INTEGRATING ALTERNATIVE ENERGY:

A FARM CASE STUDY AT EMERALD, QLD

JUNE 2019

JW POWELL & JM WELSH

CottonInfo

AgEcon
RESEARCH, DEVELOPMENT & EXTENSION SERVICES

Report Outline

Executive Summary

National environmental objectives have led to the development of government policies that create incentives for businesses to invest in renewable energy. Under these policies, increasingly affordable renewable energy and storage technology have aligned to deliver economic benefits to farmers, and co-benefits to the environment in on- and off-grid scenarios.

This analysis aims to determine the economic feasibility of renewable and innovative energy systems to help reduce grid electricity costs for irrigation pumps and small industrial applications. Using a case study approach, optimal engineering and economic assessment are applied on a farm characterised by energy in three different scales and usage patterns: sporadic large seasonal use, uniform industrial use, and small-scale industrial consumption.

The case study farm's electricity demand and pricing agreements were assessed and entered into the Hybrid Optimisation of Multiple Energy Resources (HOMER) design software to analyse a range of hypothetical microgrid installations. A major aspect of the study is the connectivity between government incentives, tariff uncertainty, and the electricity retailer's rules regarding feed-in tariffs and network connection criteria. While the challenge of aligning seasonal demand with renewable energy supply remains, the cost competitiveness of solar energy proves a realistic supplementary source for grid-connected agricultural loads where year-round use rates are high. Of each of the case study sites evaluated in this paper, the highest returning economic and environmental business case occurred where the modelled microgrid included photovoltaic (PV) and remained eligible for a feed-in tariff – enabling revenue creation out of season. Larger PV systems exceeding the export limit of 30 kW still showed a lower cost of energy than the grid, however, where a diesel genset was included to avoid peak tariffs, carbon emission abatement was negligible. Designing optimal engineering solutions to reduce on-farm energy costs is heavily dependent on awareness of current carbon and energy policy incentives, as well as the changing landscape of connection rules and feed-in tariffs.

1 Introduction

The case study was undertaken to consider the economic and environmental impact of installing microgrids to offset the energy use of surface water irrigation pumps and a small grain drying facility in the Fitzroy Valley of Queensland. The study aims to find solutions ultimately leading to lower energy costs and greater sustainability through carbon emissions abatement.

1.1 Irrigation energy demand – a cotton industry overview

Water is critical to the cotton industry to maximise crop yields and fibre quality. During the production cycle in most cotton-growing regions, crop water demand exceeds rainfall supply. Although rain-fed cotton crops are grown successfully in some areas, irrigation enables high-quality, high-yielding cotton to be grown in a wider range of regions. Data collected by the Australian Bureau of Statistics (2017) found that in 2015-16, of the 280,422 ha of cotton harvested, 211,298 ha (75 per cent) was irrigated. The average volume of water applied across the irrigated area was 6.8 ML/ha. Figure 1 shows the cotton-growing regions of Australia, which includes a placemark for Emerald, Queensland – the nearby location of the case study.

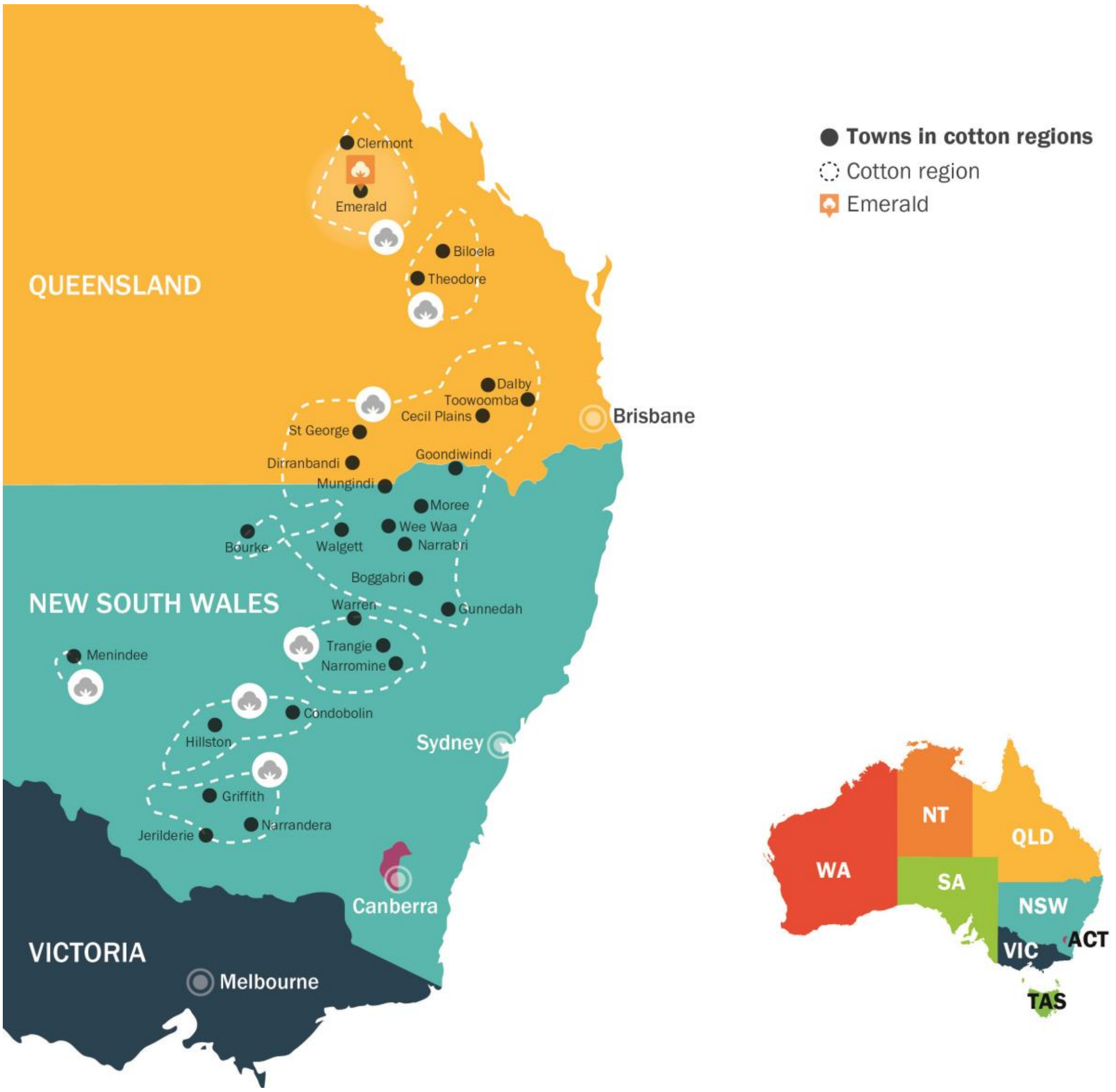

FIGURE 1: COTTON-GROWING REGIONS OF AUSTRALIA. THE CASE STUDY LOCATION: EMERALD, QUEENSLAND

Methods of transferring irrigation water to fields vary between gravity, scheme water, pumped groundwater, and deep wells pumping into storage. The further water is pumped, the more energy required to move it. For simplicity, assuming an average 30 m total pumping head and an efficient pump consumption of 4.55 kilowatt hour (kWh)/ML/m of electricity (Foley, 2015), the industry would use around 195,481 megawatts (MW) of power per annum – if all irrigation pumps were grid-connected. If the water is moved once at a cost of $0.27/kWh, the annual total energy spend is just over $52.8 million. Further, applying an emissions factor of 0.94 kg of CO_2e/kWh (Department of the Environment and Energy, 2016), then an estimated 183,752 tonnes of CO_2e would be generated from this practice annually. Therefore, adoption of industry-wide energy efficiency measures or capital installations aimed at improving water productivity have potential to make both economic and environmental gains.

The application of renewable energy in Australian irrigated agriculture at an industrial scale is relatively underexamined. A feasibility study into alternative energy sources for irrigated cotton production by Chen et al. (2013) found solar resources to be unsuitable for irrigation, but useful in offsetting domestic electricity consumption. The study also found wind resources were regarded as unreliable and expensive. Eyre et al. (2014) concluded that renewable energy infrastructure is not cost effective and unable to meet peak irrigation demands. Similar studies abroad concur with these findings: e.g. irrigated rice in Qinghai Province in China, by Campana et al. (2013); irrigated cotton, corn and wheat in the United States, by Vick and Clark (2009), Vick and Almas (2011), Vick and Neal (2012); and vineyard drip-irrigation in the Mediterranean area (Carroquino et al., 2015).

