Milestone D7.4 – Attachment G

# Desktop Analysis of Solar PV Hybrid Energy Irrigation Potential at Bundaberg

**Introduction**

A trial of Solar PV hybrid energy irrigation at Bundaberg was conducted on a sugarcane and peanut farm at Sharon west of Bundaberg from January 2018 to May 2020. The trial equipment included 82.5 kW solar array linked to a 45 kW Zenner ECODRIVE motor frequency management system which accessed supply from both DC solar and AC grid energy supplies. The principal of the ECODRIVE is primarily access DC to meet the pump motor demand and as a secondary (supplementary) supply blend AC from the grid to manage shortfalls in solar PV output.

The role of this desktop analysis is to utilise information collated during the trial process to examine the potential of the hybrid energy concept in other irrigation locations and methods of application.

A comparison of three scenarios is considered which includes:

- Outcomes of the current trial of travelling gun irrigation with the limitations of farm layout identified in the trial;
- A equivalent system operated on a farm layout considered to be the most efficient for travelling gun operation on a similar area of cropping land; and
- Replacement of the travelling gun irrigation on the most efficient layout with a low pressure lateral move irrigator.

Aspects of the daily operational hours (day v night), potential productivity and energy cost/savings are analysed.

**Benchmark**

The benchmark irrigation system for this analysis it the travelling gun irrigation system. Travelling gun irrigation method was first introduced into the Bundaberg district sugar industry in the 1970's and 1980's and remains the prominent method of overhead irrigation today.

A significant number of Bundaberg farms receive water from the Bundaberg Irrigation Area (BIA) supply system which is a Queensland Government owned irrigation scheme operated by SunWater. This piped water supply is delivered at a range of pressures generally from 7 – 200 kpa and in some put sites inflow pressure exceeds this range. The supply system flow rates for a majority of pump sites are 30 l/sec which is generally the required supply to support travelling gun operation.

Generally, the pumping system design for travelling irrigation methods is a 100 x 75mm centrifugal pump driven by a 45 kW electric motor with a gate valve system to manage pump output pressure within farm irrigation system distribution design capacity. This process has ensured that in many cases the created internal pump pressure exceeds the sprinkler and distribution operational demand.

A travelling gun irrigator energy audit conducted at Bundaberg (Table 1) indicated that mean energy demand by pumping systems applying water to the travelling guns is 41kW.h. The gate valve management strategy results in mean pump discharge pressure greater than the sprinkler and distribution system demand which after allowance for friction loss in the distribution pipes, valves and hoses etc rarely exceeds 700kpa which is 211 kpa less than audited mean pump pressure 911 kpa.

Design of the hybrid energy trial took this issue into account and included Variable Frequency Drive (VFD) technology to minimise excessive demand of energy. In the trial situation the VFD ECODRIVE lowered the specific pump pressure from 1310 kpa to 700 kpa which reduced the hourly demand from 39kW.h to 29kW.h. This energy reduction potential has been applied to all scenarios discussed in this irrigation system analysis.

