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Improving Energy Efficiency on Irrigated Australian Cotton Farms

Farm level benchmarking report of direct energy consumption in Australian irrigated cotton production

Improving energy efficiency on irrigated Australian cotton farms

Benchmarking Report

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Executive Summary

Executive Summary

The Australian Cotton Industry is one of the most highly mechanised sectors of the Australian broad-acre agricultural industries, and in particular, the irrigated component of this industry is subject to high levels of direct energy consumption in the form of diesel fuel and electricity.

This benchmarking report collates and analyses results collected at the farm level in the Australian Cotton Industry, and develops broad direct energy consumption metrics for irrigated Australian cotton production from a wide array of data sources. The outcomes from this benchmarking exercise clearly highlight that there are opportunities for growers to identify practices where energy consumption is high, and modify to reduce direct energy use on farm.

Key findings from this work for Australian irrigated cotton growers include:

- The median direct energy use per hectare from a total of 198 whole of farm energy assessments in this study is 11.2 GJ per hectare,
- The middle 50% of growers from the total dataset used between 7.4 and 16.4 GJ per hectare of direct energy in fully irrigated cotton production,
- These results, within the error bounds of the assessment processes applied in this study, are closely aligned with results from recent studies across seven farms where direct energy use was 10 GJ per hectare,
- With a median yield across 198 results of 10.7 bales per hectare, the median direct energy use is 1.1 GJ per bale,
- Generally, half of the direct energy consumed will be through irrigation, and about 25% will be used for high load tractor operations during the field prep and post-harvest phases of cotton production,
    - a single pump make and model is used to pump up to 60% of the water volume in the industry, and uses up to 30% of the total direct energy of the industry
    - significant tractor energy savings of up to 20% are possible with correction of tractor and implement setup
- Diesel fuel provides at least 90% of the direct energy used on farm,
- Expenditure on diesel fuel is at least 85% of the total direct energy expenditure,
- The median direct energy expenditure across 198 farm results is $298 per hectare across the two separate data sets, and represents 8.5% of 2013 average cotton production costs reported in industry as $3627 per hectare,
- Median GHG emissions are 920 kg CO_2-e per hectare and 91 kg CO_2-e per bale across the total of 198 results, with the middle 50% of growers emitting between 575 and 1255 kg CO_2-e per hectare,

Key recommendations are that :

- Whole of farm energy use benchmarks are generated and incorporated into *my*BMP to allow individualised on-farm per year benchmarks characterised according to:
    - region / locality
    - amount of irrigation water used
    - irrigation system type (surface, CP&LM)
    - water sources / pump type (i.e. scheme, water harvesting, bore etc)
    - cropping practices