More-recent studies related to irrigated cotton (Powell and Welsh, 2016a, Powell and Welsh, 2016c) found that unless renewable energy generation closely matches the timings of irrigation energy demand, or the water can be pumped and stored in reservoirs, the economics become marginal at best. Use of surplus renewable energy generation was identified as a potential area for improving project economics when incorporating renewable sources into existing loads. However, recent advances in PV and pumping technology have reduced the capital cost of installation. These advances, in conjunction with substantial increases in power prices, feed-in tariff mandates, and storage capabilities becoming more affordable, have changed the economic feasibility considerably. Hybrid power systems with renewable energy can be reliable, economic, effective and more sustainable than either grid-connected or standalone generators using a single fossil fuel-based power source. This research aims to quantify investment feasibility, using HOMER optimisation software within the policy framework and connection rules identified in the next section.

2 Policy, network and retail considerations

Most Australian electricity demand is supplied by energy generated from fossil fuels, such as natural gas, fuel oil and coal. However, the use of fossil fuels in electricity generation causes carbon dioxide (CO_2) emissions that harm the environment. In recent years, many efforts have been made to increase the implementation of renewable sources of energy through research and government investment incentives. From a policy viewpoint, a future energy mix has been proposed to replace energy supply from combustion of fossil fuels, and encourage sustainable energy development from renewable sources.

Grid-connected irrigators, particularly in Queensland, have been subject to a sustained period of electricity price increases. Queensland's electricity prices doubled between 2007–2008 and 2013–2014, predominantly driven by increases in network charges, which increased sixfold from 2004–2005 to 2014–2015, accounting for over 95 per cent of the total electricity price increases during the period (Davis, 2018). Irrigators would like to minimise further exposure to prices rises, but conversely, as national policy initiatives strive for more-efficient use of water, studies by Eyre et al. (2014) found the more water-efficient systems are generally the more energy intensive. For example, transferring water in closed pipes rather than channels, or installing drip or pivots to replace flood irrigation requires more energy than the systems they would replace. Therefore, solutions that can address sustainable use of energy and water will greatly assist in irrigated agriculture's competitiveness over the long term.

2.1 Policy installation incentives

One influential factor of the analysis is that renewable energy installation falls under the Australian Government's Renewable Energy Target (RET). The RET has two parts: Large-scale Renewable Energy Target (LRET), and the Small-scale Renewable Energy Scheme (SRES). These schemes are discussed in detail in terms of the Australian cotton industry in Powell and Welsh (2016b). In the context of this analysis, the two key differences considered in participating in either scheme were: (a) solar installations limited to 100 kW are within the SRES, where the government rebate is received upfront as Renewable Energy Certificates (RECs); and (b) solar systems over 100 kW are in the LRET, where Large-scale Certificates (LGCs) are sold at auction annually from the installation date to 2030, with estimations made for future pricing. The SRES market has a price ceiling of $40 per certificate set by the Australian Energy Regulator, as opposed to the LRET free market price discovery and delivery on forward contracts. Participating in these schemes lowers the cost of renewable installations. The LRET includes legislated annual targets that require significant investment in new renewable energy generation capacity in coming years. The large-scale targets ramp up until 2020 when the target will be 33,000 gigawatt hours of renewable electricity generation (Department of the Environment and

Energy, 2018). Post-2020 policy is unknown and dependent on the outcome of the federal election due in 2019.

2.2 Network considerations

Reliability of electricity supply over a vast land mass with a sparse population has been an ongoing challenge for governments since the rollout of the national electricity grid in the 1960s. The network operator or Transmission Service Provider (TSP) in regional Queensland is government owned and, hence, is a highly regulated asset. TSPs are required to maintain supply to a connection point to a set of standards consistent with rules set by the Australian Energy Regulator. These organisations operate to achieve minimum rates of return. Consumer groups raise concerns about the profit levels of regulated electricity businesses and consult with state-based competition authorities to provide checks and balances. They argue the regulatory framework enables TSPs to achieve super-normal profits – given the low levels of risk they face (Queensland Competition Authority, 2014). For most small businesses, in broad terms, about half of the electricity bill is made up of network and 'green' costs – those costs for government programs to save energy and support the development of renewable energy (Australian Energy Regulator, 2018).

In some Australian states and territories, the government regulates retail energy prices. That means that the price is determined by the government, so retailers must charge this price on their contracts. Regional Queensland has a highly regulated distribution and retail electricity market. Unlike in other states, Ergon Energy, a government-owned organisation, is both the TSP and the energy retailer. In deregulated markets, such as south-east Queensland and New South Wales, consumers are free to move between energy companies offering the least-cost alternative. In regional Queensland (and the case study site), Ergon Energy is the only provider. The customer has pricing options divided into a number of tariffs designed to offer choice to the consumer, and to best fit their individual demand profiles. These tariffs are part of Ergon Energy's demand side management (DSM) used to encourage consumer behaviour. Typically, the goal of DSM is to increase energy use during off-peak times, and reduce energy use during peak times, thereby reducing peak demands, and reducing the need for transmission infrastructure upgrades and added cost sharing for the energy consumer.

While Ergon has provided some choice, consumers must remain on the same primary tariff for at least 12 months before they can change to another primary tariff. There may be other costs for consumers associated with changing tariffs that will vary, depending on individual circumstances and time-of-use (TOU) metering configurations. Specifically, irrigation electricity tariffs in Queensland have risen over 136 per cent in the past decade, and post-2020, this rise will be unsustainable with the withdrawal of these specific, 'non-cost reflective' (and thus transitional) irrigation tariffs. Analysis by Davis (2018) found of an estimated 42,000 electricity connections for businesses in regional Queensland, almost one-third were on eight different tariffs classified as transitional or obsolete. Almost half of connections are for agricultural purposes. The calculated bill impacts post-2020 are shown as follows (Queensland Productivity Commission 2016):

- Tariff 62 – over 50% of the 8800 small customers will have a significant bill increase, and 93.8% of the 290 large customers would be worse off.
- Tariff 65 – over 40% of the 4900 small customers and 98.4% of the 100 large customers will be considerably worse off.
- Tariff 66 – almost 30% of the 2900 small customers and 100% of the 100 large customers will be considerably worse off.

2.3 Feed-in tariffs and eligibility

A feed-in tariff (FIT) is a premium rate paid for electricity fed back into the electricity grid from a designated renewable generation source. FITs can be applied in two forms:

- A 'gross metering' FIT is a bi-directional meter where all electricity produced feeds back into the grid, with the retailer setting an agreed price for all the renewable generation, with consumption on the premises kept separate
- A 'net metering' FIT occurs when on-site generation is fully used first, then surplus electricity is exported to the grid.

FITs can be used as a policy lever or static subsidy, or can gradually decrease over time to promote behind-the-meter innovation (Parliament of Australia, 2018). Connection conditions such as FIT rate, available metering, and inverter capacity can have a large impact on the economic feasibility of connecting energy generation and storage solutions. According to the Queensland Government (2018), to be eligible for a FIT in regional Queensland you must satisfy the following criteria:

- ✓ Operate a solar system with a maximum inverter capacity not exceeding 30 kW (approximately 38 kW of PV)
- ✓ Be a small business customer (consume less than 100 MW per annum)
- ✓ Be a retail customer of Ergon Energy and be connected to the grid
- ✓ Have a network connection agreement with an electricity distributor approving the system
- ✓ Have only one power system receiving the FIT per National Meter Identifier (NMI).

2.3.1 Feed-in tariffs and smart meters

In regional Queensland, the TSP offers gross 'smart' metering for new connections. Alterations to aging metering configurations are often required when embedded generation or energy storage connection applications for works are undertaken. Smart metering does not necessarily mean 'net metering'. The features of smart meters for all customers is described below.

- Smart meters monitor average half-hourly power consumption, and allow determination of the load profile (Power vs Time) of individual homes and businesses. This facilitates full cost-reflective pricing and peak demand management.

- Gross smart metering (separate bi-directional meter for PV output and consumer load) allows full performance assessment of PV system output, normally done via the inverter energy meter because most inverters log power/energy output. Measurement of energy use (kWh) and peak power demand (MVA) within residences or businesses allows full assessment of energy efficiency measures.

However, gross smart metering with import and export registers does not allow full measurement of demand with residences or businesses, and so cannot easily measure energy efficiency savings from solar. Gross smart meters measure only the exported part of PV energy generation and do not show the part that is supplied directly to home or business appliances (Berril, 2016). In this instance, the consumer is charged line-rental on incoming energy used when on-site generation is available to meet the load during daylight hours.