Table 1 – Travelling gun audit data

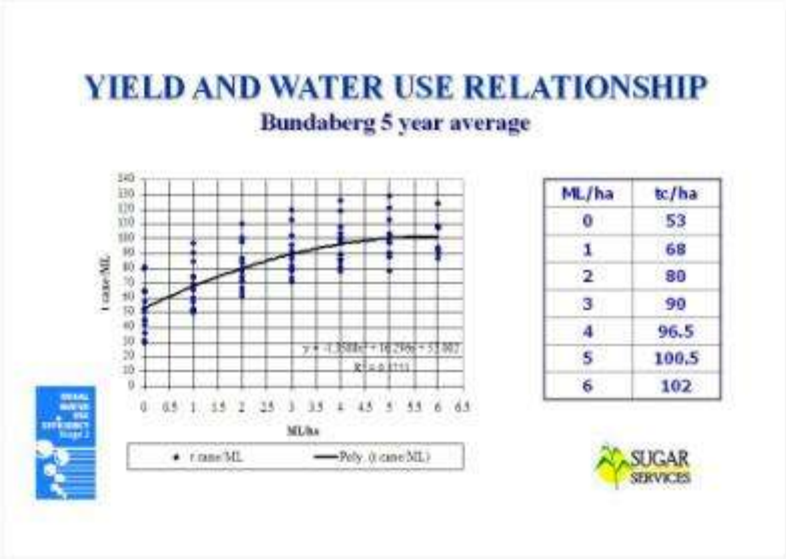
| Site | Motor | Pump flow | Pump | Sprinkler | Energy | Spray |
|---|---|---|---|---|---|---|
| | | rate | pressure | pressure | use | wetted |
| | kWh | l/sec | kpa | kpa | kWh/ML | radius m |
| 1 | 42 | 24 | 1158 | 588 | 480 | 124 |
| 2 | 30 | 25 | 930 | 480 | 336 | 120 |
| 3 | 45 | 25 | 910 | 490 | 496 | 120 |
| 4 | 47 | 31 | 813 | 482 | 416 | 130 |
| 5 | 49 | 27 | 737 | 580 | 500 | 130 |
| 6 | 40 | 28 | 790 | 580 | 392 | 130 |
| 7 | 48 | 29 | 735 | 586 | 460 | 132 |
| 8 | 39 | 24 | 1310 | 588 | 451 | 126 |
| 9 | 36 | 21 | 861 | 490 | 483 | 118 |
| 10 | 36 | 27 | 862 | 636 | 370 | 130 |
| Mean | 41 | 26 | 911 | 550 | 438 | 126 |

The travelling gun irrigation method is struggling to maintain local sugar industry production with current energy costs and the prevalence of highly variable seasonal conditions. The Bundaberg region is currently under drought declaration which has been the situation more often than not over recent years. An application efficiency factor of 0.75 is also applied to travelling gun systems due to issues with wind and single sprinkler overlapping requirements. These issues are not as prevalent with low pressure overhead systems and an efficiency factor of 0.9 is generally applied wit lateral move irrigation.

This desktop analysis will illustrate the difficulties that occur when irrigating a farm of irrigular shape with a system such as travelling gun. Travelling gun was once seen as the most approriate for irrigular shaped lanscapes because of the flexibility that a hose operated system allowed; this is a resonable assumption when the system is required to supplement mean annual rainfall. However, as rainfall totals diminish the demand for increased irrigation is required and the benificial effect of the extra input cost is determined by the compatibility of the distribution system to the specific land area under irrigation.

Benchmark data in Figure 1 (Yield and Water Use Relationships) shows that Bundaberg sugarcane yield response to increased irrigation follows the normal principal of diminishing returns. The data shown is based on mean annual rainfall with yield for no irrigation (dryland) at 53 tonnes cane per hectare (tc/ha) which increases by about 15 tc/ha for the first ML/ha of irrigation applied, 12 tc/ha for the next ML/ha and 10 tc/ha for the third ML/ha. The fourth extra (4) ML/ha produces an extra 6 tc/ha while moving from 4 to 5 ML/ha generates an extra 4 tc/ha.

