimate the capacity factor for a solar PV array by considering a number of variables:

- Peak sun hours per day – since the output of a solar PV system is directly related to the number of sun-hours it receives daily, the theoretical maximum capacity factor can be calculated using the following formula:

$$CF = \frac{Actual\ output}{Theoretical\ output} = \frac{Avg.\ peak\ sun\ hours/day * S}{24\ hours * S}$$
$$= \frac{Avg.\ peak\ sun\ hours/day}{24\ hours}$$

    - Where S = system size

- Efficiency loss over time – constant exposure to sunlight eventually causes degradation of the cells. The actual value varies from panel to panel with the annual degradation value for the LG Neon R being 0.3%/year. From this, it can be calculated that after the 10-year lifespan of the supercomputer project, any panel given module should still be operating at 97% capacity.
- Inverter efficiency – 98.2% (Fronius, 2019).
- Using the avg. peak sun hours/day for Brisbane values from figure 10, the total calculated capacity factor is then:

$$CF = \frac{Avg.\ peak\ sun\ hours/day}{24\ hours} * 0.97 * 0.982 \qquad \text{Equation 1}$$

4.2.4.6. System sizes and grid offset amounts

Six different solar PV system sizes were compared to find the most viable option: 100kW, 123.58kW, 150kW, 200kW, 250kW, and 300kW. For each power level FAT, SAT, and DAT were all considered. The actual output (kWh) of each variation was calculated as follows:

$$CF = \frac{Actual\ output}{Theoretical\ output}$$

$$Actual\ output = CF * Theoretical\ output = CF * S * 24$$ Equation 2

Since the supercomputer only requires 123.58kW at any one time, the solar arrays can only offset a set amount of grid electricity each day without the use of energy storage.

4.2.4.7. Land usage

Using the physical size of each solar module (1700 x 1016 x 40mm), and the following assumptions, the required areas were found.

Assumptions:

- 2.5m will be left between FAT and SAT panel rows to allow easy access for small vehicles (e.g. golf buggies). This will ensure that cleaning can be completed quickly and easily.
- FAT and SAT arrays will consist of multiple rows 1 panel wide, orientated vertically (see appendix III). There will be an upper limit of 100 modules per row.
- The DAT system has a maximum module surface of 8.3m x 5.3m (40m^2) and can rotate 360 degrees. Therefore, a minimum of 1.5m should be left between tracking arrays at their closest point.

4.2.5. Solar PV + Storage – Basic design

Calculations for the Solar PV + lithium ion batteries cases were completed for four theoretical setups: Full, ¾, ½, and ¼ offset of grid power. It was decided that a SAT array system would be used to offset daytime energy expenditure as well as charge the batteries. The following properties of the design were considered important for consideration:

4.2.5.1. Product choice

The panel modules, tracking apparatus, and inverters were decided upon in the Solar PV section. Therefore, after careful consideration of available options it was decided to use Tesla Powerpacks for the purpose of this feasibility analysis.

Table 14 outlines the various properties of the Tesla Powerpack:

Table 14: Tesla Powerpack information

Property:	**Value:**
Energy Capacity	210kWh (AC) per Powerpack
AC Voltage	380 – 480V, 3 Phase
Power	50kW (AC) per Powerpack
Discharge Depth	100%
System Efficiency	89% round trip
Dimensions:	
Powerpack	1308 x 822 x 2185mm – 1622kg
Inverter	1014 x 1254 x 2192mm – 1200kg
Cost	$107500/unit (Inc. installation)
Warranty	10 years or 60% SOC – 4000 cycles

(All values sourced from Tesla, 2019)

4.2.5.2. System size and grid power offset

In order to calculate the required solar PV array size and required battery storage, a number of assumptions first had to be made:

- A SAT solar PV array will be used to offset daytime grid usage of the supercomputer.
- Excess generated power will be used to charge the battery packs.
- Once the array is no longer producing the required power, the batteries will kick in and provide power until they are depleted.
- The solar PV and batteries will need to subsidize **2965.98kWh** per day and be able to provide at least **123.58kW** of power.
- The SAT solar PV array alone can only offset a maximum of **769kWh** per day – the remaining **2196.98kWh** will be provided either by batteries or the grid.
- Assume that lithium ion batteries degrade at a rate of approximately 3% per year (Cadex, 2008)

4.2.5.3. Land usage

The same assumptions made for solar PV alone are also applicable here. However, the additional area required for the battery packs was calculated from their specified dimensions:

- Powerpack - 1308 x 822 x 2185mm
- Inverter - 1014 x 1254 x 2192mm

4.2.6. Cost analysis

A detailed cost analysis is one of the most important aspects of any feasibility analysis. Without insights into capital, installation, and operation and maintenance (O&M) costs, it would be difficult to give any viable conclusions or recommendations. Particular care was taken to ensure that estimated costs accurately matched real-life examples. When comparing technology options from, the most important values considered were:

- Total capital cost
- Net present value (NPV)
- Effective $/kWh price (Levelized cost of energy – LCOE)
- Payback period (PBP)

Due to the differing nature of the technology options, each cost analysis required a different set of values and assumptions. However, they shared the same key analysis techniques:

4.2.6.1. Net present value (NPV)

This analysis method is commonly used in capital budgeting and is defined as the difference between the present value of cash inflows and the present value of cash outflows over a period of time (Kenton, 2019). It is calculated using the following formula:

$$NPV = \sum_{t=1}^{n} \frac{R_t}{(1+i)^t} \qquad \text{Equation 3}$$

Where:

- R_t = net cash inflows-outflows during a single period t
- i = discount rate, or return that could be earned in an alternative investment
- t = number of time periods

Typically, if the NPV value is positive then it constitutes an attractive investment, the larger the NPV, the better the opportunity.

4.2.6.2. Levelized cost of energy (LCOE)

Another important analysis technique, the LCOE is similar to NPV in that calculates the present value of the total cost of building and operating a power generation plant over a set lifetime (U.S. Department of Energy, 2015). A simplified LCOE calculation can be found using the following formula:

$$LCOE = \frac{\sum_{t=1}^{n} \frac{I_t + M_t + F_t}{(1+i)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+i)^t}}$$ Equation 4

Where:

- I_t = total investment expenditures in year t
- M_t = total O&M expenditure in year t
- F_t = fuel expenditure in year t
- E_t = total electricity generation in year t
- i = discount rate
- n = life of the system

The LCOE is measured in terms of $/kWh and allows for the comparison of several different technologies at once, so it was well suited to the current project. A lower LCOE indicates cheaper electricity generation.

4.2.6.3. Payback period

The payback period is the amount of time required for cash inflows generated by a project to offset its initial capital investments and cash outflow (AccountingTools, 2018). It is typically calculated with the following formula:

$$PBP = \frac{Cost\ of\ the\ investment}{Annual\ net\ cash\ flow}$$ Equation 5

PBP is an important tool when considering the viability of different technology options within a set project lifespan. Shorter payback periods indicate a more attractive investment.

4.2.6.4. Solar PV – Properties and assumptions

The following table shows all properties and values that are required to complete the solar PV cost analysis:

Table 15: Solar PV properties and assumptions table

Property:	Cost:	Source:
Module costs:	$1100/kW	(LG, 2019)
Land preparation and installation:	~$1000/kW	(Peacock, 2019)
Inverters:	$240.56/kW	(Ecoelectric, 2019)
Base total cost (inc. GST)	**$2574.616**	**-**
SAT tracker:	$200/kW	(NEXTracker, 2019)
Base SAT cost (inc. GST)	**$2794.616/kW**	-
DAT tracker:	$454.06/kW	(DEGERENERGIE, 2019)
Base DAT cost (inc. GST)	**$3074.0776/kW**	-
US total overnight cost estimates (2018) – no tracking:	$2576.28/kW AUD	(U.S. Energy Information Administration, 2019)
US total overnight cost estimates (2018) – SAT tracking:	$2845.04/kW AUD	(U.S. Energy Information Administration, 2019)
Base electricity price:	$0.35/kWh	-
Solar feed in tariff:	$0.09369/kWh	(Ergon, 2019)
Discount rate:	7%	(Infrastructure Australia, 2016)

Additionally, the following assumptions are required to conduct the NPV, LCOE, and PBP analysis:

- Any electricity that would have otherwise been bought from the grid is considered a positive cash flow.
- It is assumed that the current price of Ethereum in May 2019 will remain relatively constant over the 10-year lifespan of the project.
- Over the 10-year lifespan, any electricity generated through solar PV will firstly be used to offset the grid power use of the supercomputer. After the completion of the project, all power generated will be fed into the grid at the feed in tariff rate as per Ergon energy in 2018.

- 10-year lifespan for the project, 25-year lifespan for the solar PV array.
- All capital expenses will be spent within the first year of the project, and it is assumed that it will take approximately 6 months before the supercomputer begins mining.

4.2.6.5. Solar PV + Storage – properties and assumptions

All values from table 15 above are also applicable for the Solar PV + Storage calculations.

The following table shows all additional properties and values that are required to complete the solar PV + storage cost analysis:

Table 16: Solar PV + Battery storage properties table

Property	Cost:	**Source:**
SAT solar PV	**$2794.616/kW**	Table 15
Tesla Powerpack	~$107500/unit	(Tesla, 2019)

Additionally, the following assumptions are required to conduct the NPV, LCOE, and PBP analysis:

- Any electricity that would have otherwise been bought from the grid is considered a positive cash flow.
- It is assumed that the current price of Ethereum in May 2019 will remain relatively constant over the 10-year lifespan of the project.
- When possible, generated solar energy will power the supercomputer first, then any excess power will be used to charge the battery packs.
- After the 10-year lifespan of the project, all electricity generated will be sold back to the grid at the fixed feed in tariff of $0.09/kWh as per Ergon Energy 2018.
- 10-year lifespan for batteries and supercomputer, 25-year lifespan for solar PV.
- All capital expenses will be spent within the first year of the project, and it is assumed that it will take approximately 6 months before the supercomputer begins mining.

4.2.7. Alternative grid tariffs

As it stands, the supercomputer’s predicted power draw of 123.58kW classifies Paasifica as a large business in terms of energy usage. After research into the topic, it was discovered that many energy providers offer discounted electricity prices, and a range of tariffs to large power consumers. By switching energy provider and selecting a more effective commercial energy tariff, the company stands to make significant savings from grid electricity. However, it proved difficult to find the actual values that the various energy provider was offering. Many providers required a full evaluation of the business in order to give an accurate quote.

Despite this, careful consideration was taken to find the most viable alternative grid tariff. In the case of this project, Ergon Energy's large business demand tariff – Tariff 45, was chosen.

In order to accurately calculate costs, a number of figures and assumptions needed to be established:

- The system size is **123.58kW** and draws an average of **2965.98kWh** per day.
- The system has a lifespan of 10 years, after which time the project will be re-evaluated.