2.3.2 Time-of-use FITs

Time-of-use (TOU) FITs are a new demand management tool for network providers. In the 2017-18 financial year, domestic customers in regional Queensland had a choice between a flat-rate tariff or a time-varying feed-in tariff. The rates for each option (not subject to GST) are shown below.

- Flat rate – 10.2c per kWh
- TOU rates – 13.606c (3pm–7pm) and 7.358c per kWh all other times.

In other states of Australia, more stringent and better paying TOU FITs are being implemented to encourage a shift in demand, to orientate their panels to the west, rather than to the north to change demand patterns, or to encourage battery storage. Considering these developments, and the results of a study by ACIL Allen consulting (2017), of the changing nature of the grid and demand management, it is likely that TOU incentives will become more common as a policy lever in the future.

2.4 Connecting embedded generation > 30 kW

Connecting to the Ergon networks requires different levels of assessment and technical applications. TSPs such as Ergon have an obligation to ensure the network can provide a reliable network and safe connection for customers. To manage high voltage, distributors' connection guidelines place limitations on the network connection of embedded generation. This means many renewable energy connection applications go through the technical assessment process with the effect of adding time (and, in some cases, cost) to the process of installations. Technical assessments may require customers to modify the size (or export capacity) of their chosen system, restrict the system's ability to export excess solar generation to the grid or, for larger systems, pay a capital contribution (of between $10,000 and $60,000) toward the cost of a network upgrade before the system is installed. These requirements can reduce the attractiveness and financial viability of installing solar PV for some customers, and the renewable energy industry's ability to grow (Dept of Energy and Water Supply, 2017).

2.5 Avoided emissions

The installation of solar technology on-farm is an environmental consideration. When renewable energy is substituted for traditional grid-supplied energy, emissions are avoided. This can be substantial and is a clear environmental benefit. For this 25-year project, the avoided emissions were calculated using the total electricity offset from the use of solar energy over its life. Emissions from combusted diesel fuel generation have also been considered. The emissions factor of 2.697 kg CO_2e per litre is underpinned by the Intergovernmental Panel on Climate Change (United States Environmental Protection Agency, 2016) assumptions to include all nitrous oxide and methane emissions. Electricity generation and environmental impacts vary, depending on types of generation in that state. Emissions factors have been calculated using data obtained from the Australian Government Department of the Environment and Energy (2017) for Queensland electricity. This value is the scope 2 emission factor, for the state, territory or electricity grid in which the consumption occurs (kg CO_2e per kilowatt hour). Table 1 shows the emissions factors of various jurisdictions in Australia.

Table 1: Emissions factors for consumption of purchased electricity or loss of electricity from the grid. Source: Department of the Environment and Energy (2017)

State or territory	Emissions factor kg CO_2e
New South Wales and Australian Capital Territory	0.83
Victoria	1.08
Queensland	0.79
South Australia	0.49
SW Western Australia	0.70
NW Western Australia	0.63
Northern Territory	0.64
Tasmania	0.14

3 Method

The study uses the HOMER optimisation software to design microgrid systems with the view to reduce energy costs and emissions (Hybrid Optimisation of Multiple Energy Resources, 2018). Before undertaking HOMER analysis, a detailed assessment of each load, site layout, constraints, component pricing, and available resources on the case study farm is conducted. Once data has been collected and technical details have been verified by engineers and TSPs, the information is entered into the software. The HOMER analysis combines engineering design with economic assessment by comparing a wide range of equipment, each with different initial and ongoing cost structures and constraints, to determine the optimal system design. Other factors influencing system design include investigation of all interacting variables – physical (plant and soil type, irrigation system specifications, renewable plant and battery sizing, site attributes), meteorological (solar radiation, air temperature, relative humidity, wind speed, precipitation) and managerial (irrigation scheduling) – within the system (Maurya et al., 2015). Sensitivity analyses on component pricing and other key variables were completed using HOMER. Three individual loads, with their own unique seasonal energy demand attributes, have been analysed.

3.1 Site characteristics

3.1.1 Site overview

The case study farm is a 2600 hectare (ha) broadacre irrigated and grazing farm in the Fitzroy catchment of Central Queensland, Australia. The nearest town is Comet, about two kilometres to the south of the farm. Flat, low-lying areas have been developed for irrigation. Water is harvested from the Comet River, and from overland flow during storms on hilly terrain to the south-east of the farm. Site details are summarised in Table 2.

TABLE 2: DETAILS OF THE CASE STUDY FARM

Particulars	Details
Nearest township	Comet
Catchment	Fitzroy Valley
State	Queensland
Latitude	23°36’3”
Longitude	148°32’39”
Elevation	161 m
Irrigable land	618 ha
Farm size	2600 ha
Annual average rainfall	592 mm

Cotton is the primary source of income for the farming business. However, climate and agronomic conditions also favour cereal and peanut production. Farm grain infrastructure has been developed to enable peanuts to be stored, dried to marketing specifications, and sold. Drying peanuts for sale uses considerable energy for two months of the year. The cropping rotation consists of cotton (summer), wheat (winter), peanuts (summer) before being returned to cotton over a four-year period. A schematic of the cotton-wheat-peanut crop rotation is shown in Figure 2**Error! Reference source not found.**.

FIGURE 2: SCHEMATIC OF THE FIRST FOUR YEARS OF A 20-YEAR CONTINUOUS CROPPING ROTATION OF COTTON, WHEAT, FALLOW AND PEANUTS

Irrigation infrastructure (labelled in Figure 3) on the case study farm is made up of the following sites:

A. A grid-connected 415 volt, 3-phase 330 kW river pump used for transferring surface water into on-farm storage
B. A grid-connected 415 volt, 3-phase pump house containing two (110 kW and 132 kW) independent pump motors supplying three centre pivots. Both pumps can be run at the same time.
C. A grid-connected grain storage and drying facility near the pivot pump house has a 415 volt, 3-phase connected grain facility with a combined nameplate capacity of 40 kW, made up of small grain auger motors and a 37 kW electric fan used for drying peanuts.

The farm map (Figure 3) shows the location of the three sites within the case study. Site A is the river pump, Site B is the pivot pump house, and Site C is the grain storage and drying facility. Figure 3 also illustrates the farm layout, showing the flood-irrigated farm land in the north-west corner and three centre pivots (CP) in the centre of the property.