Figure 1



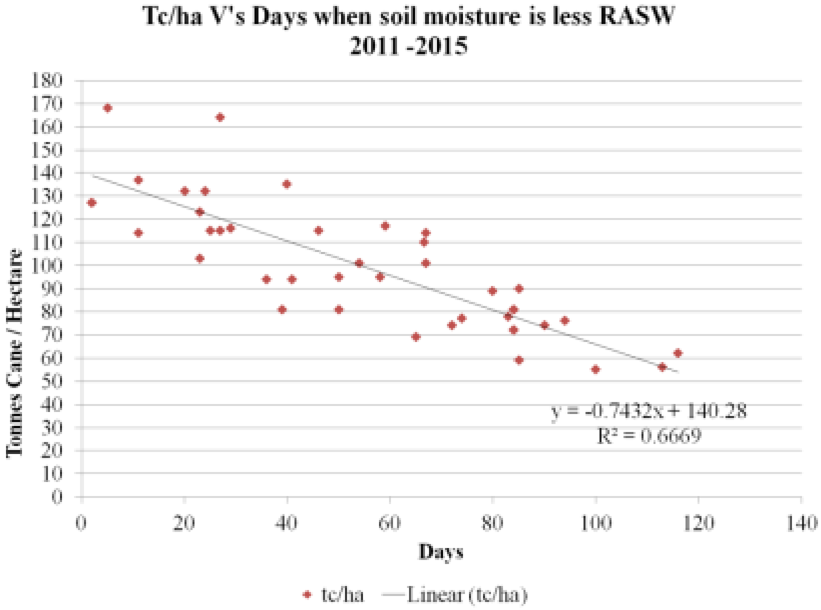

This production curve is based on indicative information formulated from 5 consecutive years of Bundaberg district metered irrigation water use data and yield reports from Bundaberg Sugar Company mill crushing data. The data points in Figure 1 represent the range of yield outcomes for each ML/ha of irrigation applied. The yield data reflects the yield outcome after the impact of irrigation management, irrigation efficiency, rainfall efficiency and other incalculable factors that impact of crop production. Calculations based on the benchmark shown in Table 2 illustrate yield potential with reducing annual rainfall under similar crop reducing management and operational factors.

Table 2 – Yield impact and irrigation demand with reducing rainfall

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 100% = Mean annual rainfall 1020 mm ( 10.2 ML/ha) | | | | | | | |
| tc/ha | 53 | 68 | 80 | 90 | 96 | 100 | 102 |
| Eff rainfall | 7.14 | 7.14 | 7.14 | 7.14 | 7.14 | 7.14 | 7.14 |
| Irrigation | 0 | 1 | 2 | 3 | 4 | 5 | 6 |
| Tc/ML (effective rain + irigation) | 7.42 | 8.35 | 8.75 | 8.88 | 8.62 | 8.24 | 7.76 |
| | | | | | | | |
| 80% = Mean annual rainfall 1020 mm ( 8.16 ML/ha) | | | | | | | |
| tc/ha | 42 | 56 | 67 | 77 | 84 | 88 | 91 |
| Eff rainfall | 5.71 | 5.71 | 5.71 | 5.71 | 5.71 | 5.71 | 5.71 |
| Irrigation | 0 | 1 | 2 | 3 | 4 | 5 | 6 |
| Tc/ML (effective rain + irigation) | 7.42 | 8.35 | 8.75 | 8.88 | 8.62 | 8.24 | 7.76 |
| | | | | | | | |
| 60% = Mean annual rainfall 1020 mm ( 6.12 ML/ha) | | | | | | | |
| tc/ha | 32 | 44 | 55 | 65 | 71 | 76 | 80 |
| Eff rainfall | 4.28 | 4.28 | 4.28 | 4.28 | 4.28 | 4.28 | 4.28 |
| Irrigation | 0 | 1 | 2 | 3 | 4 | 5 | 6 |
| Tc/ML (effective rain + irigation) | 7.42 | 8.35 | 8.75 | 8.88 | 8.62 | 8.24 | 7.76 |

Crop water balance monitoring has been conducted at Bundaberg since 2011 to assist sugarcane growers to improve their irrigation scheduling efficiency. During this monitoring program a yield loss of 0.74 tc/ha for each day of stress was identified which highlights the potential economic cost of lengthy irrigation cycles. This information is shown in Figure 3.

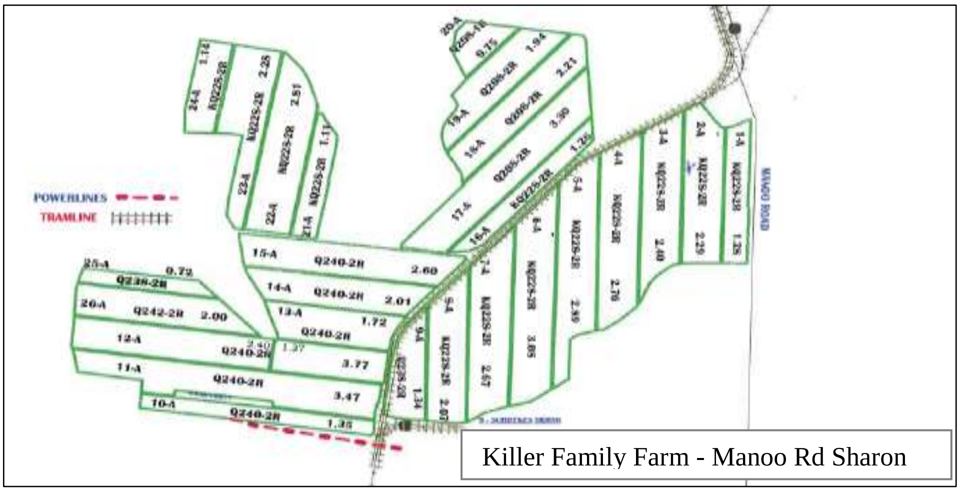
Figure 3 – Impact of stress days on sugarcane production