Table 17 shows the potential costs of switching to Ergons tariff 45:

Table 17: Ergon energy tariff 45 costs

From 1 July 2018	COST/KW	COST/KWH	COST/DAY
Demand charge	$29.572		
All usage		$0.16082	
Supply charge			$167.58756

(Demand threshold: 120kW. Sourced from Ergon Energy, 2018)

The demand charge relates to the total power requirement of the system in terms of $/kW and is charged quarterly. There is a minimum demand threshold of 120kW, which is satisfied by the 123.58kW system. This tariff has a constant usage cost which is charged quarterly on the total electricity drawn (kWh) within that period. It also includes a standard cost per day charge, regardless of how much electricity is used.

4.2.8. Emissions analysis

The total emissions analysis was conducted the same way for all three options. Emissions are typically categorized into 2 main scopes:

- Scope 1 – Direct emissions e.g. combustion engines, and;
- Scope 2 – Indirect emissions, generally from fossil fuel energy generation

Despite there being a number of prominent greenhouse gases, emissions are put into units of equivalent tonnes of CO_2 (CO2e) for easy comparison between sources. According to the *National Greenhouse Accounts Factors* by the Australian Government in 2017, scope 2 emissions are calculated using the following formula:

$$Y = Q * \frac{EF}{1000} \qquad \text{Equation 6}$$

Where:

- Y = emissions in $tonnes\ CO_2e$
- Q = quantity grid electricity purchased in kWh
- EF = state dependant emissions factor in kgCO2e/kWh

The full table of state emissions factors can be found in Appendix IV.

The following table outlines the properties necessary to conduct the emissions analysis for all 3 options:

Table 18: Manufacturing embodied energy for solar PV and lithium ion batteries

Property	Value:	Source
QLD Emissions Factor	0.79	(Aus. GOV., 2017)
Monocrystalline silicon PV cell embodied energy:	4200kWh per kW manufactured	(Reddaway, 2016)
Lithium-ion embodied energy:	457kWh per kW manufactured	(Reddaway, 2016)

As the embodied energy/kW values in table XX include allowances for transport and framing; it was assumed that the embodied energy associated with the tracking structures alone is negligible. Therefore, FAT, SAT, and DAT will all have the approximately the same embodied energy.

The different Y values of each technology option were compared to evaluate the most sustainable technologies.

4.2.8.1. Energy payback period

This value, typically expressed in years, is the amount of operational time it takes a renewable energy source to offset its embodied energy. It is calculated using the following formula:

$$Energy\ payback\ period = \frac{Embodied\ energy\ (kWh)}{Grid\ electricity\ offset\ (kWh)/year} \qquad \text{Equation 7}$$

Despite that fact that FAT, SAT, and DAT have approximately the same embodied energy values, they offset different amounts of grid electricity per day. Therefore, they will have varying payback periods.

5.0. Results

5.1. Evaluation criterion

The following page contains the completed evaluation criterion including the final scores and rankings of all considered energy generation technologies:

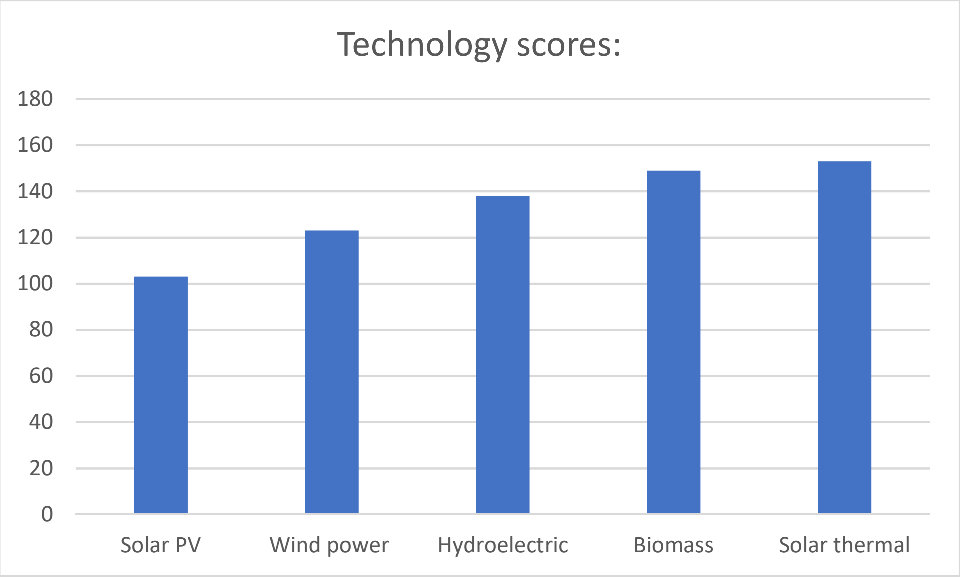
Table 19: Completed evaluation criterion

	Cost			Pollution			Risk			Difficulty				
	Capital	Operating	Maintenance	Emissions	Aesthetic	Noise	Environmental	Capital	Operating	Maturity	Installation	Operating	Dispatchability	
Weighting factor:	5	3	3	4	1	3	3	5	4	5	4	3	5	
Technologies:														**Total:**
Solar PV	3	1	1	1	2	1	1	4	1	2	2	1	5	**103**
Wind power	2	1	2	1	4	4	2	4	2	2	3	1	5	**123**
Hydroelectric	5	3	3	1	3	1	4	5	3	1	5	2	1	**138**
Biomass	4	4	3	4	3	2	2	4	4	1	4	5	1	**149**
Solar thermal	4	3	3	1	3	1	2	5	3	5	4	2	3	**153**

Table 20: Evaluation matrix key

Cost	
Capital	1 – 5, where 5 is the most expensive
Operating	1 – 5, where 5 is the most expensive
Maintenance	1 – 5, where 5 is the most expensive
Pollution	
Emissions	1 – 5, where 5 is the most emissions
Aesthetic	1 – 5, where 5 is the least visually pleasing
Noise	1 – 5, where 5 is the noisiest
Risk	
Environmental	1 – 5, where 5 is largest risk
Capital	1 – 5, where 5 is largest risk
Operating	1 – 5, where 5 is largest risk
Difficulty	
Maturity	1 – 5, where 5 is least mature
Installation	1 – 5, where 5 is most difficult
Operating	1 – 5, where 5 is most difficult
Dispatchability	1 – 5, where 5 is least dispatchable

Figure 11: Evaluation criterion technology scores



The total score represents how applicable a given technology is to the Paasifica project, in this case a lower score is deemed more desirable. As can be seen in *table 19*, after all options were evaluated, the final ranking list of energy generation technologies is:

1. **Solar PV**
2. Wind power
3. Hydroelectric
4. Biomass
5. Solar thermal

It is clear from the evaluation criteria that solar PV is the best possible (non-grid) option given the parameters and scope of the report. Therefore, after careful consideration it was decided that the detailed feasibility analysis was to be conducted using variations of solar PV energy generation.

5.2. Feasibility analysis results

5.2.1. Solar PV

5.2.1.1. Basic design

Capacity factors

The capacity factors for each tracking method were calculated using equation 1, and values from table 10. These are outlined in table 21 as follows:

Table 21: Solar tracking capacity factors

	FAT	SAT	DAT
Capacity Factor	0.2143	0.2593	0.2679

It can be seen that a single axis tracker will produce approximately 21.0% more power than a fixed axis tilt array, and a dual axis tracker will produce an estimated 25% more over a given time period.

System sizes and grid offset amount

Using *equation 2* and the capacity factor values from *table 21* above, the grid offset amounts and potential excess energy output were calculated and summarized in the following table:

Table 22: Solar PV system sizes and grid offset amounts

Tracker:	**FAT**		**SAT**		**DAT**	
System Size:	Grid offset amount (kWh)	Excess energy generation (kWh)	Grid offset amount (kWh)	Excess energy generation (kWh)	Grid offset amount (kWh)	Excess energy generation (kWh)
100	523.9	0.0	622.3	0.0	643.0	0.0
123.58	635.6	0.0	769.1	0.0	794.6	0.0
150	635.6	135.9	769.1	164.4	794.6	169.9
200	635.6	393.0	769.1	475.6	794.6	491.4
250	635.6	650.2	769.1	786.7	794.6	812.8
300	635.6	907.4	769.1	1097.9	794.6	1134.3

The proposed supercomputer will only draw a maximum of 123.58kW at any one time. Therefore, solar PV regardless of system size is only able to offset grid electricity during peak sunlight hours and has a maximum offset amount per day. This value can be improved by increasing the peak hours of sunlight received by tracking the sun throughout the day.

The maximum amount of grid offset for the FAT array is 635.6kWh/day, while the SAT and DAT systems had maximum grid offsets of 769.1kWh and 794.6kWh/day. This represents a 21% and 25% respective increase in daily productivity using tracking options. This percentage increase also applies to the excess energy generated, which will be sold back to the grid at a fixed price. This will be covered in further detail in the cost analysis section.

Land usage

Using the assumptions made in the methodology, the following table was calculated:

Table 23: Solar PV land use calculations

Tracker:			**FAT**	**SAT**		**DAT**	
System Size (kw):	Required modules	Module area (m^2)	Total array size (m^2)	Number of trackers:	Total array size (m^2)	Number of trackers:	Total array size (m^2)
100	271	468.1	1026.16	3	1026.16	12	717.03
123.58	334	576.9	1452.88	4	1452.88	15	906.75
150	406	701.2	1879.60	5	1879.60	18	1096.47
200	541	934.4	2306.32	6	2306.32	24	1475.91
250	676	1167.6	2733.04	7	2733.04	30	1855.35
300	811	1400.8	3586.48	9	3586.48	36	2234.79

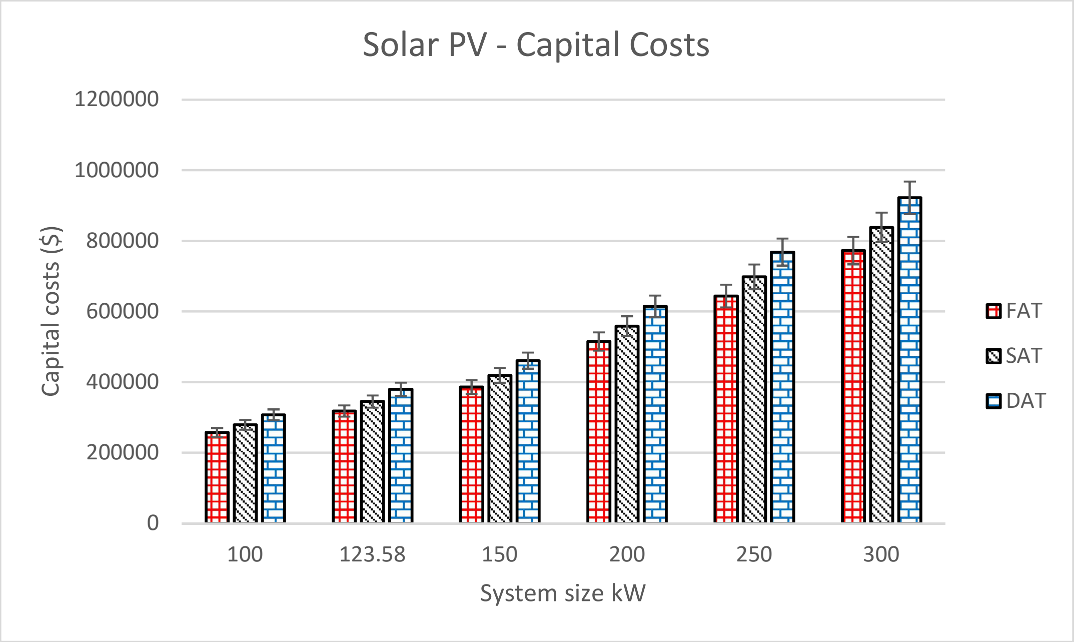
For each system size the table shows: the required number of LG panels, their total area, and the total array size. Note that the FAT and SAT arrays have the same array size, while the DAT array requires less total array size. This is due to the 360 degrees nature of the DAT systems.

