Milestone 7.5 – May 2020

Proceedings of the Australian Society of Sugar Cane Technologists, volume 42, 375–385, 2020

ASSCT

Peer-reviewed paper

Adapting solar energy to irrigated sugarcane production at Bundaberg, Queensland

MG Haines[1] and G Davis[2,3]

[1]Bundaberg Sugar Services Limited, Bundaberg, Qld 4670; mhaines@sugarservices.com.au
[2]Queensland Farmers' Federation and [3]Australian Rivers Institute, Griffith University, Brisbane, Qld

Abstract The concept of renewable and Hybrid Energy systems (HESs) are highlighting opportunities for electrification of isolated or energy-deficient areas, and where grid-supplied electricity costs exceed these alternatives. The concept of utilising solar photovoltaic (PV) as an energy source for irrigation in sugarcane production has been promoted by grower representatives and governments as a solution to the energy trilemma, particularly the escalating cost of grid-supplied electricity. However, there is a deficit of independent, publicly available data on the true value proposition of solar in this context. The critical issue is whether such a system is capable of maintaining the peak irrigation requirement for the daytime energy demands of current sugarcane production; and whether solar powered systems could change irrigation management practice leading to increased farm productivity. Adoption of new technology is limited by knowledge around capability and viability, particularly where the technology is to be deployed to meet a specific crop demand, such as irrigated sugarcane production, and where significant capital investment will be required. A demonstration and evaluation trial of new energy technologies on-farm was installed at Bundaberg to overcome barriers to adoption, such as attaining proof-of-concept and to provide financiers with confidence to support the capital expenditure required. This paper outlines the design specifications and crop considerations associated with the adoption of HES across a range of irrigation methods utilised in the Australian sugar industry. The Bundaberg project also trialled ECODRIVE Variable Speed Drive (VSD) technology in combination with solar, providing an opportunity to test the benefits of lower pump motor energy demand with a hybrid or blended system that enables longer daytime operating hours to meet the motor energy requirement regardless of time-of-day or atmospheric conditions. Variable speed technology also provides ongoing cost reduction during night-time operation. The hypothesis posed is, can a solar system provide a stand-alone energy supply for sugarcane farming operations that have high seasonal demand for irrigation and, if not, what combinations of solar and grid or other energy are the most efficient. This project has demonstrated that when optimally designed, HESs prove to be more reliable and economical than single energy source systems for irrigation and can lead to productivity gains.

Key words Sugarcane, Bundaberg, renewable, hybrid energy systems

INTRODUCTION

Bundaberg is located on the coast of Queensland with the local government area covering 6,433km^2. It has an average daily temperature range of 15.8°C to 26.7°C and an average rainfall of 996mm (Queensland Treasury, 2019). Agriculture is a significant employer in the area, directly employing 3,217 people, representing over 10% of the working population, and making agriculture the third largest employment sector in the area after retail and health care. This is consistent with 21% of registered businesses (1,360 businesses) in the region being agricultural (Queensland Treasury 2019).

Sugarcane is critical for the wellbeing of the area. Bundaberg is the fourth-largest sugarcane-growing region in Queensland, supporting three sugar mills and exporting opportunities via the Bundaberg Port located at the mouth of the Burnett River. The sugarcane sector provides around $440 million of local economic activity and supports 1,800 full time jobs (CANEGROWERS 2019). However, the sugarcane industry is experiencing a decline which is due to a decrease in the land allocated to sugarcane production as farmer's diversify to higher-value horticultural products.

The area has also been drought declared several times over the past decade, with the most recent drought declaration for the area announced on 1 May 2019 (Queensland Government 2019). These factors have negatively impacted on total sugarcane production levels in the area jeopardizing the viability of existing infrastructure, critical to the financial and employment prosperity of the region. As such, it is essential that sugarcane productivity is maximised through the efficient use of inputs (namely irrigation water and energy), as energy and water are inextricably connected in agricultural systems (Davis 2018).

Hybrid Energy Systems (HES) can provide more reliable and economical energy than single-source energy systems (Aziz *et al.* 2019). However, their design and scale require critical consideration as it determines the behaviour of the system, not least the stability of the system, continuity of power, cost of the energy (Aziz *et al.* 2019) and wear and tear on critical components such as irrigation pumps. In grid-connected systems the energy management strategy is critical to balance irrigation pump requirements and continuous operation while being mindful of the source of energy and its associated costs.

Based on outcomes of sugarcane farm irrigation energy efficiency audits conducted at Bundaberg (2008 to 2017) several major farm irrigation redevelopment projects were undertaken to transition irrigation methods from high pressure travelling gun to low pressure lateral move.

Participating growers found that they achieved a significant yield increase resulting from introduction of a system with capacity to deliver summertime peak crop water demand and gained significant reduction in energy demand from low pressure operation which translated into a lower cost of energy per ML of irrigation applied.