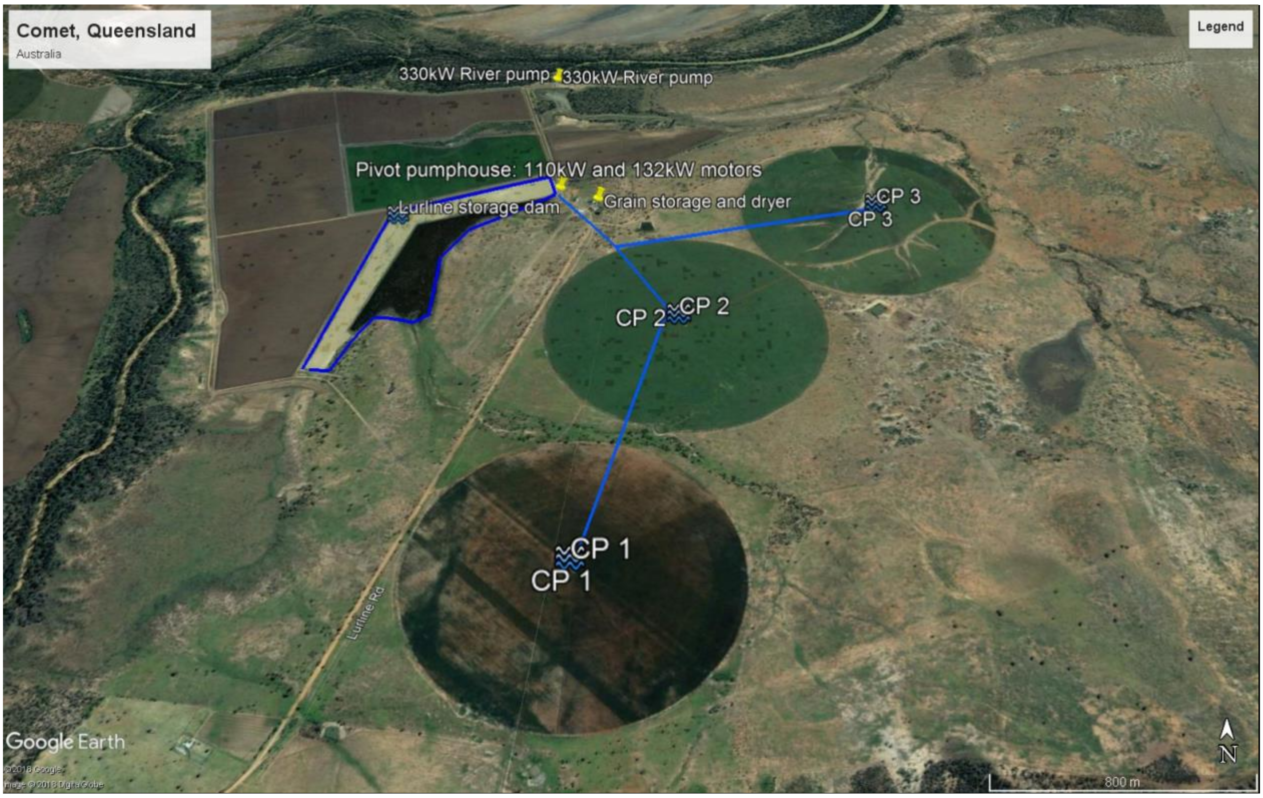

FIGURE 3: CASE STUDY FARM MAP SHOWING THE IRRIGATION LAYOUT AND GRID-CONNECTED LOADS (YELLOW PLACEMARKS). MAP IMAGE COURTESY GOOGLE EARTH.

3.1.2 Climate and implications for energy use

Australia has one of the most variable climates in the world, making farm management decisions challenging (Love, 2005). The Köppen climate classification for the Fitzroy Valley is Subtropical, with a wet summer and moderately dry winter (Bureau of Meteorology, 2018b). On an irrigation farm, energy and climate are intrinsically linked, because plant demand for water is driven by evapotranspiration and seasonal climate variability. On the case study farm, when considering rainfall and irrigation, water is harvested in summer during sporadic and intense rainfall events. Summer crops are planted in spring, and regulated irrigation water is also pumped from the Comet River into storage during this period, to be then applied through centre pivot irrigators. Seasonal rainfall patterns largely determine crop water demand, and thus, the water harvesting, irrigation use and energy demand. Over the 20-year period 1997-2017, the annual average rainfall at Comet totalled 555 mm. The rainfall monthly profile (Table 3) reflects the Köppen classification as a summer-dominant rainfall with the highest totals occurring in the monsoon period between December and March. The coefficient of variation (CoV), a measure of relative dispersion, is used to compare variation in a series that differs in the magnitude of their averages (Simpson and Kafta, 1977). This is calculated by the standard deviation of the sample month divided by the mean. The higher the CoV, the higher the variation, and the lower the reliability of rainfall occurring in that month. The calculations show January and February as the most reliable months for rainfall, with CoV values of 0.55 and 0.61 respectively.

TABLE 3: RAINFALL MEAN, TOTAL AND CO-EFFICIENT OF VARIATION FOR COMET, QUEENSLAND FOR THE PERIOD 1997-2017. SOURCE: BUREAU OF METEOROLOGY (2018A)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Mean rainfall	75	83	66	28	18	36	20	19	21	37	50	102	555
CoV	0.55	0.61	0.92	1.21	1.16	1.05	1.68	1.44	2.08	1.21	0.88	0.89	

The lower CoV observed through January, February, March and December in Figure 4 shows water harvesting from rainfall is likely to occur in these months. Water stored on-farm is applied to high-value crops, such as cotton and peanuts, in the summer, and on wheat crops consistently through a mainly dry winter. Energy use from centre pivot irrigation is therefore relatively consistent when compared with the river pump, which reflects smaller periods of higher energy use throughout the year.

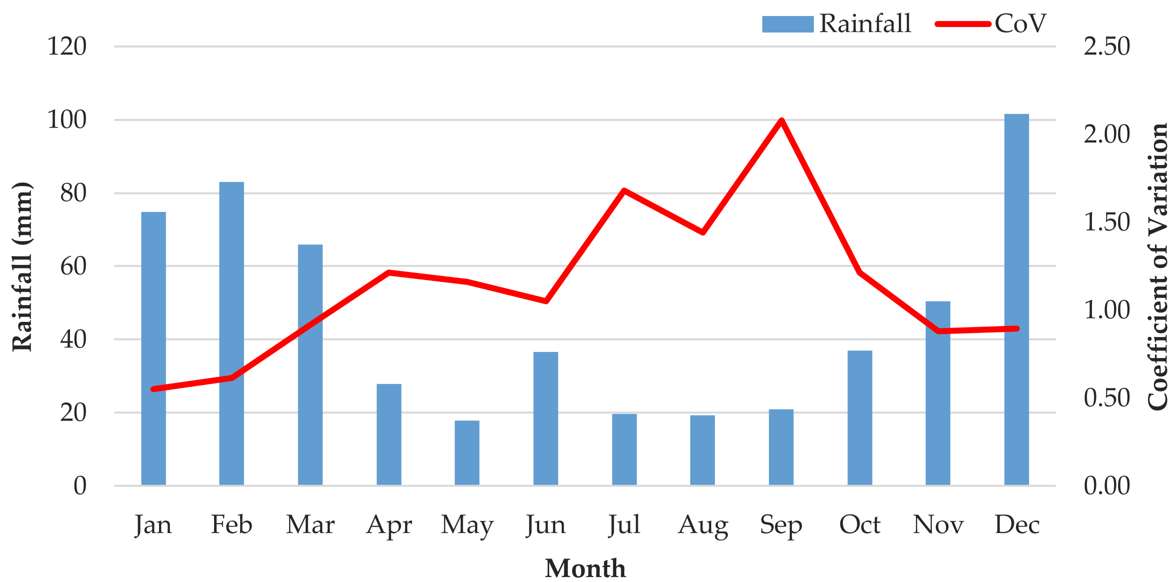

FIGURE 4: COMET RAINFALL MONTHLY MEAN AND COV FOR THE PERIOD 1997-2017. SOURCE: BUREAU OF METEOROLOGY (2018A)

3.1.3 Load assessment and electricity pricing

An electric load is the power consumption of one or more components, for a specific timeframe, usually measured by a meter. The load profile considers the variation of usage over time. The case study farm has three electricity connection points with differing seasonal load profiles and random variability. This section looks at the characteristics of each connection in more detail.

Site A: River pump

The 330 kW river pump is the only load for this connection. The pump is off for long periods and then operational at a constant level for 24 hours a day, often for several days when conditions permit. This usage pattern is a result of the availability of allocated water in the river that needs to be pumped to the farm within a designated time. If there is no water to be pumped, then there is zero electricity usage. A 12-month load profile of half-hourly interval data was sourced from the TSP and analysed. The usage showed a large day-to-day variance in the electricity load, with the one component off (0 kW) or on (max. 336 kW). However, as the pump is off for weeks at a time and on for days at a time, the hour-to-hour variance is low, creating a block-like profile. The peak demand exceeds the capacity due to soft start componentry for the motor. October has the highest monthly usage in the dataset. The random day-to-day and time-step variability of the river pump is summarised in Table 4.

Site B: Pivot pump house

The pivot pump house contains two electric motors that supply energy to the centre pivot irrigators in three different fields (see Figure 3). These motors, sized 132 kW and 110 kW, can be used together or independently, i.e. one motor at a time. The pivot irrigators are used for both summer and winter cropping, however higher crop evapotranspiration in summer results in more water needed to be applied to the summer crops, particularly early in the season prior to the onset of the monsoon. A 12-month load profile of half-hourly interval data was sourced from the TSP to better understand energy demand. October to March had the highest electricity use, however month-by-month demand is heavily influenced by crop evapotranspiration, which can change each year. For example, 70 mm of rainfall was recorded at Comet during October 2017, twice the mean of 36 mm (Bureau of Meteorology, 2018a). The energy demand from pivot irrigating for that month was negligible due to abundant soil moisture. From April to September, the pumping load is reduced, as wheat crop demand for water is less due to cooler season growing conditions. The day-to-day variability shown in Table 4 is less than that of the river pump, with more consistent use.

Site C: Grain dryer

A 37 kW capacity electric fan is used to reduce the moisture content of freshly harvested peanuts during April and May. Two augers totalling 3 kW transfer the grain in and out of the grain-drying facility. A synthetic electric load has been created from information provided by the landholder. The 36 kW operating load has been calculated at 90 per cent power factor of the 40 kW electric motors. The dryers typically run for 8 hours on fine days, between 10am and 6pm, when the air is warm, and humidity is low. Consumption and day-to-day variability assumptions are shown in Table 4.