**Trial site 1 - Analysis of solar PV trial farm with travelling gun**

A characteristic of the trial farm (Figure 2) is the lack of row length uniformity which is influenced by the farm boundary and is also not aided by the Bundaberg Sugar Company cane railway line that divides the property into two sections. This results in variability in length of irrigator travel paths which ensures that operating hours change on a daily basis but more importantly each path is of sufficient length that it is rarely possibly to irrigate more than one path per day.

Figure 2 Trial Farm Map




Under the current farm irrigation plan each irrigation cycle applies approximately 70 mm which is sufficient to maintain steady crop growth for approximately 14 days across the main crop growth period (October to April). Each irrigation cycle is 23 days which is 9 days more than water applied will support the crop which leads to a potential 9 days of crop stress each irrigation cycle.

Additionally, two extra hours of pumping is required each day (one hour at each end of the travel path) to wet up the ends of the field which equates to 46 additional pumped hours per cycle.

During periods of mean rainfall, cycling deficits exert less impact on the final yield as rainfall supplements the irrigation during these periods. However, during periods of below mean rainfall the number of irrigation cycles per season must increase if the required volume of water needed to balance annual crop water demand is to be achieved.

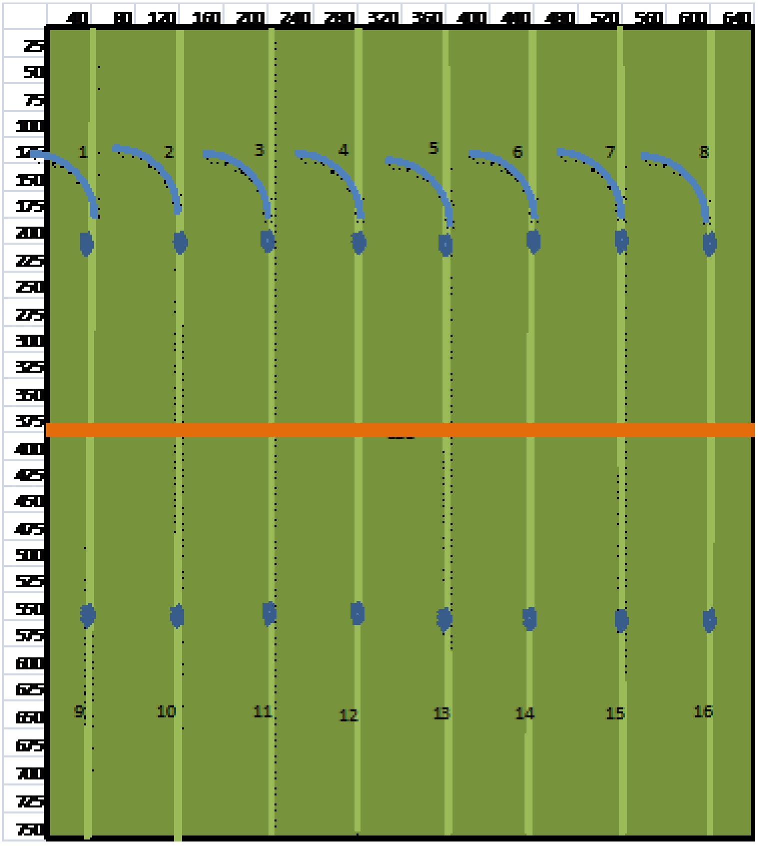
Unfortunately, additional volumes provide limited increase to productivity if the system lacks the capacity to deliver the required water within the crop demand period. The issues of application capacity such as the previously mentioned 9 deficit days per cycle can regularly occur with farms irrigated by big travelling irrigation systems.