The same growers also found that when energy cost and time of use constraints to operation imposed by grid tariff structures (*e.g.* high cost day time and/or summer time use) were no longer at the forefront of decision making the focus of farm planning returned to the agronomic timing and inputs required to achieve higher yielding crops.

These outcomes posed this hypothesis; for farming situations where replacement of travelling gun systems with low pressure overhead applicators is not feasible due to farm layout and topographical or water supply constraints:

1. Could a HES be developed and proven to deliver similar combined effect of cost reduction and greater operational freedom without the constraints of tariff cost and time of use restrictions; and
2. Could this system improve yield potential?

A trial site to test the potential of a solar-grid HES with travelling gun irrigation was proposed by the Bundaberg Regional Irrigators Group (BRIG) which represents irrigators in the Bundaberg district across a range of commodity groups including sugar cane, grain crops and horticulture. Funding was acquired in 2018 for a project titled 'Adapting Renewable Energy Concepts to Irrigated Sugar Cane Production at Bundaberg' from the Australian Renewable Energy Agency (ARENA).

INCREASING ELECTRICITY PRICE

Escalating energy costs associated with irrigation coupled with low commodity prices have impacted on the reliably of sugarcane production in the Bundaberg region. The following example illustrates the dilemma confronting irrigators; peak (daytime) and off peak (night-time) cost (c/kWh) for Ergon Tariff 62 and 65 which were commonly used by local irrigators escalated by 230% from 2008 to 2018.

Daytime irrigation operation with travelling gun irrigation reached a cost that is out of proportion with the value of the commodity being produced. A critical statistic is that the actual cost differential between peak and off-peak became much greater (Figure 1) by virtue of equal price rises on the lower priced off peak and high price peak. Irrigators were forced to take up one of two options: (a) cease daytime operation and accept the inevitable drop in production as a result of applying less annual water than is adequate to meet crop moisture demand; or (b) investigate alternative energy options for daytime operation.

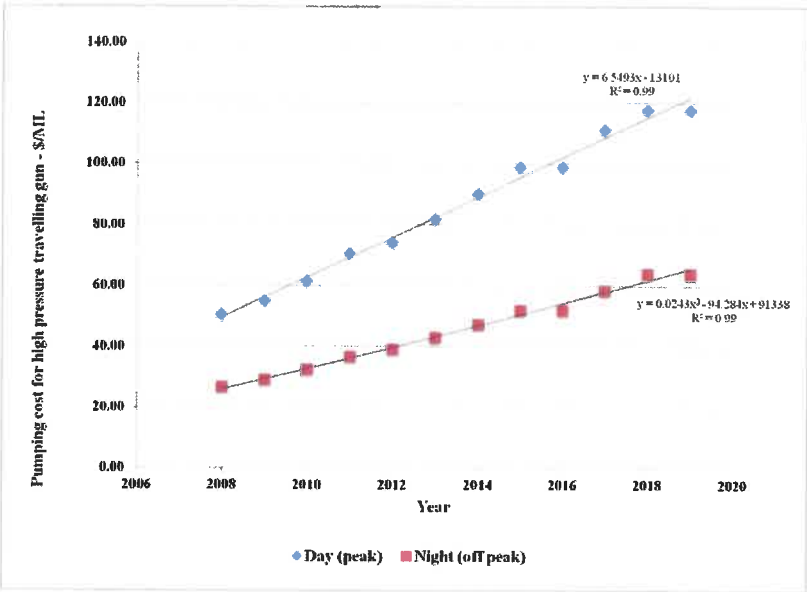

Figure 1. Energy price increase 2007–2018 for peak and off-peak compared as $/ML of water pumped.

RENEWABLE ENERGY OPTIONS

The main growth period for the Bundaberg sugarcane crop is from October to March. This aligns with the longest days of the year, which provides a potential for farmers to harness the benefit of solar energy for irrigation. Solar PV generation has the potential to reduce energy cost with travelling gun irrigation, but what configuration and size should such a system be? Queensland energy regulations limit grid connected solar PV with feed-in tariff (FIT) to 30 kW (AC) that poses the question; how many hours per day would a 38 kW (DC) – 30 kW (AC) system offset the grid requirement of currently installed irrigation systems and would FIT (9 c/kWh) sufficiently offset the cost of grid energy required in excess of solar input? Solar radiation and ambient air temperatures also have substantial impacts on the output of solar PV systems (Aziz *et al.* 2019). Bundaberg Sugar Services Ltd who manage 11 dedicated sugar-industry weather stations provided information about cloud impact on daily solar radiation potential (Figure 2) that showed atmospheric conditions would play a significant role in the configuration of the system selected for trial. This potential for a high level of solar-radiation intermittency demonstrated the need for HES technology to ensure continuous pumping operation during daylight hours.