TABLE 4: A SUMMARY OF LOAD DETAILS OF EACH SITE FOR THE HOMER ANALYSIS

Site	Description	Capacity (kW)	Peak (kW)	Average kWh/day	Day-to-day variability (%)
A	River pump	330	336	858	295
B	Pivot pump house	242	234.8	1085	186
C	Grain dryer	40	36	35	6

Figure 5 illustrates monthly grid-consumption from each site from two years of consumption data. The seasonal usage of each site combined with TSP rules provide a unique set of challenges when modelling technology options for each connection.

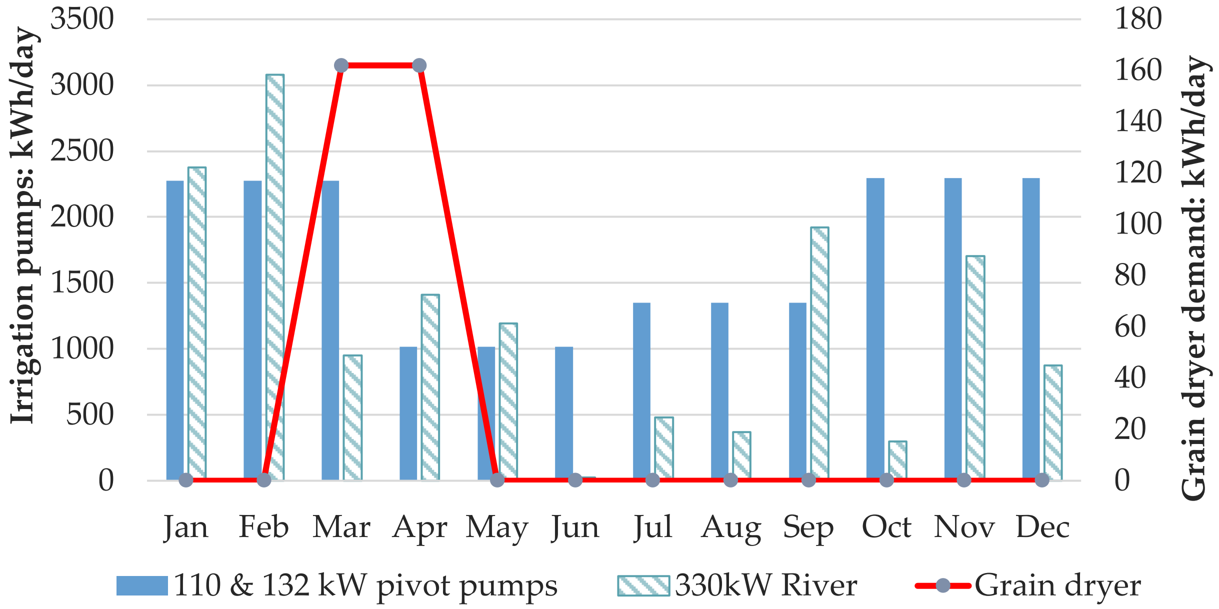

FIGURE 5: MONTHLY AVERAGE ENERGY DEMAND FOR EACH SITE: RIVER PUMP (SITE A), PIVOT PUMP HOUSE (SITE B), AND GRAIN DRYER (SITE C).

3.1.4 A review of retailer prices and tariffs

As the case study farm is in regional QLD, the consumer has only one available electricity retailer, but there are several tariff options for each connection to best fit energy consumption. With the retailer reforming tariffs post-2020, making assumptions over the 25-year investment is challenging (Ergon Energy, 2016). Because speculation on future tariff structures and charges is outside the scope of this study, modelling has been conducted on existing tariffs. Any future increase in electricity prices would further improve the feasibility results reported in this analysis.

A summary of the tariffs used is provided in Table 5. Ergon's time-of-use (TOU) Tariff 62 has been used for case study sites A and B. As annual energy demand exceeds 100 MWh, it is assumed no FIT is available because it fails the eligibility criteria set out in Section 2.4 on 'connecting embedded generation'. Tariff 20, a flat-rate 'business general supply' is the current supply structure for Site C with a TOU FIT added.

TABLE 5: TARIFF ASSUMPTIONS FOR EACH SITE

Site	Tariff name	Supply charge	Peak tariff	Off-peak tariff	FIT all hours	FIT (3-7pm)
A	Tariff 62	$286	$0.410	$0.165	N/A	N/A
B	Tariff 62	$286	$0.410	$0.165	N/A	N/A
C	Tariff 20	$440	$0.2772	$0.265	$0.07358	$0.13606

3.2 Resource assessment

The analysis considers solar and wind resources for the case study farm. Solar exposure and wind resource data were both downloaded from NASA (2018) Surface Meteorology and Solar Energy website for the case study location (23°36.3 S latitude and 145°32.7E longitude). Annual average Global Horizontal Irradiance (GHI) whichis solar radiation was 5.7 kWh/m^2/day, and a clearness index was 0.6168, as shown in Figure 6. The location can provide consistent solar production throughout the year, although cloudiness reduces the clearness index during the wet season and improves considerably during the drier winter months. Peak months for energy production are November, December and January when day lengths increase and are aligned with usage of the pivot pump house.

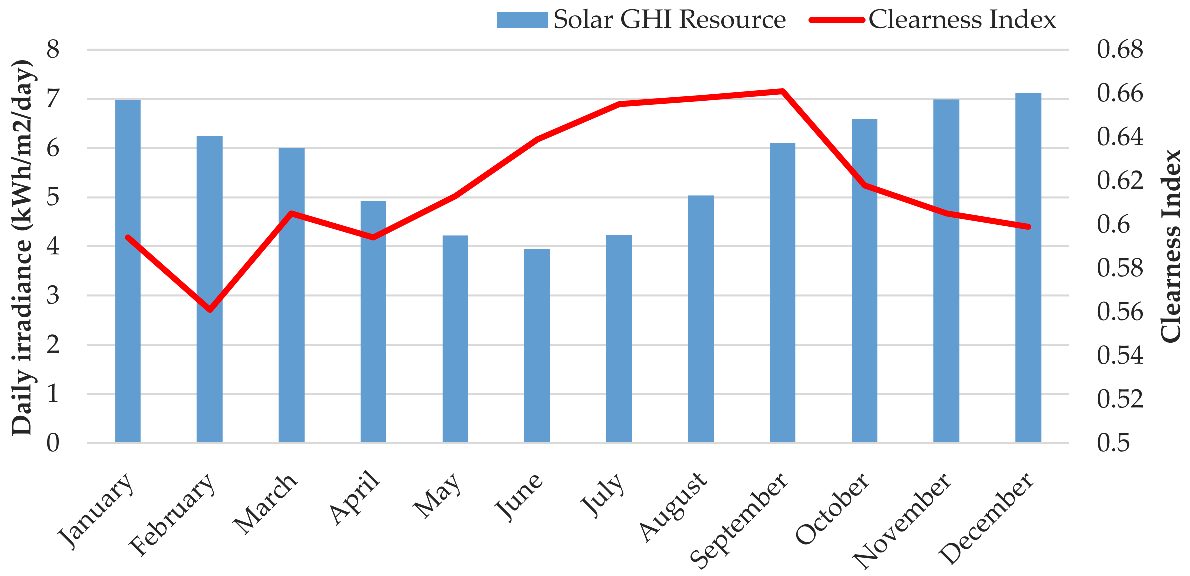

FIGURE 6: MONTHLY AVERAGE SOLAR GHI FOR COMET, THE CASE STUDY LOCATION

The annual average wind speed for the location is 5.04 m/s at the height of 10 m. The resource data from NASA Surface Meteorology and Solar Energy database is based on the closest weather station. It should be noted that significant variance in wind resources between locations is caused by existing vegetation, topography and proximity to buildings. Simulated wind speed data for a given location should not be relied upon. Instead, on-site data collected at hub height is the more accurate resource assessment for wind generation.

3.3 Component assessment

The components within a microgrid system either generate, store, control or use energy. For this analysis, the generating resources considered were solar PV, wind turbines, diesel generators, and the existing grid and tariff structure. Lithium-ion batteries were considered for storage, and converters for the control of the energy. Figure 7 is the schematic system configuration for Site B, pivot pump house.