**Trial site 2 – Analysis of best option travelling gun**

This option (Figure 3) provides for 16 travel paths requiring 18 hours per day including one hour per day for end wet up (288 hrs per cycle). Variable length travel paths are not an issue and the daily operating hours complete one path per day and the length of each cycle is reduced from the previous 23 to 16 days.

The volume of applied irrigation is reduced (70 – 52 mm) as the principal adopted is for a faster turnaround to reduce time between irrigation application; this system travels slightly quicker to ensure each 375 m run is completed each day. A sixteen (16) day irrigation cycle enables a reduction in deficit days from 9 to 5.5 days.

Figure 3 - Schematic diagram of best option plan for travelling gun

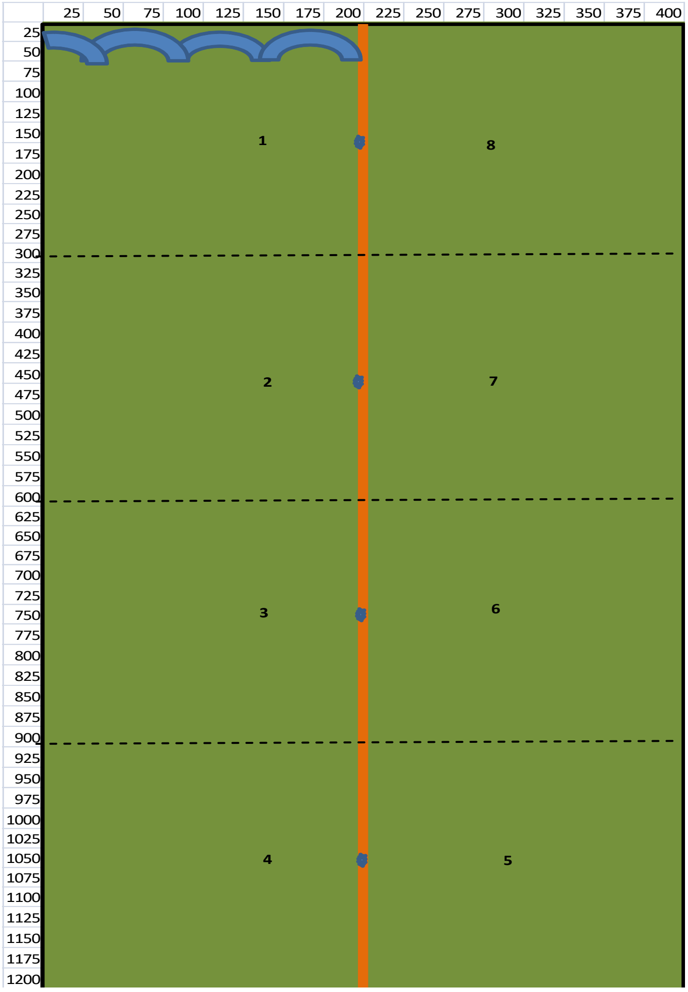



**Site 3 – analysis of a lateral move plan**

Lateral move irrigation systems provide a low pressure overhead option for farming enterprises that have a rectangular farm. It is also necessary to have access to higher flow rate from the district irrigation supply as the required flow if often twice that required for the travelling gun. It is possible to combine the allocated flow of two outlets into one to supply the lateral move.

Lower operating pressure usually means that energy demand per ML is much less than the high-pressure operation of the travelling gun.

Figure 4 - Schematic diagram of lateral move irrigation plan




The lateral move has one travel path down the centre of the farm where the water supply hydrants are placed at even intervals. The main control cart and hose travel along the centre path and the irrigator spans water down one side of the farm.

When the system reaches the end of the centre path the irrigator spans pivot around to the other side and the irrigation process is repeated on the return run. This plan takes 8 days to complete

For this lateral move analysis there are no deficit days between each irrigation cycle which allows the crop to maximise its growth potential. A yield of 10 tc/ML (effective rain + irrigation) is commonly accepted as a benchmark yield to water use factor when conditions are ideal (100% mean rainfall). For this study, a factor of 9 tc/ML is applied to the 80% of mean rainfall scenario and 7.5 tc/ML to the 60% of mean rainfall scenario. The lower factors are in recognition of weather related issues (abnormal wind, temperature and humidity) that impact crop growth during unseasonal and drought conditions.