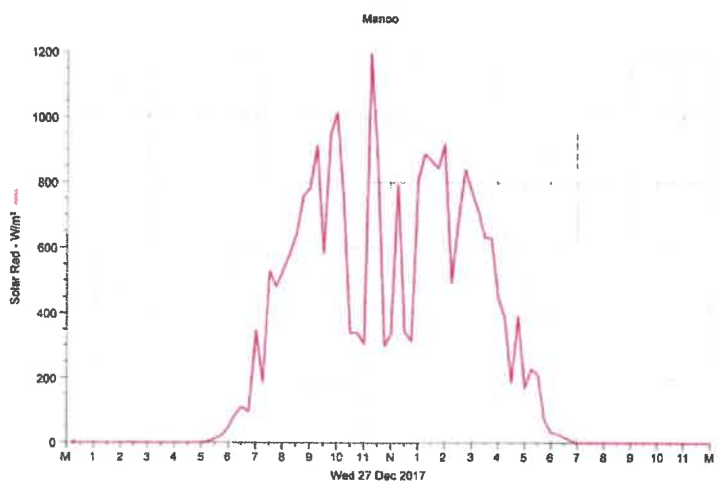

Figure 2. Example of cloud-induced solar-radiation intermittency at Bundaberg.

SUGARCANE MOISTURE DEMAND

The highest priority of farm irrigation systems is to provide production security for income sustainability and profitability. To successfully incorporate HES into sugarcane cropping, system design should focus on capacity to deliver daily peak moisture requirement to limit crop water deficits with the objective of achieving potential crop yield.

It is generally accepted at Bundaberg that a yield potential of 10–12 t cane/ML of effective rainfall + irrigation is readily achievable (Kingston 1994). Haines and Linedale (2006) reported industry efforts to achieve optimal production showing historical data from monitoring of farm level outcomes which included annual yield based on actual farm management factors. Individual farm data correlated into a district result indicated that the yield to effective rain + irrigation increased from 1989 (7.4 t cane/ML) to 2004 (9.7 t cane/ML).

The established benchmark for average E_T/mm/day at peak growth in Bundaberg is 6.7–7.1 (Kingston and Ham 1975). It is therefore essential that design of HES irrigation takes in to account this benchmark. Pumping demand (ML/day) increases as the season progresses and whole-of-farm crop E_T/mm/day develops in combination with temperature, day length and the relative crop canopy factors for each specific crop category (Figure 3).

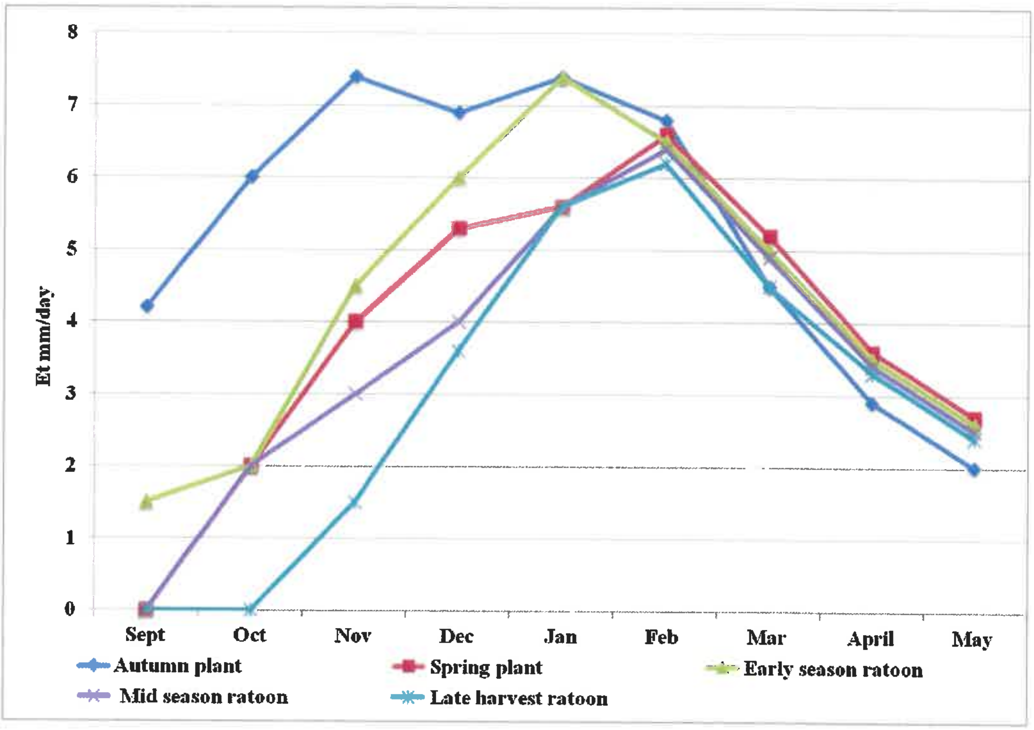

Figure 3. Estimated crop E_T/mm/day for different sugarcane crop-development stages at Bundaberg.