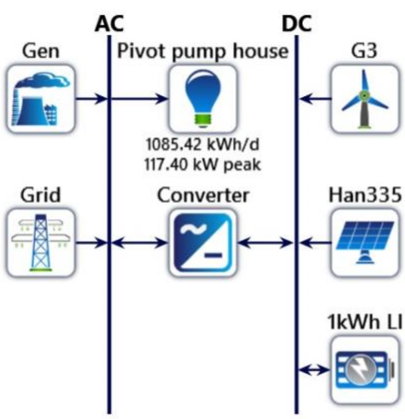

FIGURE 7: HOMER COMPONENT SCHEMATIC FOR SITE B – PIVOT PUMP HOUSE

Component pricing considers all applicable costs, and are an 'installed and commissioned' price. All pricing and monetary terms are in AUD. The solar PV capital costs are $1500 for 1 kW ground mounted at Site A, $1400 for Site B, and $900 for 1 kW on the aluminium roof in Site C. The pricing differences account for the mount and racking requirements of each site. Site A mounts are quoted to be high enough to keep the panels out of flood water, Site B mounts are slightly lower, and Site C is basic roof racking. These prices are net of the applicable government rebates: SREC (Site C) and LGC (sites A and B). The solar PV has a 25-year lifetime, so does not need to be replaced within the 25-year analysis. Annual operating and maintenance is $4/kW. To account for the effects of temperature, dust and time, a derating factor of 85% has been used. The panels are modelled on a fixed tilt facing north, with a slope of 26.3°. Tracking systems are not considered. Panels on the aluminium roof are modelled with a 40% ground reflectance, but at 10% on ground mounts.

A generic 3 kW wind turbine is considered in the modelling, with a capital cost of $14,000/kW, a life time of 20 years, and a replacement cost of $12,000. The annual operating and maintenance cost is $180/kW.

Site A modelling considered a 500 kVA (400 kW) generator sized to account for soft start capability. It has an installed capital cost of $102,712, a lifetime of 90,000 hours, and a replacement cost of $80,000. Costs to connect embedded generation to the network have been estimated at $20,000 (Ergon Energy, 2017). These costs have been independently verified by local engineers who size, supply and install gensets. Telemetry for remote monitoring, start/stop, as well as commissioning has been included in genset capital costs. Site B and C modelling considered the HOMER autosize diesel generator with a capital cost of $240/kW, a lifetime of 15,000 hours, and replacement cost of $240/kW. All generators had an annual operating and maintenance cost of $0.03/hour. The diesel price was modelled at $1/litre (net of taxes), with a real indexation of five per cent per annum, and sensitivity tested for Site A.

The storage option in the modelling was an autosize generic lithium-ion battery, with a capital cost of $800/kWh, a lifetime of 3000 hours, and a replacement cost of $500/kWh. The annual operating and maintenance costs are $10/kW.

The capital costs for a generic system converter are $300/kW, a lifetime of 15 years, and a replacement cost of $300. The annual operating and maintenance is $0. The inverter and rectifier efficiencies are 95%.

3.4 Economic inputs

Parameters uniform to each site include the project lifetime of 25 years, an annual discount rate of 7%, inflation rate of 2%, and an installation date of 2018.

3.4.1 The grid

Each site has an existing grid connection, so the grid scenario is used as the base case in HOMER to compare all other scenarios. The grid is modelled using the existing regulatory environment and existing policy frameworks for the TSP and retailer, as outlined Section 2. The tariffs outlined in Section 3.1.4 are used for each site. Indexation within the model has also been incorporated to account for price movements that in recent times have exceeded inflation. Queensland's electricity prices doubled between 2007–2008 and 2013–2014, predominantly driven by increases in network charges, which increased sixfold from 2004–2005 to 2014–2015, accounting for more than 95% of the total electricity price increases during the period. The proportion of network charges relative to the wholesale price of power has also changed over time. Network charges now account for over half of Queensland's retail electricity prices, whereas in 2004–2005, they accounted for only about 20 per cent (Davis, 2018). Graham et al. (2015) researched the issue of Australian electricity prices in detail to 2040 and considered different jurisdictions and bill components. Although outcomes are sensitive to carbon policy outcomes, a value of five per cent has been used as a price index over the investment period. Key grid restrictions were no net metering on all sites, no export of energy on sites A and B, and export capacity limited to 30 kW for Site C.

One characteristic of the existing grid is the random and common supply interruptions known as 'blackouts'. During the storm season from November to April, the case study farm currently has blackouts for up to six hours at a time. These periods, ranging anywhere from less than a minute to several days, occur more regularly in summer when water application can be critical to crops. New technology currently under development aims to allow an appropriately sized, grid-connected microgrid to operate a load/s independently of the grid when the grid fails. More reliable energy reduces production risk through better agronomic management. While reliability would be a welcome benefit to a microgrid, the benefit has not been valued in this analysis.

3.4.2 Indexation of diesel fuel

Amid rapid recent changes in energy markets, the predicted penetration of electric passenger vehicles is almost certain to displace a portion of traditional hydrocarbon-based fuels in the future. The outlook and indexation assumptions for future diesel fuel cost have used the global oil price outlooks as a proxy to the year 2040. Although forecasts do not account for domestic exchange rate variation, Australia remains highly dependent on imported petroleum products. All reporting agencies surveyed suggest four factors underpin the future price of oil: global economic growth and consumer demand; the rate of urbanisation in non-OECD countries (particularly China and India) affecting energy demand; energy innovation (nuclear and renewables); and government carbon policies/adoption of innovative technologies. Analysis by Powell et al. (2018) found the average real indexation across various agencies to be 2.79 per cent, which is used in the analysis.

3.5 Sensitivity of inputs

Utilisation rates of solar power (to offset grid electricity costs), the amount received for a FIT, and falling technology costs are key variables that have been discussed previously (Powell and Welsh, 2016a). In this analysis, four other key inputs are sensitivity tested. Site A considers a varied diesel price – $1, $1.20 and $1.40 per litre – net of excise and goods and services tax. Site B compares the results when the PV is limited to 100 kW to be eligible for upfront small-scale technology certificates (STCs). Site C compares the results on the flat FIT vs the TOU FITs and a net metering scenario.

3.6 Economic modelling and optimisation

The HOMER model optimises system componentry to minimise total net present cost (NPC) using simulation. In this case, Site A has been optimised using HOMER across all inputs except the genset component – due to technical limitations. Scenarios for Site C have been altered slightly upon consideration of TSP connection limitations, and access criteria for renewable energy subsidies. The rationale behind limiting the size of some components is summarised in Table 6.

TABLE 6: ECONOMIC MODEL PARAMETERS AND RATIONALE FOR EACH SITE

Site	PV	Wind	Genset	Battery	Inverter	Rationale
A	Optimise	Optimise	400 kW	Optimise	Optimise	Genset fixed due to motor soft-start
B	Optimise	Optimise	Optimise	Optimise	Optimise	
C	38 kW	Optimise	Optimise	Optimise	30 kW	PV/inverter sized for FIT eligibility

4 Results and discussion

This section shows the results of the analysis. The optimisation results are presented, followed by the outcomes of the sensitivity analysis and environmental outcomes.

4.1 Optimisation results

The optimal combinations based on lowest net present cost for the three sites are summarised in Table 7. These sites have been compared with the grid-connect business-as-usual scenario. Due to the sporadic energy use of the river pump at Site A, incorporating solar PV at a size to match the electric pump load was found to be uneconomical. The diesel generator (DG) was found to be optimal, incorporated as a substitute during peak tariff periods. The optimal combination on Site B was load sharing between solar PV, DG and grid. Site C was chosen as the optimal size to fit current TSP connection requirements, where 38 kW of PV is the upper limit for FIT eligibility. Other input combinations, such as DG and batteries, did not feature as low-cost alternatives.

TABLE 7: OPTIMAL COMPONENT COMBINATIONS FOR EACH SITE

Site	PV	Wind	Genset	Battery	Inverter	Rationale
A	0	0	400 kW	0	0	Load shared DG/grid (44%/56%)
B	225 kW	0	130 kW	0	115 kW	Load shared PV/DG/grid (60%/6%/34%)
C	38 kW	0	0	0	30 kW	PV/inverter sized for FIT eligibility

The optimal combination of componentry on Site A included remaining connected to the grid, which results in the generator replacing 44 per cent of the pumps annual electricity. This combination had the lowest NPC of $1.5 million, 28 per cent lower than business-as-usual (BAU). The payback period of five years, and a 24 per cent internal rate of return (IRR) showed a good investment at the current diesel fuel price. The avoided CO_2e from a change in fuel source to include diesel generation is a meagre 294 tonnes of CO_2e over 25 years. This scenario requires $122,712 of initial capital and $99,075 operating each year, which is 32 per cent lower than the BAU operating cost of $145,204 a year. The resulting levelised cost of energy is $0.338/kWh, 27 per cent lower than the BAU levelised cost of $0.464/kWh. PV did not feature in the economically optimal scenario as the sporadic load profile combined with no FIT and underuse of a solar resource. Although the use of a DG reduces the cost of electricity, it does little to avoid emissions.