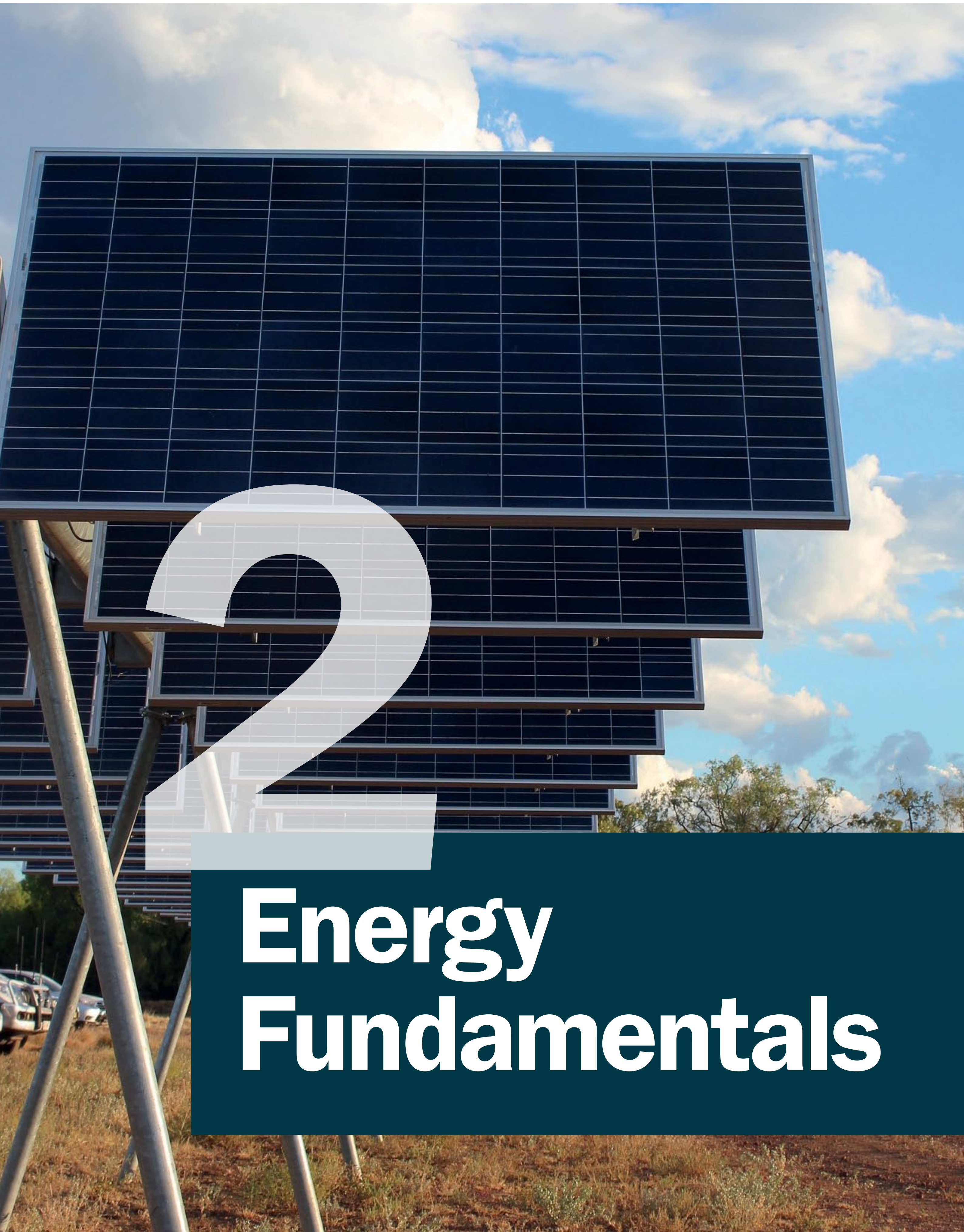
- A significant improvement in the application and use of simple energy measurement equipment is required across the industry, especially for large energy consuming equipment such as pump stations with water flowrate, pump shaft speed, pump pressures, and diesel fuel metering.
- Education on the fundamentals of irrigation pump station design and installation of appropriate monitoring points for routine evaluation of pump performance is required. Measurements could not be undertaken at a number of sites due to inaccessibility of measurement points for water flowrate and pressure
- Explore in more detail the large variation in direct energy expenditure experienced across the farm and the contributing factors (i.e. $90 to $740 per hectare).
- Identify the features of low energy farms and farming practices.
- As potential water savings in surface irrigated cotton fields can be 10 to 20%, and 20 to 40% in on-farm storages, every effort should be made to always conserve irrigation water at the field level, in distribution systems, and in water storages, as any water lost that has already been pumped is simply lost energy expenditure.
- While generally the focus has been on irrigation, it is apparent that tractor operations can be a significant component of direct energy use, and in some instances were up to 50%; greater analysis of tractor operations, farmer practice and appropriateness of machinery setup is required.
- Education on the fundamentals of tractor setup and performance (incorporating on-board tractor performance technologies i.e. IVT) is required once a more detailed assessment of tractor operations identifies particular issues experienced in industry.
- Incorporate the Level 1 analysis from this work into standard industry reporting such as Boyce & Co. Cotton Comparative Analysis reports.
- More awareness of, and support for the application of, the energy assessment methodology is required; some difficulties were encountered by industry service providers in undertaking these assessments, and the insights from Level 2 assessments conducted by industry service providers were limited.