## Analysis of study scenarios

Table 3 –Results of scenario 1 (trial farm with travelling gun)

| Long term average rainfall % | Flow Rate | Pumping Hours | Irrigation per cycle | Application Rate | Crop Demand | Irrigation Cycle | Cycle Deficit | Annual Irrigation | Annual irrigation | Annual volume applied |
|---|---|---|---|---|---|---|---|---|---|---|
| | L/sec | day | ML | mm | days supplied | days | days | days required | cycles | ML/ha |
| 100 | 26 | 15.25 | 32.85 | 68 | 13.7 | 23 | 9.3 | 105 | 4.55 | 3.1 |
| 80 | 26 | 15.25 | 32.85 | 68 | 13.7 | 23 | 9.3 | 144 | 6.3 | 4.3 |
| 60 | 26 | 15.25 | 32.85 | 68 | 13.7 | 23 | 9.3 | 184 | 8.0 | 5.5 |

| Long term average rainfall % | Irrigator travel distance per year | Irrigated Area | Pumping Hours | Irrigation hrs/day | Irrigation hrs/night | Irrigation per year | Solar PV per year | Grid energy per year | Potential production |
|---|---|---|---|---|---|---|---|---|---|
| | meters | Ha | per year | average per cycle | average per cycle | no of cycles | kWh | kWh | Tc/ha |
| 100 | 34622 | 48 | 1594 | 10 | 5.25 | 4.55 | 26346 | 18285 | 90 |
| 80 | 47766 | 48 | 2199 | 10 | 5.25 | 6.3 | 36348 | 25227 | 86 |
| 60 | 60909 | 48 | 2804 | 10 | 5.25 | 8.0 | 46350 | 32169 | 78 |

| Long term average rainfall % | Yield | Grid energy | Solar PV | Total energy | Energy use /tc | Solar PV energy saving | Solar PV energy |
|---|---|---|---|---|---|---|---|
| | Tc/ha/yr | kWh/yr | kWh/yr | kWh/yr | kWh/tc/yr | kWh/tc/yr | % of total consumption |
| 100 | 4320 | 18285 | 26346 | 44631 | 10.33 | 6.1 | 59 |
| 80 | 4128 | 25227 | 36348 | 61575 | 14.91 | 8.8 | 59 |
| 60 | 3744 | 32169 | 46350 | 78519 | 20.97 | 12.4 | 59 |

Table 4 –Results of scenario 2 (best option farm layout with travelling gun)

| Long term average rainfall % | Flow Rate | Pumping Hours | Irrigation per cycle | Application Rate | Crop Demand | Irrigation Cycle | Cycle Deficit | Annual Irrigation | Annual irrigation | Annual volume applied |
|---|---|---|---|---|---|---|---|---|---|---|
| | L/sec | day | ML | Mm | days supplied | days | days | days required | cycles | ML/ha |
| 100 | 26 | 18 | 26.96 | 56 | 11.2 | 16 | 4.8 | 105 | 6.6 | 3.7 |
| 80 | 26 | 18 | 26.96 | 56 | 11.2 | 16 | 4.8 | 144 | 9.0 | 5.0 |
| 60 | 26 | 18 | 26.96 | 56 | 11.2 | 16 | 4.8 | 184 | 11.0 | 6.5 |

| Long term average rainfall % | Irrigator travel distance per year | Irrigated Area | Pumping Hours | Irrigation hrs/day | Irrigation hrs/night | Irrigation per year | Solar PV per year | Grid energy per year | Potential production |
|---|---|---|---|---|---|---|---|---|---|
| | meters | Ha | per year | average per cycle | average per cycle | no of cycles | kWh | kWh | Tc/ha |
| 100 | 39600 | 48 | 1882 | 10 | 8 | 6.6 | 27809 | 24882 | 94 |
| 80 | 54000 | 48 | 2596 | 10 | 8 | 9.0 | 38367 | 34328 | 88 |
| 60 | 66000 | 48 | 3311 | 10 | 8 | 11.0 | 48925 | 43775 | 82 |