PERFORMANCE OF IRRIGATION PUMPING SYSTEMS

Current irrigation methodology at Bundaberg is predominately travelling-gun irrigation systems that operate at sprinkler pressures between 490 kPa and 590 kPa and average water application flow rate is 26 L/s; energy demand is 35–50 kWh (Table 1).

Excessively high pump operating pressures are common and are generally the outcome of pumping installation design where a gate valve restriction is applied to the delivery pipe on the pressure side of the pump to stabilize underground mainline and sprinkler pressure to design capacity. These practices exert heavy loads on pumping systems, which results in excessive energy costs. HES with variable speed technology will effectively reduce energy demand where these practices exist by reducing pump shaft loads.

Table 1. Indicative data from Bundaberg Irrigation Energy Use Audit Program.

Site	Motor energy kW/h	Pump flow rate L/s	Pump pressure kPa	Sprinkler pressure kPa	Energy use/ML kWh/ML
1	42	24	1158	588	480
2	30	25	930	480	336
3	45	25	910	490	496
4	47	31	813	482	416
5	49	27	737	580	500
6	40	28	790	580	392
7	48	29	735	586	460
8	39	24	800	588	451
9	36	21	861	490	483
10	36	27	862	636	370
Average	41	26	860	550	438

IRRIGATION DEMAND PLANNING AND SCHEDULING

The full benefit of the HES will only be realised if the supply capacity of the system and the delivery capacity of the field application method are compatible. The Adapting Solar Energy to Irrigated Sugarcane Production at Bundaberg, Queensland trial chose a travelling-gun system, which is noted for lower application efficiency than most other methods, to test HES ability against relatively low flow rates over extended pumping hours. Irrigation demand planning identified crop water requirement relative to effective rainfall and crop development stage which enabled estimates of peak mm/month irrigation demand. The required monthly irrigation volume (ML) relative to the hourly irrigation distribution volume (L/h) determines the scheduled pumping days/month and hours/day (Table 2). The plan shows the delivery time (3,251 h/year) to deliver peak irrigation (304 ML/year) through a system applying 26 L/s.

Table 2. HES (50 ha) trial irrigation-demand plan including crop-water demand, monthly irrigation-demand and operational monthly and daily hours.

Daily crop moisture demand (mm/day = E_T x crop factor)	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	
Average crop water use (mm/day)	1.1	2.4	4.1	5.2	6.2	6.5	4.8	3.3	2.4	
Farm irrigation demand	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Total (mm)**
Monthly crop demand (mm/month	34	74	122	160	192	182	149	100	76	1090
Monthly average effective rainfall (mm/month)	21	41	58	90	123	127	91	52	62	664
Effective crop moisture deficit (mm/month)	13	34	64	70	70	55	58	48	14	426
Gross irrigation required (mm/month) @ 70% efficiency factor	19	48	92	101	100	78	83	69	19	609
Irrigation schedule – Farm area 50 ha	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Total**
Irrigation volume required (ML/month)	9	24	46	50	50	39	42	35	10	304 ML
Irrigation operating hrs/month	101	256	491	537	532	418	444	370	103	3251 h
Scheduled irrigation days/month	6	12	23	25	25	21	23	18	16	168 days
Scheduled pumping hrs/day	17	21	22	22	21	20	19	21	7	

The distance between each irrigation travel path (lane) plays a significant role in the application efficiency of travelling-gun irrigation systems. Gordon (2000) reported on Bundaberg travelling gun irrigation trials with 75 m lane spacing (approximately 45 sugarcane rows). Twenty-five percent of the trials achieved application uniformity efficiency above 80% and 15% were below 60%. Uniformity of the remaining 60% of tests were between 60 and 80%, a median application efficiency of 70% was adopted for irrigation scheduling strategies when preparing the design of the HES trial. When the operating travel speed is 20 m/h on a 75 m travel path, the travelling gun effectively irrigates 0.15 ha/h. Average flow rate 26 L/s (0.0936 ML/h) irrigates 1 ha every 6.66 hours applying 64 mm, which at 70% application efficiency delivers an effective irrigation application of 45 mm. The scheduling plan indicates that at least 10 irrigation cycles per season are required which will require 400 m irrigation travel paths to support operating hours up 22 hours per day. The HES with travelling gun will need to operate for 3251 hours per year to offset potential peak crop water deficits on 50 ha.

HYBRID ENERGY SYSTEM (HES) TRIAL

Bundaberg Regional Irrigators Group (BRIG) formed a project steering committee comprising: Dr Georgina Davis – Queensland Farmers' Federation (QFF); Axel Braunsberger – Ergon Energy; Tim Couchman – Australian Renewable Energy Agency (ARENA); and Maurie Haines – Bundaberg Sugar Services Limited (BSSL). Expressions of interest (EOIs) were opened to select a suitable local farm site to conduct the trial. The Killer Family property at Sharon, west of Bundaberg was selected from six applicants.