5.2.1.2. Cost analysis

Capital costs

Capital is a simple way to compare technology options. The total capital expenditure amounts were found using the estimated overnight costs in $/kW for FAT, SAT and DAT systems. Figure 12 provides an overview of the total required capital expenses for every option:

Figure 12: Solar PV - Capital Costs



There is a clear upward sloping trend to the data. Capital costs vary from approximately $260,000 for a 100kW FAT system, to over $920,000 for a 300kW DAT array.

Net present value (NPV)

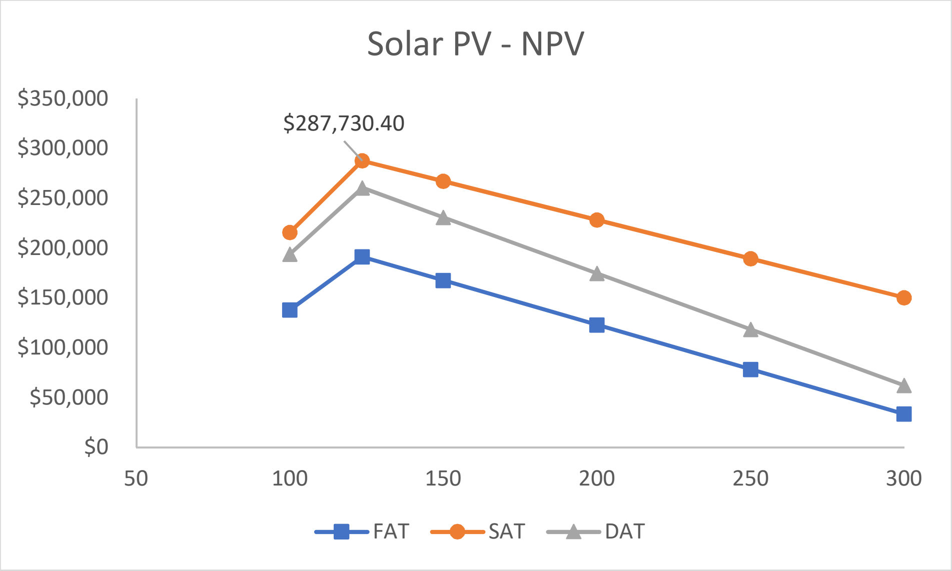
The following is a summary table of NPV values for all system sizes and tracking options:

Table 24: Solar PV - NPV summary

System size (kW)	FAT	SAT	DAT
100	$138,165.74	$216,057.01	$194,105.55
123.58	$191,472.37	**$287,730.40**	$260,602.78
150	$167,853.66	$267,189.15	$230,917.24
200	$123,155.11	$228,314.70	$174,737.17
250	$78,456.57	$189,440.26	$118,557.10
300	$33,758.02	$150,565.82	$62,377.03

The following plot outlines the same data but showcases the comparison of tracking options over a range of system sizes:

Figure 13: Solar PV - NPV values

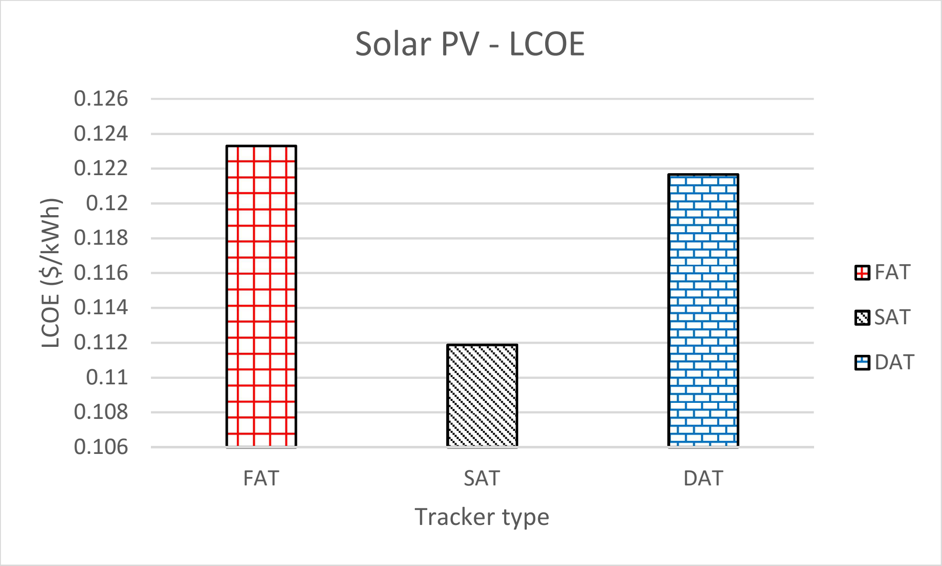


It is clear from the data that SAT arrays dominate the other tracking options in terms of NPV value, with consistently higher values for the same system sizes. Additionally, the 123.58kW system size provides the best NPV value across all tracking options. The downward slope of the NPV values after this point indicate that purchasing a larger system size than required is not financially sound.

Levelized cost of energy

Figure 14 provides a comparison of LCOE values for the different tracking options:

Figure 14: Solar PV - LCOE values



Single axis tracking provides a considerably lower $/kWh value than either the FAT or DAT arrays. This once again reinforces that SAT is the most financially viable tracking option. It should be noted that system size has no effect on LCOE value.

Payback period

The payback periods for the various tracking and system size options are outlined in table XX. These values range from less than 3 years for a 100kW FAT system, up to almost 8 years for the 300kW DAT array.

Table 25: Solar PV - payback period summary

System size (kW)	FAT	SAT	DAT
100	2.99	3.71	4.60
123.58	**2.85**	3.56	4.42
150	3.26	4.08	5.08
200	3.91	4.92	6.14
250	4.45	5.61	7.02
300	4.90	6.19	7.76

The fastest payback period is the 123.58kW FAT system at 2.85 years.

5.2.1.3. Emissions analysis

The following table summarizes the findings of the emissions analysis:

Table 26: Solar PV - emissions analysis summary

System size (kW):	100	123.58	150	200	250	300
Embodied energy (MWh):	420	519.036	630	840	1050	1260
Tonnes CO2e	331.8	410.03844	497.7	663.6	829.5	995.4

Due to the linear nature of the embodied energy equation, the total emissions value increases for each increment in system size. A 100kW system uses approximately 420MWh of electricity to manufacture, emitting 331.8 tonnes of CO2e.

Energy payback period

Table 27 provides the energy payback periods for the various system sizes and tracking options.

Table 27: Energy payback period

System Size:	100	123.58	150	200	250	300
FAT	2.24	2.24	2.72	3.62	4.53	5.43
SAT	1.85	1.85	2.24	2.99	3.74	4.49
DAT	1.79	1.79	2.17	2.90	3.62	4.34

As can be seen, the DAT system generally has lower payback periods. However, they are closely followed by the SAT system. There is then a slightly wider gap between payback periods for the FAT array.

5.2.2. Solar PV + Storage

5.2.2.1. Basic design

System size and power offset

The following table was calculated using equation 2 and values from table 22 - solar PV system sizes, table 21 - capacity factor table, and table 14 - powerpack properties. It outlines the comparison of the various offset amounts:

Table 28: Solar PV + Storage system size and power offset

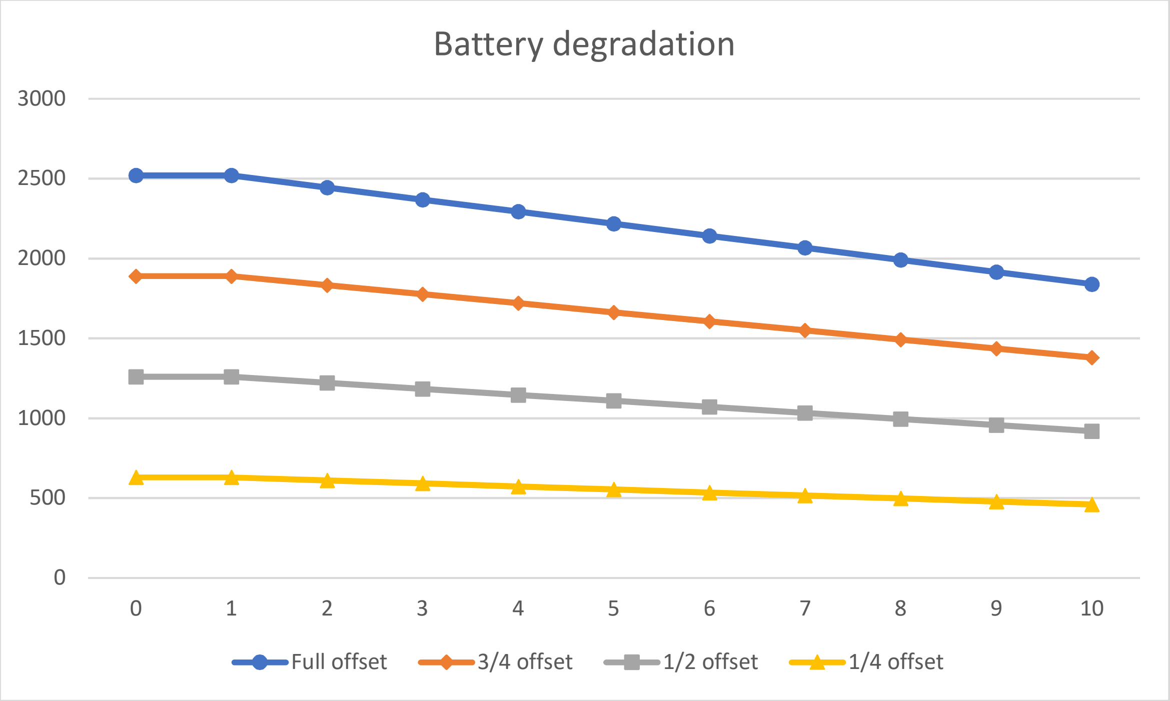
	Required battery size (kWh)	**Powerpacks required**	**Solar PV array (kW)**	**Total energy generation (kWh)**	**Total grid offset per day (kWh)**
Full offset	2520	12	528.5	3289.1	2966.0
¾ offset	1890	9	427.3	2659.1	2416.8
½ offset	1260	6	326.0	2029.1	1867.6
¼ offset	630	3	224.8	1399.1	1318.3

It is clear that the full offset of grid electricity requires a large amount of battery storage, and an equally large solar PV array to charge them. The ¼ offset option is more forgiving in terms of battery and solar array size, but still requires a significant amount of both.