1 Introduction

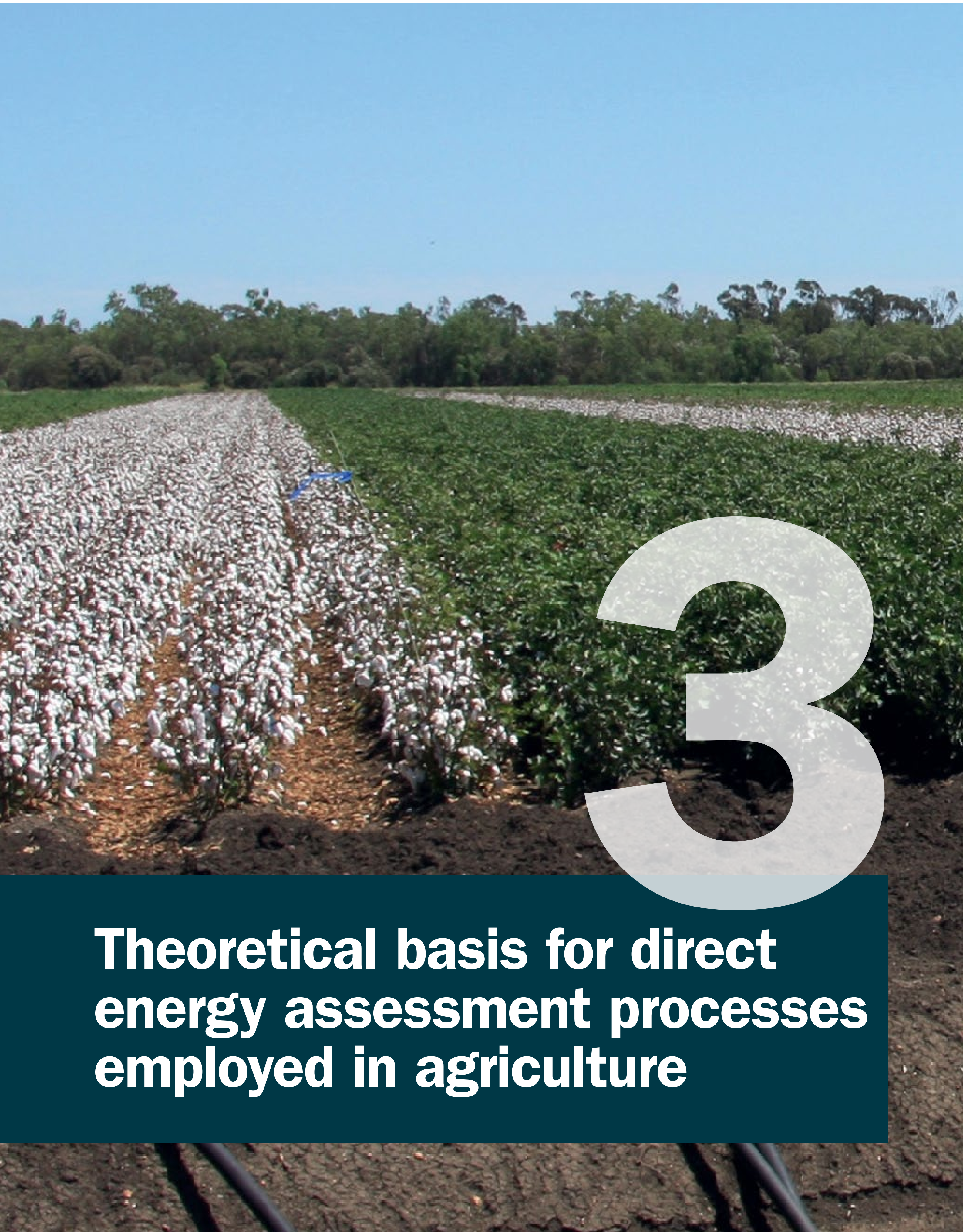
1. Introduction

This report is a result of the provision of Energy Efficiency Information Grant funding from the Department of Industry and Science to the Cotton Research and Development Corporation for the National Centre for Engineering in Agriculture at the University of Southern Queensland.

This direct energy use benchmarking report collates and analyses results from irrigated cotton production collected at: i) a whole of farm level, ii) for key production processes involved on farms, and iii) in a detailed way for particular practices on farm. The focus of this work is the irrigated Australian Cotton Industry and the direct energy use consumed in the process of fully irrigated cotton production. Broad measures of direct energy consumption for irrigated Australian cotton production have been obtained from a wide array of data sources. The outcomes from this benchmarking exercise clearly highlight that there are opportunities for growers to progress by identifying practices where energy consumption is high, and implement strategies to reduce direct energy consumption in particular processes.



2 Energy Fundamentals



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Theoretical basis for direct energy assessment processes employed in agriculture

2. Energy Fundamentals

Diesel or electrical energy are the most common forms of energy used on Australian farms to lift and move water and drive tractors up across soft tilled fields. A Litre of diesel contains 38.6 MegaJoules (MJ) of energy or 0.0386 GigaJoules (GJ) of energy. One kiloWatt-hour (kW.h) of electricity contains 3.6 MegaJoules (MJ) or 0.0036 GigaJoules (GJ) of energy.