Technical support

BRIG sourced technical advice from Gem Energy Australia (solar energy specialists), Sunfam Bundaberg (irrigation pump suppliers), Reaqua (solar pumping specialists) and Zenner Electric Pty Ltd (ECODRIVE variable speed drive) to design, supply and install the trial equipment. The system solar PV array subsequently installed included 240 panels x 340 W (81.6 kW), 45 kW motor, centrifugal pump, and variable speed ECODRIVE system. This system was designed to be a HES that would provide a seamless transition between clear and cloudy daytime conditions and/or night operation. A trial-site weather station and soil-moisture monitor were installed to record solar radiation and crop utilisation of available soil moisture.

HES trial design

The solar PV array consisting of 240 north-facing 340 W solar PV panels (81.6 kW) was assembled into 16 strings with each string of panels linked to the central pumping point by individual cable. The new 45 kW electric motor is rated 10–15% more energy efficient than the previous unit and designed to manage overheating issues when operating at low or varying speeds. The new pump is an ISO rated unit with improved efficiency due to internal design features that improve the flow of water through the pump.

The selected pump site is typical of many in the Bundaberg region; it is connected to the SunWater Bundaberg Irrigation Area (BIA) scheme which supplies irrigation water to the site at positive head. Incoming pressure of 103 kPa was recorded prior to the redevelopment of the pumping system. The ECODRIVE is connected to the solar PV (DC) and grid supplied (AC). The HES utilises energy from solar PV and grid (if required) by day and grid exclusively by night. Figure 4 shows how the ECODRIVE draws on both the solar and grid energy source.

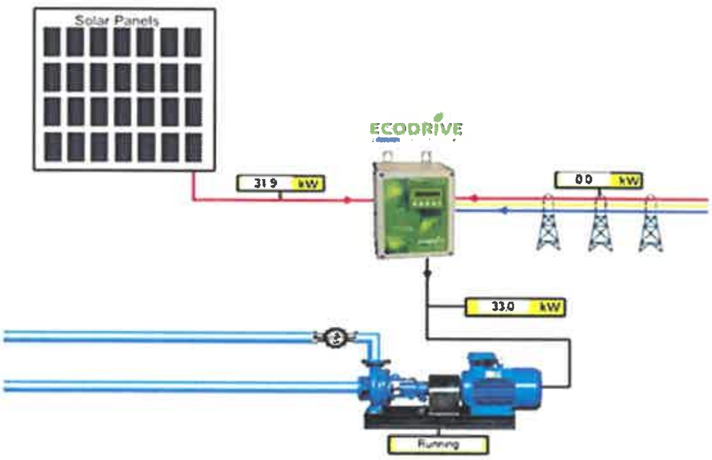

Figure 4. Illustration of solar and grid connected ECODRIVE.

The ECODRIVE fitted to the trial utilises the inflow pressure and manages the motor speed to maintain a constant pressure to the travelling irrigator within design specifications of the underground pipeline resulting in less power demand to operate the pump. This means that by day the solar system supplies a significant portion of the pump requirements and when operating periods extend into night-time there is continuous operation at substantially reduced kW/h demand due to the energy management capacity of the variable speed ECODRIVE. The blending potential is particularly pronounced when the transition from day to night is occurring (Figure 5).