Lifespan and battery degradation

Figure 15 shows the theoretical maximum capacity of each battery system over the 10-year lifespan of the project.

Figure 15: Battery degradation



As can be seen, the inevitable degradation of lithium-ion battery cells can have serious impacts on the system's capacity, with a drop of approximately 70% over 10 years.

Land usage

The following table 15 compares the physical land requirements for each other offset amounts:

Table 29: Solar PV + Storage land usage summary

System Sizes	Full offset	3/4 offset	1/2 Offset	1/4 Offset
Required modules	1429	1155	882	608
Module area (m^2)	2468.2	1994.9	1523.4	1050.1
Number of trackers	15	12	9	7
Solar array size (m^2)	6146.80	4866.64	3586.48	2733.04
Battery size (m^2)	14.17	10.95	7.72	4.50
Total system size (m^2)	**6160.97**	**4877.59**	**3594.20**	**2737.54**

The space taken up by the Powerpacks is relatively small compared to the total size of the required solar PV arrays. The full grid offset option has the largest physical footprint and is expected to take up 6161m^2 or approximately 1.52 acres. This is roughly 72% bigger than the largest solar PV without storage array.

5.2.2.2. Cost analysis

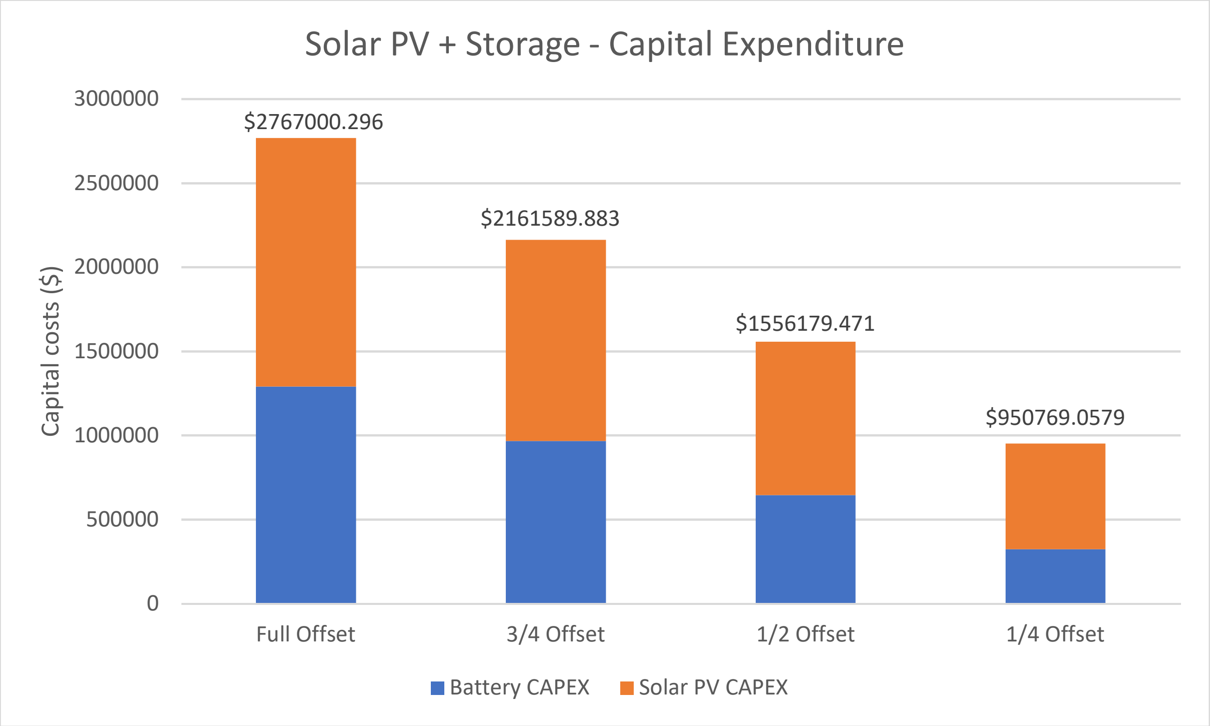
Similar to the cost analysis completed for solar PV alone. The properties and assumptions outlined in the methodology and the following models were utilized to evaluate the financial feasibility of the 4 grid offset options:

- Total capital costs
- Net present value (NPV)
- Levelized cost of energy – LCOE – effective $/kWh
- Payback period

Capital costs

Figure 17 compares 4 offset options in terms of total capital expenditure. This is assumed to be an 'overnight' model, which estimates the total cost if the project was completed instantly:

Figure 16: Solar PV + Storage capital expenditure

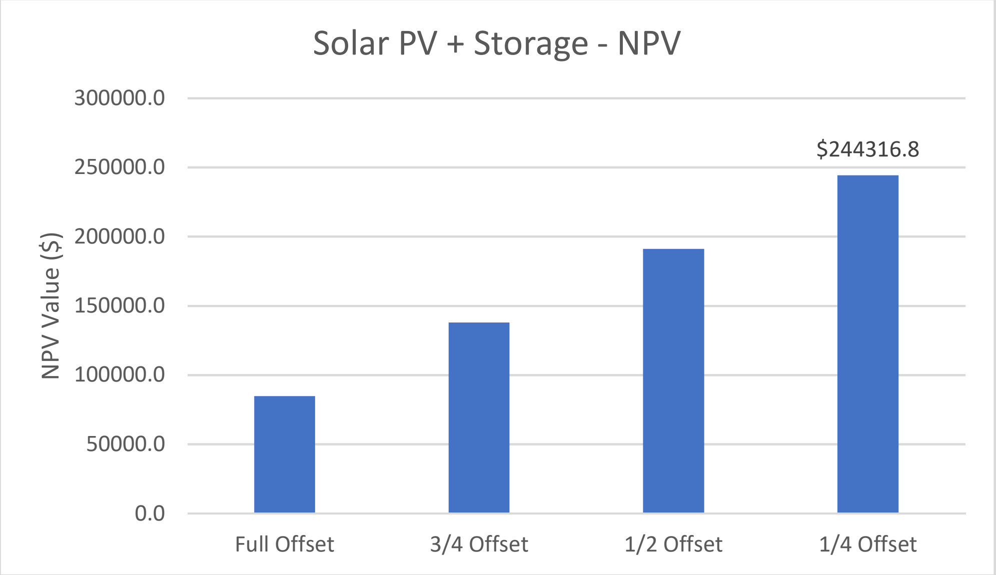


For the first two offset options, the capital costs are split roughly equally 50-50 battery and solar PV expenses. However, as less grid electricity is offset the split begins to be more heavily weighted towards total solar costs.

Net present value (NPV)

Figure 18 showcases the predicted NPV for each offset option:

Figure 17: Solar PV + Storage NPV

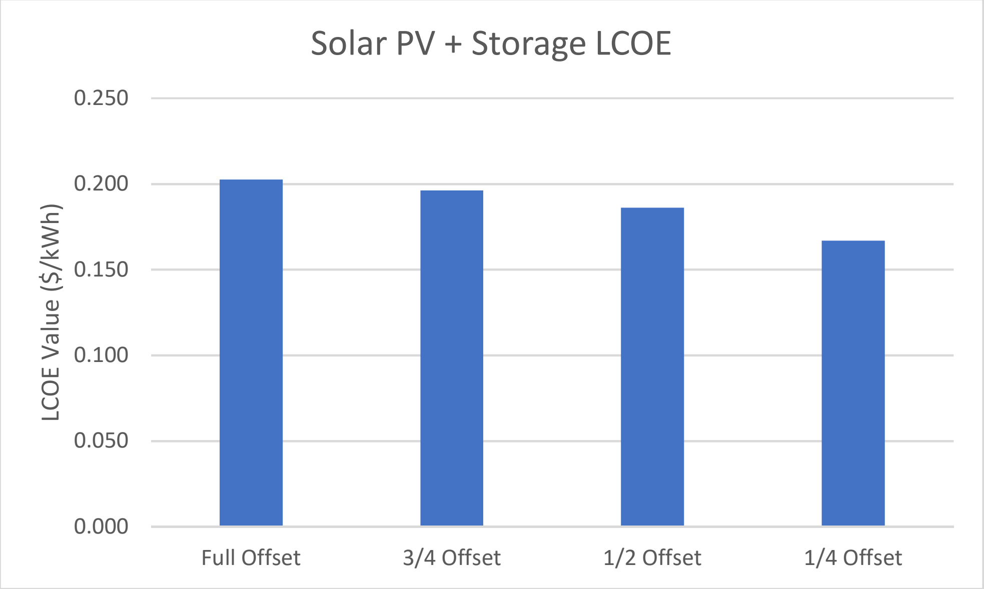


As can be seen, all 4 options have positive NPV values which indicate they are all financially viable options. There is a linear trend relating grid offset amount to the NPV value, inversely proportional to the total capital costs. The best selection is the ¼ offset with an approximate NPV value of $244,000.

Levelized cost of energy (LCOE)

Figure 19 presents the LCOE for each offset option:

Figure 18: Solar PV + Storage LCOE value



All four offset selections offer competitive $/kWh values, all of which are significantly cheaper than the current electricity cost of $0.35/kWh. However, once again the best selection is to offset ¼ of total grid electricity.

Payback period

The follow table compares the estimated payback periods for the four options:

Table 30: Solar PV + Storage payback period

	Full Offset	3/4 Offset	1/2 Offset	1/4 Offset
PBP:	8.0	7.8	7.3	6.5

The entire capital cost of the ¼ offset selection will be pay for itself in savings is approximately 6.5 years – 1.5 years earlier than full offset. Thus, further solidifying its position as the most financially viable option.