| Long term average rainfall % | Yield | Grid energy | Solar PV | Total energy | Energy use /tc | Solar PV energy saving | Solar PV energy |
|---|---|---|---|---|---|---|---|
| | Tc/ha/yr | kWh/yr | kWh/yr | kWh/yr | kWh/tc/yr | kWh/tc/yr | % of total consumption |
| 100 | 4512 | 24882 | 27809 | 52691 | 11.67 | 6.2 | 53 |
| 80 | 4224 | 34328 | 38367 | 63594 | 17.20 | 9.0 | 53 |
| 60 | 3936 | 43775 | 48925 | 81094 | 23.55 | 12.4 | 53 |

Table 5 –Results of scenario (best option farm layout with lateral move irrigator)

| Long term average rainfall % | Flow Rate | Pumping Hours | Irrigation per cycle | Application Rate | Crop Demand | Irrigation Cycle | Cycle Deficit | Annual Irrigation | Annual irrigation | Annual volume applied |
|---|---|---|---|---|---|---|---|---|---|---|
| | L/sec | day | ML | Mm | days supplied | days | days | days required | cycles | ML/ha |
| 100 | 51 | 17.5 | 25.7 | 53 | 10.7 | 8 | 0 | 105 | 10.5 | 5.6 |
| 80 | 51 | 17.5 | 25.7 | 53 | 10.7 | 8 | 0 | 144 | 14.0 | 7.7 |
| 60 | 51 | 17.5 | 25.7 | 53 | 10.7 | 8 | 0 | 184 | 18.0 | 9.8 |

| Long term average rainfall % | Irrigator travel distance per year | Irrigated Area | Pumping Hours | Irrigation hrs/day | Irrigation hrs/night | Irrigation per year | Solar PV per year | Grid energy per year | Potential production |
|---|---|---|---|---|---|---|---|---|---|
| | meters | Ha | per year | average per cycle | average per cycle | no of cycles | kWh | kWh | Tc/ha |
| 100 | 25200 | 48 | 1464 | 10 | 7.5 | 10.5 | 22582 | 19906 | 126 |
| 80 | 33600 | 48 | 2019 | 10 | 7.5 | 14.0 | 31155 | 27463 | 116 |
| 60 | 43200 | 48 | 2575 | 10 | 7.5 | 18.0 | 39729 | 35020 | 106 |

| Long term average rainfall % | Yield | Grid energy | Solar PV | Total energy | Energy use /tc | Solar PV energy saving | Solar PV energy |
|---|---|---|---|---|---|---|---|
| | Tc/ha/yr | kWh/yr | kWh/yr | kWh/yr | kWh/tc/yr | kWh/tc/yr | % of total consumption |
| 100 | 6048 | 19906 | 22582 | 42488 | 7.02 | 3.7 | 53 |
| 80 | 5568 | 27463 | 31155 | 58618 | 10.52 | 5.6 | 53 |
| 60 | 5367 | 35020 | 39728 | 74748 | 13.92 | 7.4 | 53 |

## Discussion

The trial of solar PV at Bundaberg sought to investigate outcomes and options posed in this hypothesis; for farming situations where replacement of travelling gun systems with low pressure overhead applicators is not feasible due to farm layout and/or topographical or water supply constraints:

1. Could a Hybrid Energy System (HES) be developed and proven to deliver cost effect reduction in energy demand; and

2. Could this system improve yield potential through move effective use of resources?

Each scenario in this study was analysed on the basis that each system was operated strictly to its full capacity and the main objective was to maintain the soil water balance as close as possible to that required to meet the daily demands of a growing crop. Deficit days are shown in the data where system capacity was unable to meet daily demand over each cycle.

Rainfall data is based on the mean annual rainfall at Bundaberg (1020 mm). A factor of 0.7 is applied to determine crop production efficiency of annual rainfall. The energy reduction benefit (about 28%) attributable to variable frequency technology is applied to each site and has been removed from the energy cost applied to each scenario.