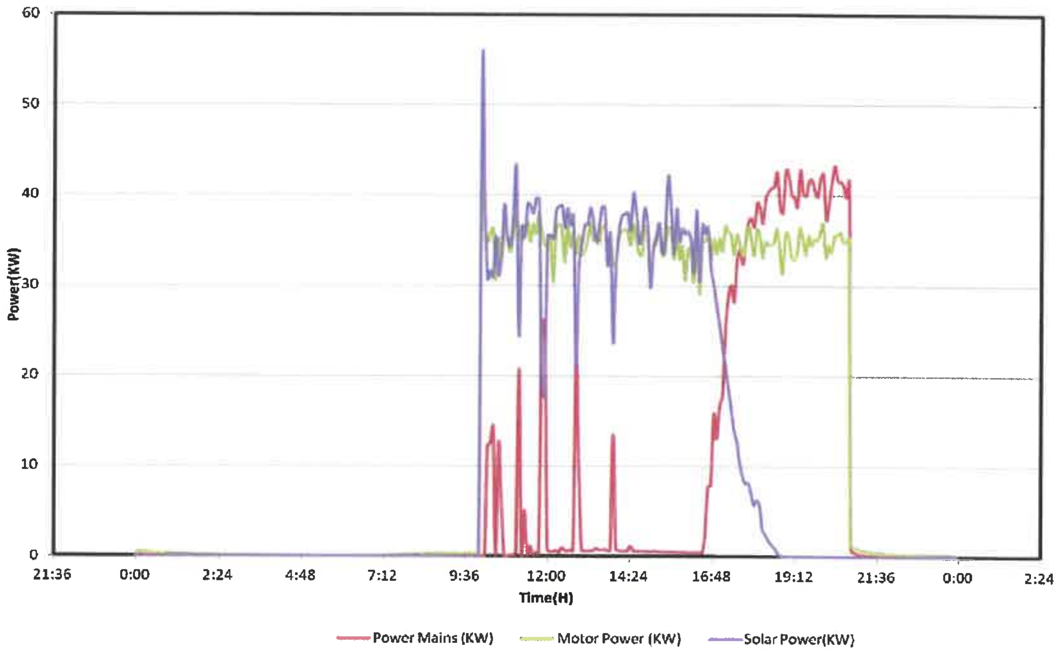

Figure 5. ECODRIVE management of variable solar-energy supply and pump-motor demand.

RESULTS AND DISCUSSION

Bundaberg average annual rainfall (1942–2019) indicates that the highest annual rainfall occurred in 1971 at 1,892 mm, and the lowest was in 2001 at 488 mm (BOM 2019). This indicates that Bundaberg weather patterns are highly variable and reliable irrigation capacity is needed to deliver crop demand in low rainfall years. The coastal location of Bundaberg often results in cloudy conditions mainly driven by sea breeze even in years of low rainfall, which impacts on solar generation capacity.

This trial has been conducted during a period of drought and weather monitoring indicates that sunrise to sunset hours since to the project commenced are 8,200 hours over 650 days but hours of radiation above the threshold 400 W/m^2 required to maintain continuous standalone operation of the pumping system was just 46% (3,760 hours or 5.8 h/day).

The trial has shown capacity to deliver up to 10 h/day (potentially 6,500 trial hours), which is 80% of available hours. Trial data (Figure 6) illustrating cumulative energy use during daytime hours indicates the mix of grid and solar energy utilised.

Two significant issues are evident: (1) grid energy was regularly required to assist with maintenance of threshold demand; and (2) solar energy use trend declines at approximately 10 h/day, which is in line with the design expectations of the system.

A pre-trial audit indicated that pump motor energy demand was 39 kW h to deliver 24 L/s, which is 451 kWh/ML. System monitoring since the installation of the HES has noted a flow rate increase from 24 to 26 L/s and recorded significant energy reduction and cost saving (Table 3) related to VSD and solar components of the HES.

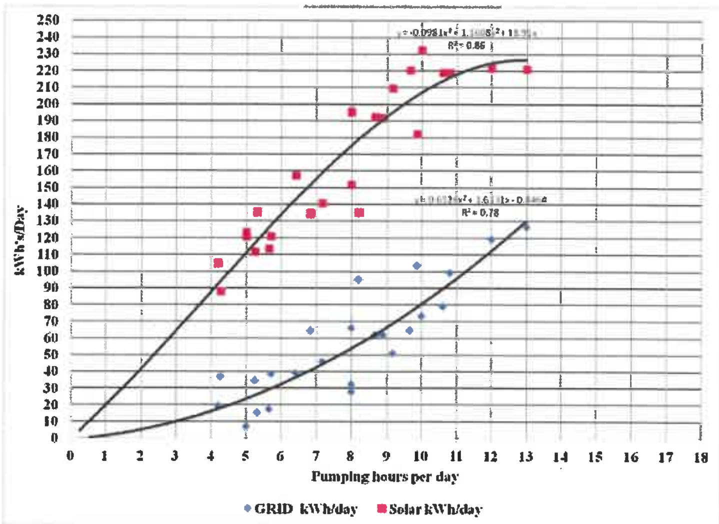

Figure 6. Energy-use trends with ECODRIVE technology.

Table 3. Energy reduction and cost saving in the HES trial.

Business as usual – Original pumping system 39 kWh grid connected to Ergon Tariff 20 (24.43 c/kWh)				
Run Hours	Pumped ML	Mains kWh	kWh/ML	Cost/ML ($)
1,850	167	72,150	451	110.2
HES Trial – Solar/Ecodrive/Grid connected to Ergon Tariff 20 (24.43 c/kWh)				
Run Hours	Pumped ML	Mains kWh	kWh/ML	Cost/ML ($)
1,850	167	16,520	99	24.2
HES Trial – Break down of energy supply and saving				
VSD saving kWh	Solar saving kWh	Mains kWh	Total kWh saved	Total saving ($)
21,125	34,427	16,520	55,552	13,571

The crop-moisture demand plan indicates that a combination of 3,251 day or night operating hours are required if crop productivity on 50 ha is to be sustained. Analysis of irrigation and energy options (Figure 7) for a range of irrigated areas indicates that the trial system would sustain a mix of 37% solar and 24% grid up to 30 ha; the cumulative solar input would then decline and the grid input increase to a grid/solar equilibrium at 42 ha.