5.2.2.3. Emissions analysis

Using the properties and assumptions in *table 18* - method emissions analysis table, the embodied energy of each offset amount, and the associated scope 2 emissions used in manufacturing (in tonnes CO2e) were calculated:

Table 31: Solar PV + Storage embodied energy and emissions

	Full Offset	3/4 Offset	1/2 Offset	1/4 Offset
Battery size (kW)	2520	1890	1260	630
Battery embodied energy (MWh):	48.0	36.0	24.0	12.0
Batteries tonnes CO2e	37.9	28.4	19.0	9.5
Solar PV array (kW):	528.5	427.3	326.0	224.8
Solar PV embodied energy (MWh):	2219.8	1794.6	1369.4	944.2
Solar PV tonnes CO2e:	1753.6	1417.7	1081.8	745.9
Total tonnes CO2e	**1791.5**	**1446.2**	**1100.8**	**755.4**

The most environmentally sustainable choice is the ¼ grid offset option.

Energy payback period

Table 32 outlines the estimated time in years before the embodied energy of each option is ‘paid back’ by offsetting grid electricity usage.

Table 32: Solar PV + Storage energy payback period summary

	Full Offset	3/4 Offset	1/2 Offset	1/4 Offset
Tonnes CO2e offset each year	855.26	696.88	538.51	380.13
Energy payback period (years):	2.09	2.08	2.04	1.99

The ¼ offset selection will payback its carbon debt in under 2 years, essentially making it carbon negative for the remainder of the project lifespan.

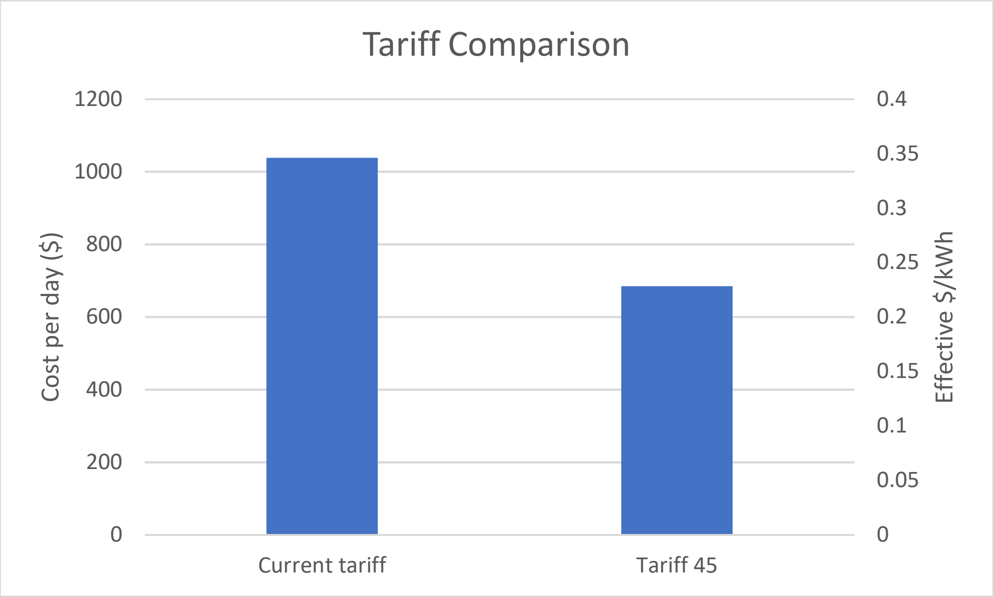
5.2.3. Alternative grid tariffs

Using the assumptions and properties outlined in the method, the costs and emissions of using an alternative grid tariff were calculated.

5.2.3.1. Cost analysis

The following figure details the comparison of the current tariff with the proposed tariff 45, the cost per day is on left most axis, and the effective $/kWh figure on the right:

Figure 19: Tariff comparison



It can be seen in figure 20 that the switching to tariff 45 would reduce the $/kWh daily figure from $0.35/kWh, to $0.231/kWh. It is estimated that this change would save Paasifica approximately $353 per day, or roughly $130,000 per year.

5.2.3.2. Emissions analysis

Since there are no renewable technologies offsetting scope 2 emissions in this option, the total emissions are directly related to the electricity consumption over the life of the project:

- Daily energy use – 2965.98kWh
- Yearly use – 1082.571MWh
- Lifetime use – 10.825GWh

The total tonnes CO2e emitted by the project, with EF value of 0.79, are then:

$$Y = Q * \frac{EF}{1000}$$

$$Y = 10.825 * 10^6 kWh * \frac{0.79}{1000} = \boldsymbol{8552.4\ tonnes\ CO2e}$$

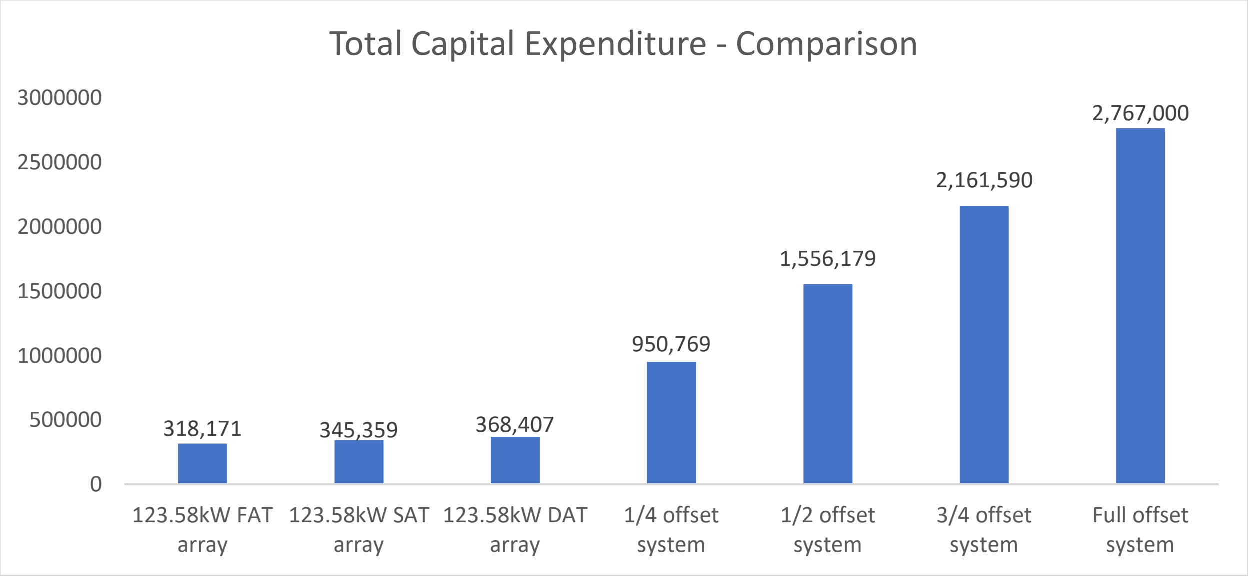
There is no energy payback period.

5.3. Comparison of results

5.3.1. Capital expenditure

Figure XX demonstrates the difference in capital expenditure between the options.

Figure 20: Capital expenditure comparison plot

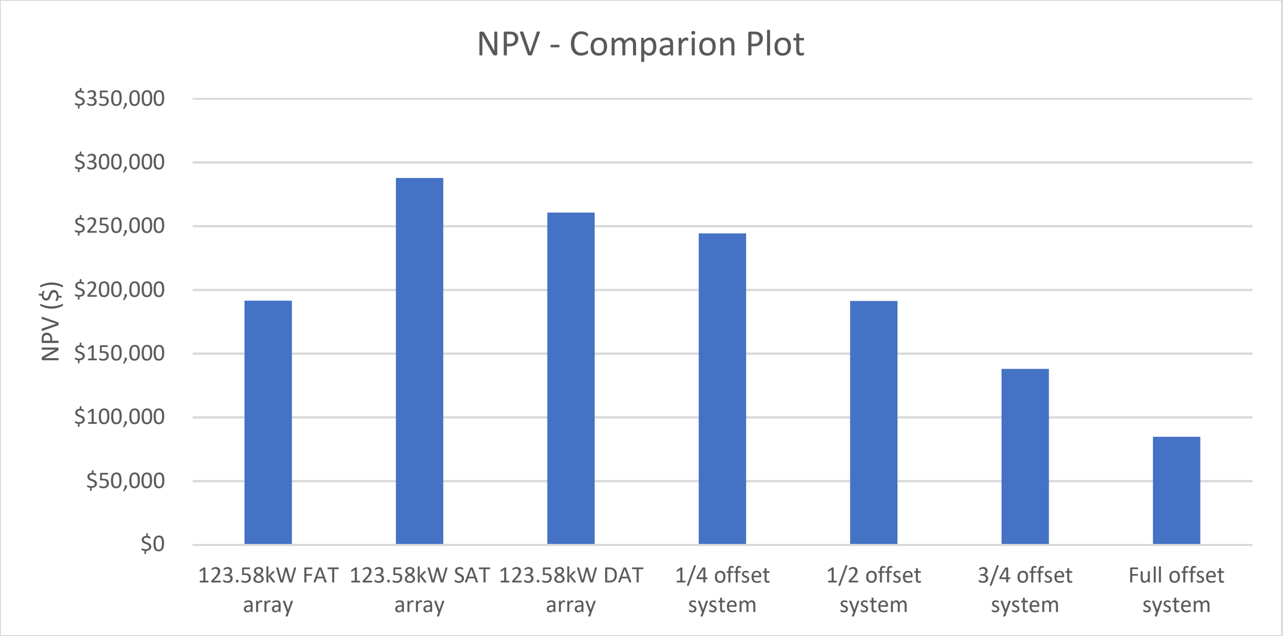


As can be seen above, the comparison of total capital expenditure within the options paints a stark comparison between Solar PV with and without storage. A 123.58kW SAT solar array carries an estimated capital cost of around $216,000, while for the ¼ offset system this value is approximately $950,000. In this instance the capital costs of implementing a full offset system are almost 9 times that of a 123.58kW FAT array.

5.3.2. Net present value (NPV)

By combining the NPV plots for solar PV alone and solar PV with storage in figure 22, it is possible to determine the financial feasibility of each option.