This desk top study has reviewed three options; the solar trial with travelling gun irrigation; a purpose designed farming example with travelling gun irrigation; and a purpose designed farming example with low pressure lateral move irrigation.

The trial site (1) is compromised by the farm plan which ensures that an excessive number of days are required to complete each irrigation cycle which ultimately leaves the crop with a moisture deficit between each irrigation event. This issue of deficit days is lesser issue in option (2) travelling gun on a specifically designed site and site (3) lateral move (also on a specifically designed site) theoretically experienced no deficit days.

Data summaries in tables 3, 4 and 5 indicate that the impact of system capacity, application efficiency and deficit days contributes to final yields which results in higher energy demand per tonne of sugarcane. This impact is illustrated in following example from the data set which shows how in years with 80 % of mean rainfall the potential yield for solar trial travelling gun is 86 tc/ha for 61575 kWh (9 deficit days) and best option farm travelling gun is 88 tc/ha for 63594 kWh (5.5 deficit days) which is in contrast to the potential yield for the same rainfall with the lateral move, 116 tc/ha for 58618 kWh with no deficit days.

It is apparent that the trial site gains some advantage in solar utilisation because the length of the travel paths limit the number of night time hours and thus the percent of the total energy mix supplied from solar PV is higher (59%) than scenarios 2 and 3 (53%). When this outcome is viewed in the context as a replacement of the previous travelling gun irrigation systems that operated at 39 kWh the total energy reduction from VFD plus Solar PV is in the range of 75 – 80%.

The question of whether to Hybrid Energy System installed at the trial site could deliver cost effective energy reduction needs to be considered in the context of full utilisation of the system. Unlike a normal grid connected irrigation system where limiting use will reduce energy bills and reduce yield which is not uncommon for irrigators to lower cost and accept lower yields when commodity values are low. A solar PV system is a portable generating system that needs to produce energy to offset the capital cost. The three scenarios considered in this study are based on maximising the system for potential yield.

## Conclusion

Using the pumping configuration prior to installation of the solar PV trial site ( pump energy use 39 kWh) as the benchmark both travelling gun sites (1 and 2) will have energy costs reducing from $9.36 to $1.90 per hour of pump operation (-$7.46). Energy costs are based on a tariff of 24 c/kWh and crop valuation is $30/tc net of harvesting cost and industry levies.

Site 1

| Long term average rainfall % | Pumping Hours | Solar PV energy saving $/hr | Solar PV energy saving $/hr |
|---|---|---|---|
| 100 | 1594 | 7.46 | 11891 |
| 80 | 2199 | 7.46 | 16404 |
| 60 | 2804 | 7.46 | 20917 |

Site 2

| Long term average rainfall % | Pumping Hours | Solar PV energy saving $/hr | Solar PV energy saving $/hr |
|---|---|---|---|
| 100 | 1882 | 7.46 | 14039 |
| 80 | 2596 | 7.46 | 19366 |
| 60 | 3311 | 7.46 | 24700 |

Examples 1 and 2 both experience the highest savings during the harshest weather periods which is likely to prove difficult to achieve in some instances and in others the potential for much needed financial assistance through an energy cost offset will be welcome in periods of drought.

The lateral move site (3) when compared against the established benchmark (e.g the solar PV trial) will show a similar reduction in grid energy cost ($7.46/hr) if the conversion is from high cost travelling operation to a solar powered lateral move and this scenario will also record a substantial yield increase through the higher efficiency in irrigation application and scheduling. A simultaneous move to both solar energy reduction and low-pressure lateral move irrigation will be a major capital expense however the potential annual financial benefit indicates that the timeline for return on investment is well within financing guidelines.

Site 3

| Long term average rainfall % | Pumping Hours | Solar PV energy saving $/hr | Solar PV energy saving $/hr | Productivity increase $/year | Total annual Benefit $ |
|---|---|---|---|---|---|
| 100 | 1882 | 7.46 | 14039 | 51840 | 65879 |
| 80 | 2596 | 7.46 | 19366 | 43200 | 62566 |
| 60 | 3311 | 7.46 | 24700 | 40320 | 65020 |

This study has not endeavoured to provide specific costing and estimates of pay back time as the systems discussed will vary in cost from location to location.