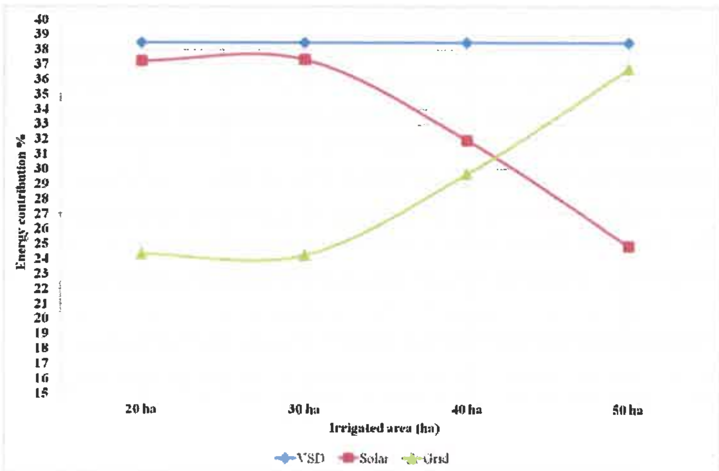

Figure 7. Energy mix per irrigated area.

Significant energy reduction and cost benefits are demonstrated (Table 4) when indicative HES trial information is applied to a range of irrigated farming scenarios. Energy use pre-trial (39 kWh) compared to the operating trial situation indicates a potential HES energy reduction of 31,443 kWh with a 20-ha scenario, increasing to 65,674 kWh for the 50-ha scenario.

Farm economic potential with HES (Table 5) assumes that HES enables increased water utilisation (2.6 ML) to all scenarios leading to an estimated 34% income increase.

Table 4. Energy (kWh) and Ergon tariff cost for pre-trial and HES scenarios. This reflects potential energy and cost savings for the HES when fully utilised.

Farm area (ha)	Grid pre-trial (kWh)	Tariff 20 @ 24.43 c/kWh ($)	HES Solar/Grid (kWh)	Tariff 20 @ 24.43 c/kWh ($)	HES Energy saving (kWh)	HES Cost saving ($)
50	103,836	$25,253	38,162	$9,281	65,674	$16,045
40	83,068	$20,202	24,609	$5,985	58,459	$14,283
30	62,301	$15,152	15,674	$3,812	46,627	$11,392
20	41,534	$10,101	10,091	$2,454	31,443	$7,682

Table 5. Potential farm income gain with pre-trial and HES scenarios. Income based on a sugarcane price of $37.00/t cane less $7.00/t cane harvesting cost.

Farm area (ha)	Historic irrigation (ML/ha)	Historic yield (t cane/ha)	Potential irrigation (ML/ha)	Potential yield (t cane/ha)	Historic income (@$30/t cane)	Potential income (@$30/t cane)	Potential gain ($/ha)
50	2.5	82	5.1	110	$123,000	$165,000	$42,000
40	2.5	82	5.1	110	$98,400	$132,000	$33,600
30	2.5	82	5.1	110	$73,800	$99,000	$25,200
20	2.5	82	5.1	110	$49,200	$66,000	$16,800

Tables 4 and 5 indicate potential combined reduction in energy cost and increase in production value of $24,482 (20 ha) up to $58,045 (50 ha). The lower economic gain from smaller production areas (20 ha) is likely to extend the HES cost recovery time beyond an acceptable rate of return. This may be accentuated by variability in capital cost for HES which can vary with geographic location resulting in construction regulations (*e.g.* wind force rating) and market driven HES component costs. Lowering energy demand through conventional efficiency measures coupled with grid connected solar PV with FIT is likely to be the most cost-effective option on smaller production areas.

The trial indicates that HES has capacity to supply the required irrigation volume to 50 ha at 63% energy reduction; however, this pumping capacity may be underutilised by the operational capability of the irrigation application method. To achieve the potential applied volume with the travelling irrigator the capability to operate 22 hours/day will be necessary; this may be unachievable in some farming situations. HES is likely to deliver most benefit on areas of 40 to 50 ha, particularly where irrigation systems with lower operating pressure and higher flow rates such as centre pivot or lateral move are suited.

Cost-recovery time (payback) is generally considered to be the benchmark to assess the economic value of solar investment particularly in the household situation where energy demand will not differ greatly, and the most apparent means of analysis is energy cost reduction. However, when applied to a business situation such as the trial farming enterprise, the cost recovery is less defined.