Figure 21: NPV comparison plot

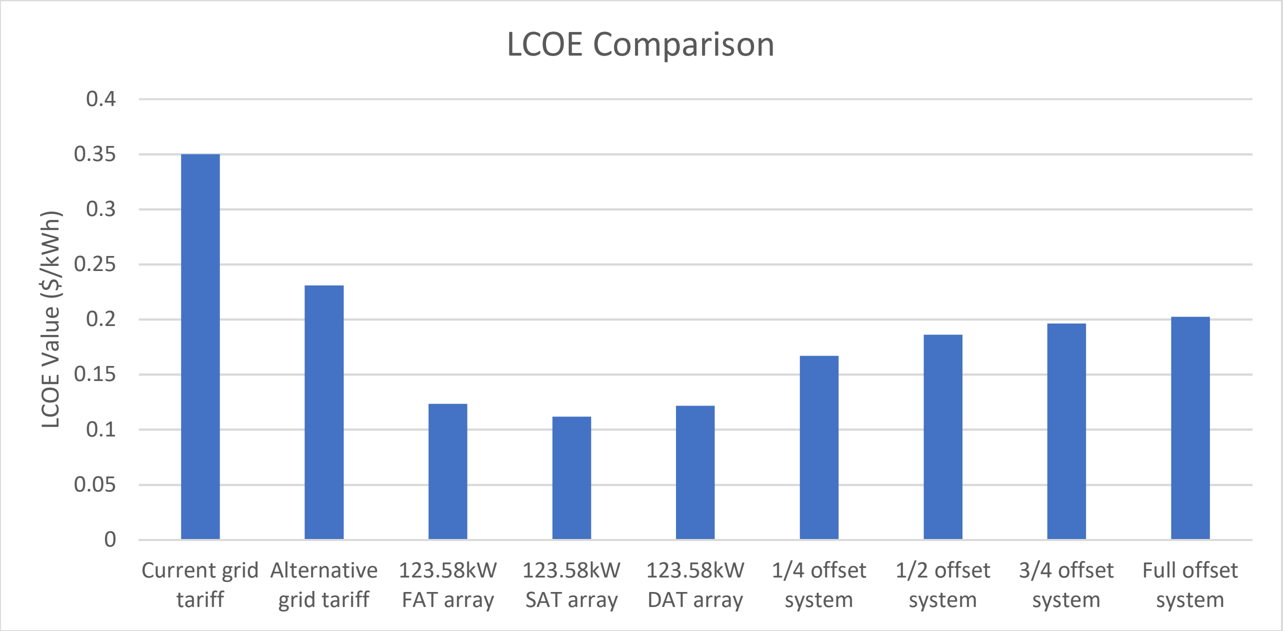


In this instance where a larger NPV value is desirable, the 123.58kW SAT array has the largest score with $287,730. This is then followed by the 123.58kW DAT array, and the ¼ offset system options with scores of $260,602 and $244,316 respectively. The full system offset achieved the lowest NPV value at $84,669.

5.3.3. Levelized cost of electricity (LCOE)

In a similar fashion to the NPV comparison, the LCOE comparison will demonstrate the effective $/kWh values of each option, including the current grid tariff and proposed alternative.

Figure 22: LCOE Comparison plot

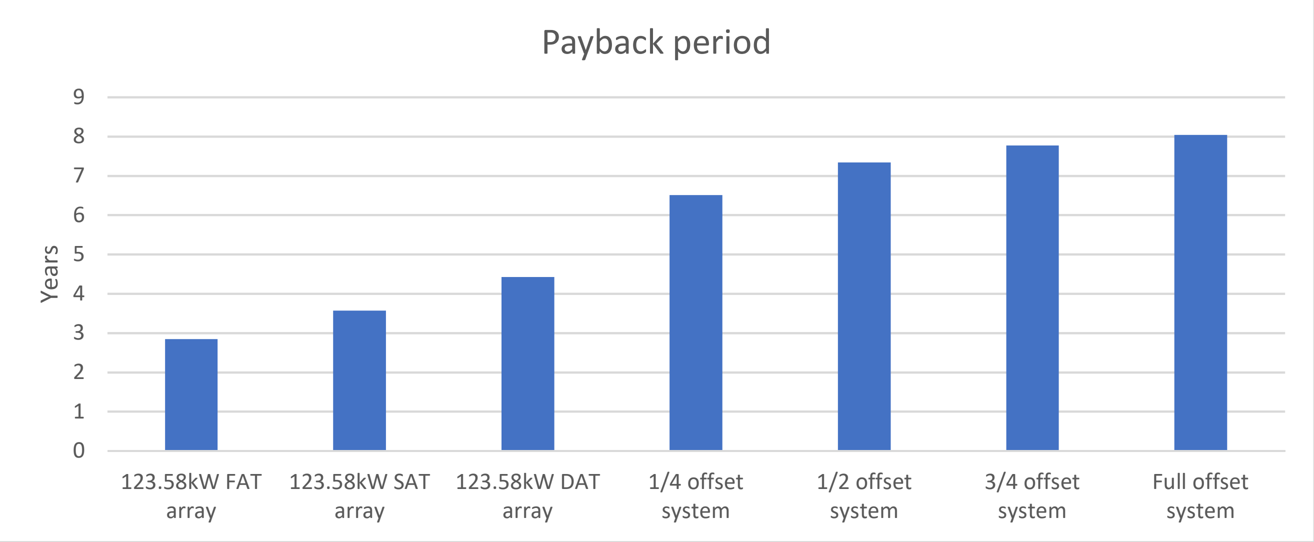


It can be seen in figure 23 that the 123.58kW SAT array achieves the lowest LCOE value at $0.112/kWh. This is over 3 times less than the current grid tariff of $0.35/kWh. All 3 solar array options with no storage have lower LCOE values than even the lowest offset system.

5.3.4. Payback period

Figure 23 demonstrates the difference in payback periods for the energy generation options:

Figure 23: Payback period comparison plot

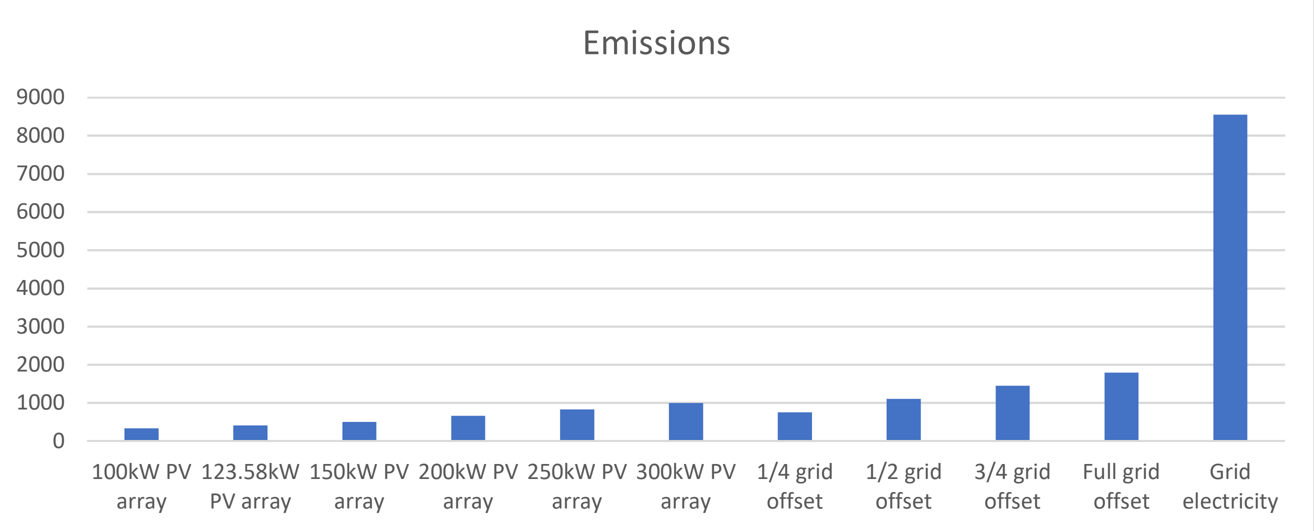


The payback period is linked to the capital expenditure, so the addition of battery storage greatly increases the time required to pay it back. The lowest payback window is the 123.58kW FAT system at 2.8 years, while the longest is the full offset system at 8 years.

5.3.5. Emissions comparison

Figure 24 demonstrates the different emission values in tonnes CO2e for the various generation options:

Figure 24: Emissions comparison



5.4. Summary

In terms of financial feasibility best technology option is the 123.58kW SAT array with no storage. It achieved:

- The second lowest total capital expenses - $345358.6
- The highest NPV of all options - $287,730.4
- The lowest LCOE value of all options - $0.112/kWh
- The second lowest payback period – 2.85 years
- A total emissions value of 410 tonnes CO2e
- An energy payback period of 1.85 years

6.0. Discussion

Evaluation criterion

Versatile method to test the viability of a technology within a pre-determined scope and with specific guidelines. Tailoring the criterion to meet the specific requirements of this project made it an ideal tool to narrow down energy generation options. Additionally, the results of the completed matrix are clear and concise, there is no ambiguity in the outcome.

One of the major weaknesses of the selection criterion model is that there are several opportunities for bias to alter the outcome. The weighting factors and attributed scores do not have rigidly defined numerical metrics supporting them, so it is possible for personal opinion to influence an options score. Efforts were taken to avoid these issues by reviewing a large range of literature for each category and technology option before attributing scores.

Another weakness of the model is it difficult to narrow down a complex system to just one number and expect that value to accurately represent it. For instance, reducing the capital risk for a hydroelectric plant down to a value between 1 and 5 without specific knowledge about the system.

In the future, a more rigorous set of metrics based off of analytical analysis into each category should be used to more accurately quantify an options score. However, such a complex criterion is out of scope for this thesis.

The results of the evaluation criterion are relatively unsurprising. Despite being slightly more expensive than wind power, the modular nature and widespread availability of solar PV make it the clear-cut choice for renewable energy generation in South East Queensland. The biggest drawback to wind power for this project is that there are very few places on the eastern seaboard that satisfy the minimum consistent wind speeds required to sustain a wind farm. The viable locations for wind power are even further reduced by the fact that the supercomputer will require a high speed NBN internet connection to operate. After researching the topics and contacting engineers working within the biomass and hydroelectric energy generation industries, it was that found that the other 3 technology options were not viable at the 123.58kW scale required.

Solar PV

One of the main limitations of the solar PV basic design is that the capacity factor calculations – and hence total system design – use values that were found from external sources rather than direct experimental data. Despite the fact that these values come from a reputable source and are specific to the Brisbane region, this potentially reduces the accuracy of calculated values across the report. This limitation could be addressed by gathering actual data and capacity factors from the UQ Gatton campus experimental solar PV arrays. Notwithstanding this potential issue, the calculated capacity factors for the FAT, SAT, and DAT systems are actually reflected quite accurately in the literature surrounding solar tracking. Additionally, the percentage yield increases found from the implementation of single and dual axis tracking closely match the expected increase found in the literature.

Land usage is not imperative to the outcomes of this thesis, since the property requirements for the supercomputer are out of scope. However, it is a convenient way to visualize the comparison between array options as well as what number of components each array will require.