One GigaJoule (GJ) of diesel energy is contained in 26 Litres of diesel, and at the current price of $1 per Litre of diesel this would cost $26. One GigaJoule (GJ) of electrical energy is contained in about 278 kiloWatt-hours(kW.h) of electricity, and at the current price of $0.25 per kW.h would cost about $70.

Unfortunately for business in the real world, large proportions of the energy we put into motors, tractors and pumps is always lost, often as heat and noise, as these machines are not 100% efficient and cannot convert all of the diesel and electrical energy we place into them, into useful motor output shaft rotating energy.

Based on realistic pumping industry values, the average pump efficiency is about 80%, the average drive train efficiency is 95%, the average large diesel motor efficiency is about 35% and the average electrical motor efficiency is about 90%.

Using these average values we can calculate that one ML of water lifted one metre of height using diesel driven pump systems will use about 0.96 Litres of diesel at a cost of $0.96. For an identical pumping system with an electrical motor, we can calculate that one ML of water lifted 1 metre of height would use 4.0 kiloWatt-hours (kW.h) of electricity at cost of $1. It is important to note that despite the very different efficiencies between diesel and electric motors, when translated to some work undertaken, the difference in diesel and electricity costs is not significant.

To pump 1 ML of water at a Total Dynamic Head (TDH) of 7 metres into on-farm storage using the realistic diesel pumping efficiencies previously stated, would use 6.72 Litres of diesel and cost $6.72. The same task completed using an electrical motor with the same pump system would use 28 kW.h, and cost $7.

In business, it is often simpler to think about what $100 worth of energy would allow you to do. The diesel driven pump system used in the example above would pump 14.9 ML into our storage at a TDH of 7 metres, and the electrically driven system with the identical pump would pump 14.3 ML into the same storage. These calculations are based on diesel fuel cost of $1 per Litre and average electricity prices of $0.25 per kiloWatt-hour (kW.h).

4 Whole farm direct energy use in irrigated cotton

3. Theoretical basis for direct energy assessment processes employed in agriculture

3.1 Introduction

The project proposal was developed on the basis of the methodology of Baillie and Chen (2008), whereby three distinctly separate levels of assessment were developed for Australian agricultural sectors in alignment with the Australian Standard AS3598 for Building Energy Assessments (2000). Baillie and Chen (2011) put forward this direct energy consumption assessment procedure for agricultural industries as a three level process. A Level 1 energy assessment is a preliminary assessment or broad overview of the direct energy consumption over the entire farm. A Level 2 energy assessment is termed a standard assessment and is a desktop study of the direct energy consumption of individual farming processes. A Level 3 energy assessment is an intensive detailed assessment of a particular item or component.

3.2 Proposed direct energy assessment process

This three level approach of preliminary, standard, and detailed assessments, allows an initial benchmarking overview of the direct energy consumption of the enterprise to: i) determine the relative level of the enterprise to others in the same agricultural sector, ii) highlight the necessity, or otherwise of a standard Level 2 assessment, and, iii) potentially a detailed Level 3 style of assessment. Each of these three levels of assessment would ideally be conducted by three different types of personnel, with skills appropriate to the measurement intensity of the assessment level.

A competent person should reasonably be able to complete a Level 1 assessment given the basic nature of the methodology, and that it has been embedded in the software EnergyCalc (Chen & Baillie 2007;Baillie et al 2009). EnergyCalc is software previously developed by NCEA, specifically to undertake on-farm energy assessments. From this software industry benchmarks can be provided.

A Level Two assessment is more detailed, focusses on key farming processes, and generally requires knowledge of typical duty cycles and fuel consumption rates of different in-field operations such as planting, harvesting and other tractor and pump based operations. The accuracy level for such an assessment should be better than ±20%. EnergyCalc can be used to undertake detailed Level 2 assessments.

A Level Three assessment requires site-specific measurement of duty cycle, load, energy consumption, production and other factors over an extended time period. Completing this work requires specialised knowledge, not only of the activity or process in question, but of the measurement, monitoring and logging techniques required to quantify the activity. This assessment process should be able to quantify energy use to better than ±10%.