The HES trial indicated that it will lower the energy cost of daily operation but to what extent this cost reduction will contribute to recovery of original installation cost will be determined by the amount of annual utilisation of the system. The HES has an operational life of up to 25 years over which time it may lay idle during years with favourable weather conditions or may be the catalyst to increase crop yields during less favourable years. The HES should be evaluated in a similar way to other farm machinery and treated as a production tool which has the ability to enhance the enterprise economic value. To ensure that the economic gains are not lost through taxation, the current Australian tax rules may allow equipment of this nature to attract a 100% write down in the year of purchase.

The trial HES was designed for the purpose of testing the concept and as such there were costs incurred that may not apply to future purchase of a HES designed for specific farm situation. For the purpose of evaluation of cost recovery potential, the cost of the trial equipment ($150,300) is compared in Table 6 to the energy savings (Table 4) and the potential production gains (Table 5). This comparison indicates that a system of this nature is unlikely to be viable on smaller production areas without a strong commitment to increased productivity gain. However, the system has potential for production areas of 40 to 50 ha which should be able to incorporate the system into the economic structure of the farming operation and even with variable seasonal conditions be able to achieve full recovery in a relatively short period of time.

Table 6. Cost-recovery analysis.

Scenario	Production (ha)	Purchase cost ($)	Energy saving ($)	Yield economic gain ($)	Cost recovery years
Energy reduction only	20	$150,300	$7,682	na	19.6
	30	$150,300	$11,392	na	13.2
	40	$150,300	$14,283	na	10.5
	50	$150,300	$16,045	na	9.4
Energy saving and production gain	20	$150,300	$7,682	$16,800	6.1
	30	$150,300	$11,392	$25,200	4.1
	40	$150,300	$14,283	$33,600	3.1
	50	$150,300	$16,045	$42,000	2.6

CONCLUSIONS

Variability in climate is continuing to affect water availability and put new stresses on energy systems (particularly in constrained areas), but the degree of future impacts is uncertain, particularly given the changing climate patterns moving towards increasing frequency and the duration of drought conditions, coupled with extreme weather events (Davis 2018). Hybrid Energy Systems represent a technological solution to improve efficiencies and ultimately productivity.

The use of HES offers a sound solution for pumping irrigation water. While the amount of power sourced from the solar PV installation is insufficient alone to operate the equipment, the utilisation of a secondary energy source is critical.

Australian decision-makers have alluded that innovation "*is the main driver of farm-level productivity growth, as farmers reduce costs by adopting more efficient technologies and management practices*" (ABARES, 2014, p3). However, this is overly simplistic. Adoption in new, innovative technologies has largely been driven by the lack of sustainability of the 'business as usual' approach. Furthermore, farmers who have adopted/implemented innovation (particularly in energy efficiency) have found that any potential savings that were identified in the project planning stage have been subsumed in the unsustainable increasing cost of electricity (Davis 2018).

REFERENCES

Aziz AS, Tajuddin M, Adzman MR, Ramli M, Mekhilef S (2019) Energy management and optimisation of a PV/diesel/battery hybrid energy system using a combined dispatch strategy. *Sustainability* 11: 683.

Bureau of Meteorology (2019) Monthly rainfall Bundaberg Areo. http://www.bom.gov.au/jsp/ncc/cdio/weatherData/av?p_nccObsCode =139&p_display_type=dataFile&p_startYear=&p_c=&p_stn_num=039128 (accessed 18 November 2019).

CANEGROWERS (2019) *The Economic Contribution of the Sugarcane Industry to Queensland and its Regional Communities*. Report July 2019, Queensland Economic Advocacy Solutions, Brisbane.

Davis G (2018) The impact of climate changes and environmental pollution on our life: the question of sustainability. In *The Climate Change-Energy-Water Nexus and Its Impacts on Queensland's Farming Sector* (Eds A Omran, O Schwarz-Herion), pp. 97–126. Springer, Wiesbaden.

Gordon G (2000) *Performance of travelling gun irrigators*. Honours thesis, University of Southern Queensland.

Gray E, Oss-Emer M, Yu S (2014) *Australian Agricultural Productivity Growth: Past Reforms and Future Opportunities. Research Report 14.2.* Australian Bureau of Agricultural and Resource Economics and Sciences, Canberra.

Haines MG, Linedale AI (2006) Impact of a sustained water use efficiency program in the Bundaberg district. *Proceedings of the Australian Society of Sugar Cane Technologists* 28: 173–180.

Kingston G, Ham GJ (1975) Water requirements and irrigation scheduling of sugarcane in Queensland. Part 1. *Proceedings of the Queensland Society of Sugar Cane Technologists* 42: 57–65.

Queensland Government (2019) Long Paddock Drought Situation Mapping. https://www.longpaddock.qld.gov.au/drought/drought-declarations/ (accessed 27 October 2019).

Queensland Treasury (2019) *Queensland Regional Profiles: Workforce Profile. Bundaberg Local Government Area.* Queensland Government Statisticians Office, Brisbane (report generated 27 October 2019).