Cost analysis

For the most part, the capital cost calculations for the varying solar PV arrays and battery system combinations can be considered quite accurate since they are based off the costs of genuine commercially available products. The calculated base total cost for a fixed array was \$2574.6AUD/kW in this analysis, while the U.S. Energy information administration estimates a value of \$2576.28AUD/kW. Despite this, the land preparation and installations costs are highly site specific and can vary substantially. The only way to have a perfectly accurate value is the have a professional quote completed.

The NPV and LCOE analysis' for both solar PV and solar PV + Storage used a discount rate of 7% as per the Infrastructure Australia recommendation. This was assumed to be constant over the 10-year lifespan of the project and batteries, as well as the additional 15 years the solar panels will be active for.

One of the major downsides to the NPV financial model is that it involves estimating future cash flows, which is especially difficulty for an experimental start-up such as Paasifica. Additionally, it is very poor at comparing projects that have a large variation in capital requirements.

It is clear from the solar PV – NPV tracker comparison plot that any system size larger than the required 123.58kW results in a downwards trend in NPV values. This is likely due to the fact that the supercomputer will only ever draw 123.58kW from the array. Without storage this excess must be sold back to the grid at a low price, which doesn't offset the additional capital requirements. This indicates that currently it is not financially viable to purchase more solar PV than necessary.

The levelized cost of energy analysis is one of the most widely used financial tools for evaluating electricity generation options. It is especially good at comparing options of various sizes, costs, and lifespans which is typically where the NPV analysis falls short.

The LCOE calculations rely on capital expenditure and O&M costs. Since the capital and O&M costs associated with increasing system size are linear within each tracking range, increasing the size of the solar array from 100kW to 300kW etc. doesn't alter the LCOE value.

For the case of solar PV, the SAT array achieve an LCOE of $0.112/kW, which is slightly above the average cost for this size range. This slight price discrepancy is likely due to panel and tracking choices. The LCOE value can be reduced by either increasing the discount rate or spreading the total investment expenditures over the lifetime of the product with a capital loan.

Solar PV + Batteries

As was seen in the Solar PV + Batteries NPV chart, there is a linear trend relating grid offset amount to the NPV value which is inversely proportional to the total capital costs. The reason for this is likely the short 10-year lifespan of the project and batteries. Full grid offset has a payback period of 8 years, there is simply too much capital expenditure and not enough time to recover it. However, if the lifespan of both the supercomputer and the batteries were increased to say 15 – 20 years, then the full offset option would easily be the best overall option.

Emissions

A shortcoming of the embodied energy and effective emissions calculations is assuming that the addition of tracking equipment doesn't add to the embodied energy of an array. Each DAT weighs approximately 950kg, and is mostly made of aluminium, which has a particularly energy intensive manufacturing process. However, this assumption is appropriate since emissions values have less influence over the final decisions than other design factors.

7.0. Conclusions

- All options examined in this report are financially viable and will provide a lower effective $/kWh value than the current grid tariff. However, some options make more financial sense than others.
- As demonstrated in both the NPV and LCOE charts, and with low embodied energy and payback periods, the 123.58kW single axis tracker solar PV array is clearly the best choice for solar.
- In terms of offsetting grid electricity using battery storage, the ¼ grid offset approach is the most viable. Compared to the other battery options, it has the highest NPV value, lowest LCOE, shortest payback period, and lowest embodied energy.
- However, as was seen in the comparison tables the ¼ grid offset option is still not as financially viable as the 123.58kW SAT array by itself.
- Over the short 10-year lifespan of the project, the savings gained from offsetting more grid electricity do not make up for the large additional capital costs associated with implementing battery storage.
- Simply switching to another grid tariff can potentially save Paasifica hundreds of dollars per day.
- All examined options in this study, regardless of their embodied energy, are significantly more sustainable than simply using grid electricity.

8.0. Recommendations

1. The first recommendation is to examine all grid tariff options available and select one that is most applicable to Paasificas requirements.
2. The second recommendation is to contact a reputable solar provider and get a full evaluation and quote for a 123.59kW single axis tracker solar array using the following components if possible:
    - LG – Neon R 370W modules
    - NEXTracker NX Horizon - self powered single axis tracker
    - Fronius Eco 25.0-3-S 25kW inverter
    - The total expected capital costs for the 123.58kW system are expected to be roughly $345,400
    - Or approximately $2795 per kW, including GST and estimated installation costs
3. If energy storage is required, then it is recommended to purchase 3 Tesla Powerpacks, and 224.81kW of SAT solar. This will offset approximately ¼ of daily grid electricity usage for a capital investment of around $950,000.

9.0. Bibliography

AccountingTools. (2018, March 17). *How to calculate the payback period*. Retrieved from Accounting Tools: https://www.accountingtools.com/articles/how-to-calculate-the-payback-period.html

Alternative Energy. (n.d.). *Renewable Energy*. Retrieved from Alternative Energy: http://www.altenergy.org/renewables/renewables.html

Australian Government. (2013). *Bioenergy industry in Australia*. Retrieved from Biomass Producer: http://biomassproducer.com.au/about/about-the-industry/#.W9GcMUszaUl

Australian Government. (2014, June 13). *Release of updated Australian Energy Resource Assessment*. Retrieved from Australian Government Geoscience Australia: http://www.ga.gov.au/news-events/news/latest-news/release-of-updated-australian-energy-resource-assessment

Australian Government. (2017). *National greenhouse accounts factors.* Canberra: July.

Australian PV Institiute. (2018, September 30). *Australian PV market since April 2001*. Retrieved from Australian PV Institiute: http://pv-map.apvi.org.au/analyses

BitInfroCharts. (2018, October 24). *Ethereum (ETH) price stats and information*. Retrieved from BitInforCharts: https://bitinfocharts.com/ethereum/

Buterin, V. (2013). *White Paper.* Retrieved from Github: https://github.com/ethereum/wiki/wiki/White-Paper

Byrd, J. (2018, July 18). *ABC*. Retrieved from Chart of the day: Something has gone terribly wrong with electricity prices: https://www.abc.net.au/news/2018-07-18/electricity-price-rises-chart-of-the-day/9985300

Cadex. (2019, February 8). *BU-808: How to Prolong Lithium-based Batteries*. Retrieved from Battery University: https://batteryuniversity.com/learn/article/how_to_prolong_lithium_based_batteries

Chaum, D. (1983). *Blind Signatures for Untraceable Payments.* Springer, Boston, MA: Advances in Cryptology.

Clarke, D. (2018, September 14). *Wind farms in Queensland: a page of Wind in the Bush*. Retrieved from Ramblingsdc: http://ramblingsdc.net/Australia/WindQld.html

Clean Energy Council. (2018). *Clean Energy Australia 2018 Report.* Clean Energy Council.

Clean Energy Council. (2018). *HYDRO*. Retrieved from Clean Energy Council: https://www.cleanenergycouncil.org.au/resources/technologies/hydroelectricity

Clean Energy Council. (2018). *WIND*. Retrieved from Clean Energy Council: https://www.cleanenergycouncil.org.au/resources/technologies/wind

Coindesk. (2016). *Understanding Ethereum.* Retrieved from Github: https://github.com/armdev/bitcoin-blockchain-ethereum-/blob/master/CoinDesk%20Understanding%20Ethereum%20Report.pdf

CoinLore. (2018, October 24). *CoinLore*. Retrieved from List of All Cryptocurrencies: https://www.coinlore.com/all_coins

Cunningham, D. (2017, March 27). *Difficulty*. Retrieved from Coinchoose: https://www.coinchoose.com/mining/difficulty/

DEGER ENERGIE. (n.d.). *DEGERtraker 5000HD DATA SHEET*. Retrieved from Garsol: http://www.garsol.com/pdf/DEG_DB_EN_5000HD_3000HD_AS.pdf

Drake, N. (2018, August 23). *The best mining pools of 2018 for cryptocurrency*. Retrieved from Techradar: https://www.techradar.com/au/news/the-best-mining-pools-of-2018

Energy Storage Association. (2019). *Flywheels*. Retrieved from Energy Storage Association: http://energystorage.org/energy-storage/technologies/flywheels

Ergon Energy. (2018, July 1). *Large business tariffs*. Retrieved from Ergon: https://www.ergon.com.au/retail/business/tariffs-and-prices/large-business-tariffs

Etherscan. (2018, October 24). *Ether Historical Prices (USD)*. Retrieved from Etherscan: https://etherscan.io/chart/etherprice

Frankel, M. (2018, March 16). *The Motley Fool*. Retrieved from How Many Cryptocurrencies Are There?: https://www.fool.com/investing/2018/03/16/how-many-cryptocurrencies-are-there.aspx

Fronius. (2019). *FRONIUS ECO*. Retrieved from Fronius: https://www.fronius.com/th-th/thailand/photovoltaics/products/commercial/inverters/fronius-eco/fronius-eco-25-0-3-s

Geoscience Australia. (2014, June 14). *Release of updated Australian Energy Resource Assessment*. Retrieved from Geoscience Australia: http://www.ga.gov.au/news-events/news/latest-news/release-of-updated-australian-energy-resource-assessment

Investopedia. (2018). *Block Header (Cryptocurrency)*. Retrieved from Investopedia: https://www.investopedia.com/terms/b/block-header-cryptocurrency.asp

Kenton, W. (2019, April 24). *Net Present Value (NPV)*. Retrieved from Investopedia: https://www.investopedia.com/terms/n/npv.asp

LG. (2019). *LG Neon R*. Retrieved from LG: https://www.lgenergy.com.au/uploads/download_files/c368443778f812ed588ab828f94d48665c29a89f.pdf

Marr, B. (2018, Febuary 2). *Blockchain: A Very Short History Of Ethereum Everyone Should Read*. Retrieved from Forbes: https://www.forbes.com/sites/bernardmarr/2018/02/02/blockchain-a-very-short-history-of-ethereum-everyone-should-read/#27197ce61e89

Nakamoto, S. (2008, October 31). *Bitcoin: A Peer-to-Peer Electronic Cash System.* Retrieved from bitcoin.org: https://bitcoin.org/bitcoin.pdf

Narayanan, A. B. (2016). *Bitcoin and Cryptocurrency technologies.* Princeton: Princeton University Press.