4. Whole farm direct energy use in irrigated cotton

4.1 Level 1 Energy assessment process used for whole farm

The captured data set for the Level 1 benchmarking exercise reported here has come from two distinctly different data sets. The first of these has been captured during standard accounting processes by Boyce & Co Chartered Accounting of Moree for clients who are irrigated cotton growers. The second separate data set utilised has been sourced from Level 2 assessments previously captured by NCEA during funded work for the Cotton Research and Development Corporation. In total there are 158 whole of farm energy data sets captured in this study. These include up to four separate cotton production years from any single grower. Overall, there are between 60 and 94 enterprises involved in the Level 1 data set developed here and the results span across the financial years ending 2009 to 2014.

4.2 Profile of Farms used in Level 1 process

The profile of Australian irrigated cotton production enterprises captured in the whole of farm Level 1 analysis, grow between 37 and 8456 hectares of cotton, with a median area of 675 hectares of cotton. The middle 50% of growers grew between 261 and 1490 hectares of cotton. These enterprises have come from a selection with a geographic spread from the Macquarie valley in southern central NSW through to the Condamine-Balonne valley in southern Queensland, with at least 55% (87) of the sample of 158 clearly identified as enterprises based in NSW. Due to the nature of the Boyce data being recorded by valley in which it was grown, there will be a number of additional enterprises in the border river valley of the Macintyre (34) that were based in NSW. The overall proportion of NSW growers could be as high as 70%. It should also be noted that some of these will still be supplied by the Queensland electricity grid.

The middle 50% of growers had average farm yields for cotton of between 9.0 and 11.4 bales per hectare. The mean of the average farm yields was 10.2 bales per hectare across the 158 Level 1 enterprises captured in this study. Only 12 (7.5%) of the 158 data sets recorded a yield below 7.5 bales per hectare, and the maximum yield recorded in this data set was 13.3 bales per hectare. The data contained in the 158 records in the analysis, represent 211,000 hectares of cotton fields, producing 2.12 million bales of cotton, the majority of this produced over the cotton seasons ending in the years 2011 to 2014.

4.3 Assumptions used in whole farm Level 1 direct energy assessment process

Diesel price variation over the recent period is reflected in Table 1, and due to the substantial variation in diesel price in 2009, an alternative model of average annual price on-farm was developed from the average week-day diesel prices in any year (Aust. Inst. Petroleum 2015). Grower's bulk purchasing capacity and ability to store large volumes of fuel allows them to moderate the significant price fluctuations, the likes of which occurred in 2009 and 2011, as shown in the standard deviation of prices in Table 1.

The diesel fuel specific energy capacity value for this analysis was taken as 38.6 MJ per Litre of diesel, following the guidelines on emission factors (Dept of Env. 2014), whilst noting that the variation in energy density values provided by the three or four major refiners in Australia in their Material Safety Data Sheets has a range of 38.0 to 38.6 MJ per Litre of diesel.

Diesel consumption produces greenhouse gases and for this analysis, a value of 2.68 kg of CO_2 equivalent per litre of diesel was used. This is consistent with the National Greenhouse Accounts Factors (Dept of Env. 2014) and throughout reports produced by NCEA for CRDC in recent years (Sandell et al. 2013).

Table 1: On-Farm Diesel fuel price variation over recent years from Brisbane Terminal Gate Prices on week-days for the financial year ending, after all rebates and taxes have been returned. The last row contains the true on-farm fuel prices used in the diesel price analysis used in this report.

Financial Year Ending	2009	2010	2011	2012	2013	2014	2015
Average Diesel Price c/Litre including GST	131.2	115.9	127.2	137.3	136.8	146.3	131.8
Standard Deviation	23.4	3.8	9.6	3.7	3.8	2.8	10.3
Plus 8c/L freight	139.2	123.9	135.2	145.3	144.8	154.3	139.8
Less GST (10%)	126.5	112.7	122.9	132.1	131.6	140.3	127.1
Less Rebate (38.143c/L) On-Farm	88	75	85	94	93	102	89