The optimisation of Site B resulted in a payback period of 6.8 years, which is a 17 per cent internal rate of return (IRR), and a net present cost (NPC) of $1.62m. The scenario requires initial capital of $383,900 to reduce power prices by 35 per cent, resulting in a levelised cost of energy of $0.287/kWh. These results are achieved without a FIT because current TSP rules negate a FIT for current high levels of grid consumption. The avoided CO_2e from production of 'green' energy is 2711 tonnes of CO_2e over 25 years. Batteries did not feature in the economically optimal scenario, however, as energy storage technologies improve and prices fall, a storage component could potentially be added into the PV array at a later date, further improving the investment feasibility. New technology to enable supply continuity from PV may also assist irrigation during power outages in Site B (GEM Energy, 2018). Energy reliability is a major issue in the region, and yield is lost when plant demand for water is unable to be optimised through irrigation.

The base analysis results for Site C found a payback period of 4.3 years, a 24 per cent IRR, and an NPC of -$8673 over the period, showing a net profit from the installation. The initial capital requirement of $35,000 provides a microgrid that can generate enough energy to power the site and export via FIT to result in 100 per cent offset of the variable cost of energy. The avoided CO_2e from production of 'green' energy is 150 tonnes of CO_2e over 25 years. Results of the three sites are summarised in Table 8.

TABLE 8: RESULTS OF THE OPTIMISATION OF THREE CASE STUDY SITES

Site	Optimal hybrid configuration	Cost of energy $/kW	NPC	Payback	IRR	Change in emissions from base (25 years)
A	Grid/Genset	$0.338	$1.50m	5.2 years	24%	294 t CO_2
B	Grid/Genset/PV	$0.287	$1.62m	6.8 years	17%	2,712 t CO_2
C	Grid/PV	-$0.008	-$8,673	4.3 years	24%	150 t CO_2

Results consider and discuss only the variable costs of energy. Fixed costs, such as line rental and demand charges, are still payable. As renewable investments increase, they affect the demand and supply profiles of grid energy. TSPs are likely to restructure their charges to reflect the changing nature of grid energy supply. Any increases in electricity costs to the customer will only enhance the feasibility of microgrid installations, particularly those that allow the customer to go off grid.

4.2 Sensitivity results

An analysis using static values and assumptions is subject to change or error (Pannell, 1997). For this reason, more investigation was conducted where there was uncertainty with baseline assumptions to enable consideration of other feasible component combinations. Parameters tested for each optimal combination were dependent on the primary input for each site. Diesel price was chosen for Site A, where the addition of a DG was recommended. A reduced PV array was tested for Site B to ensure qualification for the 'small' STC rebate. Site C compared the results of the flat and TOU FIT. The sensitivity parameters are summarised in Table 9.

TABLE 9: SENSITIVITY PARAMETERS FOR SITES A, B AND C

Site	Parameters	Detail
A	Diesel price	\$1.00, \$1.25 & \$1.40 Diesel indexed @ 2.79%
B	Set PV size	99.5 kW to keep within the small-scale scheme
C	FIT	Flat 10c FIT vs TOU FIT

Sensitivity analysis on the results for Site A indicate that an investment in a generator shows project returns are sensitive to diesel price increases. A 40 per cent increase in diesel price slows the payback period from five years in the base case scenario to 10 years. This 40 per cent price increase added 6.2c/kWh to the cost of energy, which, at \$0.40, is still 13 per cent below the BAU cost of \$0.46. Results are summarised in Table 10.

TABLE 10: SITE A DIESEL PRICE SENSITIVITY RESULTS

Diesel price	Optimal hybrid configuration	Initial capital	Cost of energy \$/kW	NPC	Payback	IRR	Change in emissions from base (25 years)
BASE	Grid only		\$0.46	\$2.07m			Base case
\$1	Grid/Genset	\$122,712	\$0.338	\$1.50m	5.2 years	24%	294 t CO_2
\$1.2	Grid/Genset	\$122,712	\$0.369	\$1.64m	7.0 years	19%	294 t CO_2
\$1.40	Grid/Genset	\$122,712	\$0.400	\$1.78m	10.0 years	14%	294 t CO_2

Reducing the size of the PV array for Site B resulted in a higher IRR and quicker payback period due to the lower capital outlay. The cost of energy in this scenario was slightly higher due to the PV offsetting a smaller proportion of the 242 kW maximum load, with the more costly DG making up the balance. The small-scale solar installation (<100 kW PV) achieved a levelised cost of energy 29 per cent lower than the grid-only scenario, but nine per cent higher than the optimal microgrid solution. Offset emissions for the small-scale scenario were 40 per cent lower than the optimal microgrid solution. Results of these scenarios are presented in

Table 11.

TABLE 11: SITE B PV SIZE AND OPTIMAL MICROGRID CONFIGURATIONS

PV	Optimal hybrid configuration	Initial capital	Cost of energy $/kW	NPC	Payback	IRR	Change in emissions from base (25 years)
BASE	Grid only		$0.440	$2.48m			
225	Grid/Genset/PV	$383,900	$0.287	$1.62m	6.8 years	17 %	2,711 t CO_2
99.5	Grid/Genset/PV	$201,200	$0.313	$1.76m	5.5 years	22%	1,632 t CO_2

Site C sensitivity testing considered the two FIT options available to the site, as outlined in (section 2.3.2.). The NPC of the flat FIT resulted in an $8673 benefit, as opposed to a $7054 cost for the TOU FIT. Although the flat FIT option is superior in this scenario, the TOU FIT still results in a 98 per cent reduction in the levelised cost of energy, and had a payback period of under 10 years. The comparison results are shown in Table 12. The energy consumption breakdown was: solar power used 12,672 kWh (71% of load requirements), grid purchases of 5087 kWh, and grid sales of 65,120 kWh. In this scenario, grid sales exceed grid purchases. A flat FIT results in an overall profit from installing the solar PV. Current PV pricing produces solar energy at a lower cost than existing FITs, so where eligible, it pays to install the maximum PV allowed for a FIT. Ergon does not allow net metering, however, if this scenario were net metered, the profit would be even greater.

TABLE 12: SITE C FLAT VS TOU FIT

PV	Optimal hybrid configuration	Initial capital	Cost of energy $/kW	NPC	Payback	IRR	Change in emissions from base (25 years)
BASE	Grid only		$0.469	$84,659			
Flat FIT	Grid/PV	$35,600	-$0.008	-$8,673	4.3 years	23.7%	149.8 t CO_2
TOU FIT	Grid/PV	$35,600	$0.006	$7,054	4.9 years	20.7%	4.8 t CO_2

5 Conclusions

Four factors – current government renewable energy policy; higher energy costs; advances in solar technology; and falling cost of solar installations – have all aligned to create a good opportunity for cotton growers to employ renewable energy pumping systems that will reduce on-farm costs and carbon emissions. Our search for a technically feasible and economically viable solution to supply alternative energy to an irrigation farm in Central Queensland found several factors that influenced project returns and environmental benefits. Firstly, Site A, characterised by sporadic seasonal use and high day-to-day variability, was best suited to a mix of grid and on-site diesel-powered electricity generation. However, returns were found to be very sensitive to the current diesel price, whereby a 40 per cent increase doubled the payback period from five to 10 years. Under the DG and grid scenarios, the level of carbon abatement achieved was negligible. Noting that the post-2020 Queensland tariff structure is currently under review, the analyses also assumed ongoing eligibility for a TOU Tariff (62) for the duration of the 25-year investment period. A fixed demand tariff would change results a great deal and require a new study.

The pivot pump house, Site B, was found to have the most consistent energy demand profile throughout the year, owing to the continuous cropping rotation on the farm. Optimisation results included a combination of 225 kW of PV, DG and staying connected to the grid. Although sensitivity testing identified a configuration with higher returns, the larger PV system would enable continued irrigating during periods of grid supply interruptions in daylight hours. Benefits from energy security resulting in optimal crop irrigation have not been considered in this study and may be an area of future research. The larger system offsets the highest amount of grid electricity and provides an alternative fuel source and buffer against any further grid price increases. This system also has the highest abatement of any site analysed at 2711 t CO_2e.