National Geographic. (2019). *Biomass energy*. Retrieved from National Geographic: https://www.nationalgeographic.org/encyclopedia/biomass-energy/

Origin. (2018, August 14). *What is hydropower?* Retrieved from Origin: https://www.originenergy.com.au/blog/about-energy/what-is-hydropower.html

Peacock, F. (2019, May 13). *SOLAR FOR YOUR BUSINESS '101': A BEGINNER'S GUIDE*. Retrieved from Solarquotes: https://www.solarquotes.com.au/commercial-solar-guide.html

Petersen, H. (2018, March 3). *Are solar axis trackers worth the additional investment?* Retrieved from SolarReviews: https://www.solarreviews.com/blog/are-solar-axis-trackers-worth-the-additional-investment

Reddaway, A. (2016, May 19). *Energy flows: How green is my solar?* Retrieved from renew.: https://renew.org.au/renew-magazine/solar-batteries/energy-flows-how-green-is-my-solar/

Renewable Energy World. (n.d.). *Hydrogen Energy*. Retrieved from Renewable Energy World: https://www.renewableenergyworld.com/hydrogen/tech.html

Solar choice. (2010, January 21). *Solar trackers*. Retrieved from Solar Choice: https://www.solarchoice.net.au/blog/solar-trackers/

Stapleton, J. N. (2013). *Photovoltaic systems*. Retrieved from Yourhome: http://www.yourhome.gov.au/sites/prod.yourhome.gov.au/files/pdf/YOURHOME-Energy-PhotovoltaicSystems.pdf

Stauffer, N. (2015, December 14). *The Future of Solar Energy: A summary and recommendations for policymakers*. Retrieved from MIT Energy Initiative: http://energy.mit.edu/news/the-future-of-solar-energy-a-summary-and-recommendations-for-policymakers/

Tar, A. (2018, January 17). *Proof-of-Work, Explained*. Retrieved from CoinTelegraph: https://cointelegraph.com/explained/proof-of-work-explained

Tesla. (2019). *Powerpack*. Retrieved from Tesla: https://www.tesla.com/en_AU/powerpack

the green age. (2016). *Flywheel Energy Storage*. Retrieved from the green age: https://www.thegreenage.co.uk/tech/flywheel-energy-storage/

U.S. Department of Energy. (2015, September). *Levelized Cost of Energy (LCOE)*. Retrieved from https://www.energy.gov/sites/prod/files/2015/08/f25/LCOE.pdf

U.S. Energy Information Administration. (2019, January). *Cost and Performance Characteristics of New Generating Technologies,*. Retrieved from U.S. Energy

Information Administration: https://www.eia.gov/outlooks/aeo/assumptions/pdf/table_8.2.pdf

U.S. NRC. (2019, March 21). *Capacity factor (net)*. Retrieved from U.S. NRC: https://www.nrc.gov/reading-rm/basic-ref/glossary/capacity-factor-net.html

Vorrath, S. (2018, February 16). *Home battery storage uptake tripled in 2017 in Australia, as costs tumble*. Retrieved from Renew Economy: https://reneweconomy.com.au/home-battery-storage-uptake-tripled-in-2017-in-australia-as-costs-tumble-79283/

Wise, J. (2006, November 1). *The Truth About Hydrogen*. Retrieved from Popular Mechanics: https://www.popularmechanics.com/science/energy/a926/4199381/

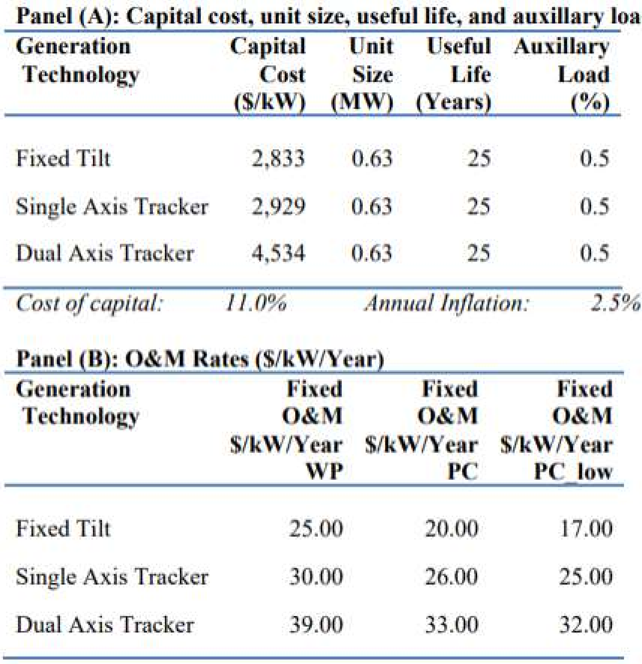
Wood, D. G. (2014). *Gavwood.* Retrieved from ETHEREUM: A SECURE DECENTRALISED GENERALISED TRANSACTION LEDGER: https://gavwood.com/paper.pdf

World Nuclear Association. (2018, October). *Australia's Uranium*. Retrieved from World Nuclear Association: http://world-nuclear.org/information-library/country-profiles/countries-a-f/australia.aspx

10.0. Appendix

Appendix I:

Sourced from https://gci.uq.edu.au/filething/get/12443/APSRC-PAPER-gsrf-lcoe.pdf



Panel (A): Capital cost, unit size, useful life, and auxillary load assumptions

Generation Technology	Capital Cost ($/kW)	Unit Size (MW)	Useful Life (Years)	Auxillary Load (%)
Fixed Tilt	2,833	0.63	25	0.5
Single Axis Tracker	2,929	0.63	25	0.5
Dual Axis Tracker	4,534	0.63	25	0.5

Cost of capital: *11.0%* *Annual Inflation:* *2.5%*

Panel (B): O&M Rates ($/kW/Year)

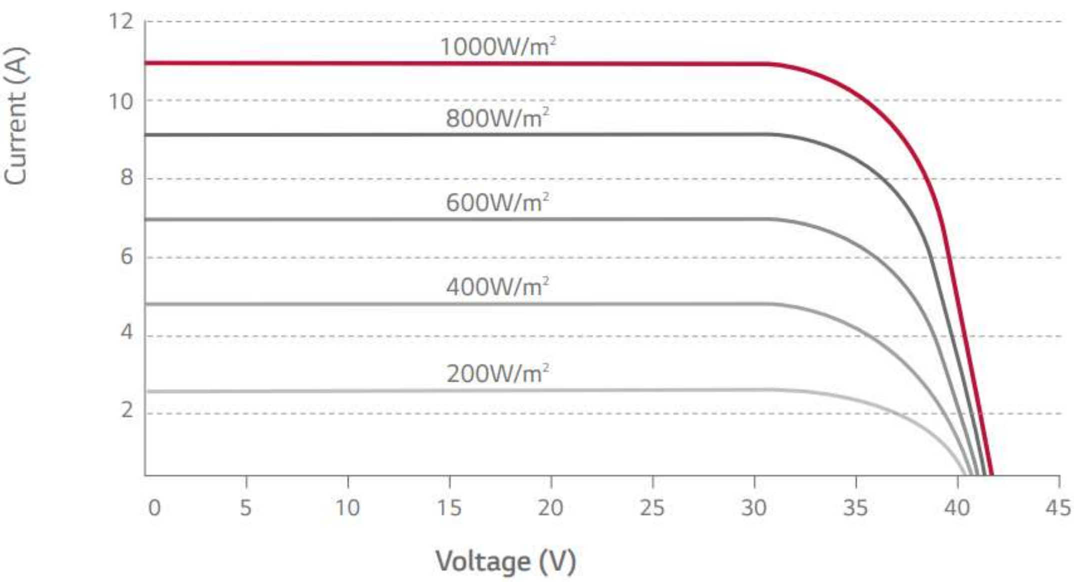
Generation Technology	Fixed O&M $/kW/Year WP	Fixed O&M $/kW/Year PC	Fixed O&M $/kW/Year PC_low
Fixed Tilt	25.00	20.00	17.00
Single Axis Tracker	30.00	26.00	25.00
Dual Axis Tracker	39.00	33.00	32.00

Appendix II:

Sourced from

https://www.lgenergy.com.au/uploads/download_files/c368443778f812ed588ab828f94d48665c29a89f.pdf

Current – Voltage characteristics at various irradiance levels



Appendix III:

Sourced from: https://www.uq.edu.au/solarenergy/pv-array/content/gatton-solar-research-facility

Appendix IV:

Sourced from: https://www.environment.gov.au/system/files/resources/5a169bfb-f417-4b00-9b70-6ba328ea8671/files/national-greenhouse-accounts-factors-july-2017.pdf

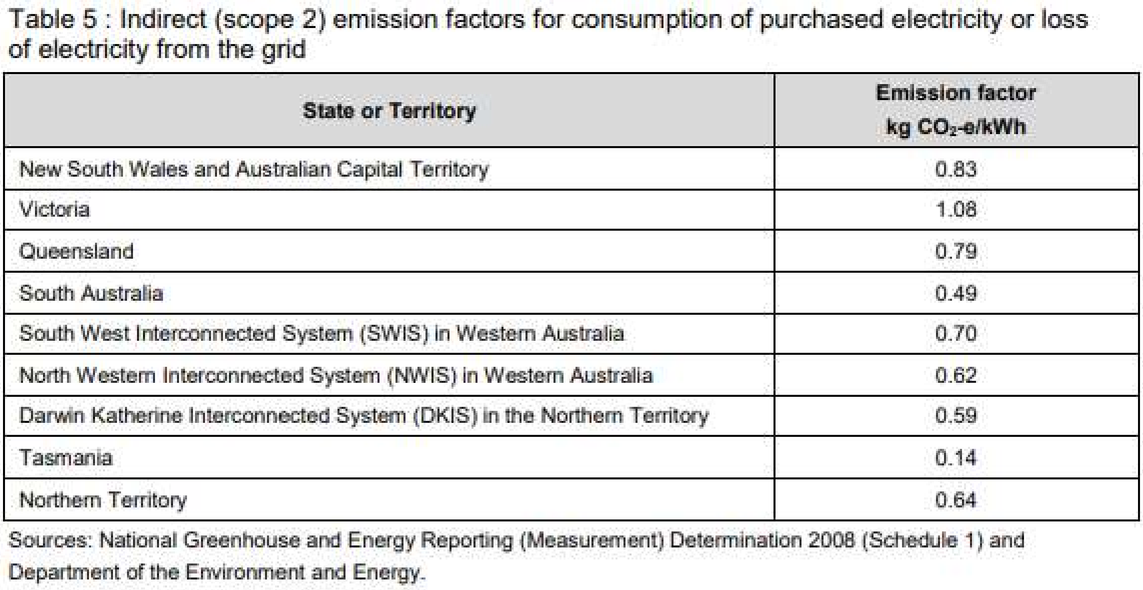


Table 5 : Indirect (scope 2) emission factors for consumption of purchased electricity or loss of electricity from the grid

State or Territory	**Emission factor kg CO_2-e/kWh**
New South Wales and Australian Capital Territory	0.83
Victoria	1.08
Queensland	0.79
South Australia	0.49
South West Interconnected System (SWIS) in Western Australia	0.70
North Western Interconnected System (NWIS) in Western Australia	0.62
Darwin Katherine Interconnected System (DKIS) in the Northern Territory	0.59
Tasmania	0.14
Northern Territory	0.64

Sources: National Greenhouse and Energy Reporting (Measurement) Determination 2008 (Schedule 1) and Department of the Environment and Energy.