Site C, a grain-drying facility, has a short two-month window of operation after harvest in March and April. This was the only site on the case study farm to comply with the FIT requirement of energy consumption under 100 MW annually, so the economic parameters were set to the maximum limits of PV (that comply with FIT eligibility). Even with a small amount of annual self-consumption, the analysis found the project returns to be highly profitable, with a payback period of between four and five years for both combinations of FIT rates. This payback benefited from the high grid sales of unused PV. If network regulations changed to include net metering, the profit would be even higher.

This study has found that the feasibility outcomes of installing innovative energy solutions to seasonal energy loads is highly dependent on the rate of self-consumption and policy settings, such as available tariff, retailer competition and access to feed-in tariffs. The economic and environmental benefits offered by low-cost PV are inextricably linked to these key parameters. The TOU tariffs in the study ascertained a viable inclusion of a diesel generator showing a competitive levelised cost of energy during peak periods. Battery storage costs did not feature in optimisation results across the three case study sites. With some international energy agencies forecasting storage prices to fall in the coming years, there is an avenue for future research. In the absence of a FIT for solar PV above 38 kW, economic and environmental benefits were achieved only where energy demand was closely matched with renewable energy supply throughout the year.

6 Acknowledgements

This study would not have been possible without support from the Cotton Research and Development Corporation. The authors would also like to thank the case study landholder for his co-operation, and Craig Brooks, Aaron Hilton and Jack Hooper (all GEM Energy) for their technical oversight, generosity and patience during this study.

7 REFERENCES

ACIL ALLEN CONSULTING 2017. Victorian Feed in tariff: estimate of energy value. web site.

AUSTRALIAN BUREAU OF STATISTICS 2017. Water use on Australian Farms-2015-16. *In:* RESOURCES, D. O. A. A. W. (ed.). ABARE: ABS.

AUSTRALIAN ENERGY REGULATOR 2018. About Energy Bills. *Energy Made Easy.* web site.

BERRIL, T. 2016. The Renewable Energy Revolution - Making it happen in the Sunshine State. *In:* QUEENSLAND, S. (ed.). web site.

BUREAU OF METEOROLOGY. 2018a. *Climate Data Online* [Online]. website. Available: http://www.bom.gov.au/climate/data/ [Accessed 10 May 2018].

BUREAU OF METEOROLOGY. 2018b. *Koeppen Climate classification of Australia* [Online]. web site. Available: http://www.bom.gov.au/jsp/ncc/climate_averages/climate-classifications/index.jsp?maptype=kpn#maps [Accessed 10 May 2018].

CAMPANA, P. E., LI, H. & YAN, J. 2013. Dynamic modelling of a PV pumping system with special consideration on water demand. *Applied energy*.

CARROQUINO, J., DUFO-LÓPEZ, R. & BERNAL-AGUSTÍN, J. L. 2015. Sizing of off-grid renewable energy systems for drip irrigation in Mediterranean crops. *Renewable Energy,* 76**,** 566-574.

CHEN, G., SANDELL, G., YUSAF, T. & BAILLIE, C. 2013. Evaluation of alternative energy sources for cotton production in Australia. Engineers Australia.

DAVIS, G. 2018. The Energy-Water-Climate Nexus and Its Impact on Queensland's Intensive Farming Sector. *The Impact of Climate Change on Our Life.*

DEPARTMENT OF THE ENVIRONMENT AND ENERGY 2016. National Greenhouse Accounts Factors. *In:* ENERGY AND ENVIRONMENT (ed.). web site: Australian National Greenhouse Accounts,.

DEPARTMENT OF THE ENVIRONMENT AND ENERGY 2017. National Greenhouse Accounts Factors. *In:* ENERGY, D. O. T. E. A. (ed.). web site: Australian Government.

DEPARTMENT OF THE ENVIRONMENT AND ENERGY. 2018. *The Renewable Energy Target Scheme,* [Online]. website. Available: http://www.environment.gov.au/climate-change/government/renewable-energy-target-scheme [Accessed 30 May 2018].

DEPT OF ENERGY AND WATER SUPPLY 2017. Decision regulatory impact statement - Queensland's statutory voltage limits. *In:* D (ed.). online: Queensland government.

ERGON ENERGY 2016. Understanding Network Tariffs. *Network.* Website.

ERGON ENERGY 2017. Ergon Energy Network Embedded Generator Information Pack. web site.

EYRE, D., ALEXANDRA, J., RICHARDS, R. & SWANN, E. 2014. The Water & Energy Nexus: a Multi-Factor Productivity Challenge. NSW FA website.

FOLEY, J. P. 2015. Fundamentals of energy use in water pumping. *In:* COTTONINFO (ed.) *Fact sheet.* web site.

GEM ENERGY. 22 June 2018 2018. *RE: GEM Energy: AC-DC drive technology for unreliable grid,.* Type to WELSH, J.

GRAHAM, P. W., BRINSMEAD, T. & HATFIELD-DODDS, S. 2015. Australian retail electricity prices: Can we avoid repeating the rising trend of the past? *Energy Policy,* 86**,** 456-469.

HYBRID OPTIMISATION OF MULTIPLE ENERGY RESOURCES. 2018. *HOMER optimisation design software* [Online]. Available: https://www.homerenergy.com/ [Accessed January-May 2018].

LOVE, G. Impacts of climate variability on regional Australia. *In:* LOVE, R. N. A. G., ed. Climate Session Papers, 2005 Canberra. Australian Bureau and Resource Economics.

MAURYA, V. N., OGUBAZGHI, G., MISRA, B. P., MAURYA, A. K. & ARORA, D. K. 2015. Scope and Review of Photovoltaic Solar Water Pumping System as a Sustainable Solution

Enhancing Water Use Efficiency in Irrigation *American Journal of Biological and Environmental Statistics,* 1**,** 1-8.
NASA. 2018. *Surface Meteorology and Solar Energy* [Online]. We site. Available: https://eosweb.larc.nasa.gov/cgi-bin/sse/grid.cgi?email=wctauber@aol.com [Accessed March 2018].
PARLIAMENT OF AUSTRALIA. 2018. *Feed In Tariffs* [Online]. web site: Australian Government. Available: https://www.aph.gov.au/About_Parliament/Parliamentary_Departments/Parliamentary_Library/Browse_by_Topic/ClimateChangeold/governance/domestic/national/feed [Accessed 10 May 2018 2018].
POWELL, J. P., WELSH, J. M. & FARQUHARSON, R. 2018. Investment analysis of solar energy in a hybrid diesel irrigation pumping system in New South Wales, Australia. . *Journal of Cleaner Production,*.
POWELL, J. W. & WELSH, J. M. 2016a. Grid connected solar: Irrigation case studies. Available at; http://www.cottoninfo.com.au/sites/default/files/documents/Cotton%20Energy_GRID%20CONNECTED%20SOLAR.pdf.
POWELL, J. W. & WELSH, J. M. 2016b. Solar Energy – policy setting and applications to cotton production. *In:* COTTONINFO (ed.) *CottonInfo reports and analyses.* website.
POWELL, J. W. & WELSH, J. M. 2016c. The sums add up for solar powered irrigation. *The Australian Cotton Grower,* October-November**,** 22-25.
QUEENSLAND COMPETITION AUTHORITY 2014. Uniform Tariff Policy & Regional Retail Electricity Price Regulation. Website.
QUEENSLAND GOVERNMENT. 2018. *Feed-in-tariffs for regional Queensland* [Online]. Available: https://www.qld.gov.au/housing/buying-owning-home/feed-in-tariff-regional-queensland [Accessed 10 May 2018].
SIMPSON, G. & KAFTA, F. 1977. *Basic Statistics,* New Delhi, Oxford and IBH.
UNITED STATES ENVIRONMENTAL PROTECTION AGENCY 2016. Direct Emissions from Mobile Combustion Sources. website.
VICK, B. D. & ALMAS, L. K. 2011. Developing Wind and/or Solar Powered Crop Irrigation Systems for the Great Plains. *Applied engineering in agriculture*.
VICK, B. D. & CLARK, R. N. 2009. Determining the optimum solar water pumping system for domestic use, livestock watering or irrigation. *Solar 2009 : Buffalo/Niagara, May 11-16, 2009 : proceedings of the 38th ASES National Solar Conference, proceedings of the 34th National Passive Solar Conference, proceedings of the 4th Annual Renewable Energy Policy, Advocacy and Marketing Conference / edited by R. Campbell-Howe*.
VICK, B. D. & NEAL, B. A. 2012. Analysis of off-grid hybrid wind turbine/solar PV water pumping systems. *Solar Energy,* 86**,** 1197-1207.