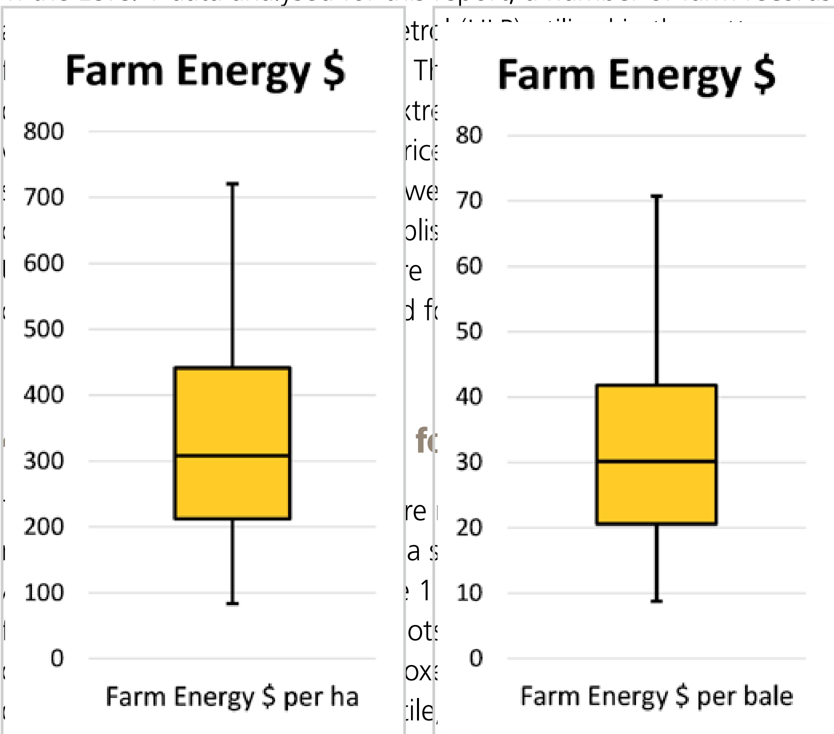
The electricity prices used for this analysis over the duration of the study are provided in Table 2, and these have been developed as averages for irrigation farmers from the range of tariffs available in the QLD and NSW electricity supply authorities. This allows a reasonably direct comparison between years and accounts for the variation in prices with years. These indicative prices are not meant to reflect any true tariff or tariffs, but are a generalised set of values that a range of growers might pay, on-average. This simplistic approach was taken in regard to electricity prices in this analysis due to the complexity of the tariff structures in both states.

Greenhouse gas production by electricity generators in each state was accounted for in this analysis by using a multiplication factor of 0.88 kg CO_2 equivalent per kW.h for NSW supplied growers, and 0.86 kg CO_2 equivalent per kW.h for QLD supplied growers.

Table 2: Averaged electricity prices in cents per kW.h for the years from 2009 to 2014 across QLD and NSW from a range of tariffs typically utilised by irrigated cotton growers.

Financial Year Ending	2009	2010	2011	2012	2013	2014
Averaged Electricity Price in cents per kW.h excluding GST	18	20	23	24	25	26

In the Level 1 data analysed for this report, a number of farm records contained information



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in this plot represent the 95th percentile and the 5th percentile. To put it another way, if there were one hundred growers in the sample, then 90 of them would be within the extremities of these whiskers.

From this Level 1 benchmarking data set represented in Figure 1, the combined energy and electricity expenditure for the middle 50% of growers ranges from $210 to $440 per hectare. The range of extremes (5th and 95th percentile) rises from about $90 to $720 per hectare, as shown by the ends of the vertical "whiskers" in the left plot in Figure 1. The lower end of this range is expected to come from partially or supplementary irrigated cotton production (12), and not fully surface irrigated systems with substantial water harvesting, tail-water pumping and ground water pumping into on-farm water storages.

The median direct energy expenditure during irrigated cotton production captured in this sample is $308 per hectare and $30.20 per bale. In other words, half of the growers (79) spent more than $308 per hectare on direct energy. CRDC and Boyce (2014) recently reported three year average production costs of $3627 per hectare and $358 per bale. Twenty-six of the 158 grower-years captured in this study had energy expenditure of over $500 per hectare on direct energy use. Importantly the range of expenditure is two-fold for the middle 50% of growers between the lower and upper quartiles.

Figure 1 : Energy expenditure on irrigation Australian cotton farms in $ per hectare and $ per bale, with the box plots in yellow capturing the upper quartile, median and lower quartile with black lines, while the upper and lower “whisker” extremes represent the 95th percentile and the 5th percentile, respectively.

In the 158 data sets from the Level 1 analysis, 12.8% of this group’s energy expenditure was on electricity (Figure 2), while the greatest proportion of expenditure was on diesel. These proportions are a direct representation of the whole farm accounting results used in this Level 1 benchmarking process. However, it is clear that individual growers pumping irrigation water solely with electricity have succumbed to substantial energy expenditure rises throughout Queensland and NSW over the last five years.

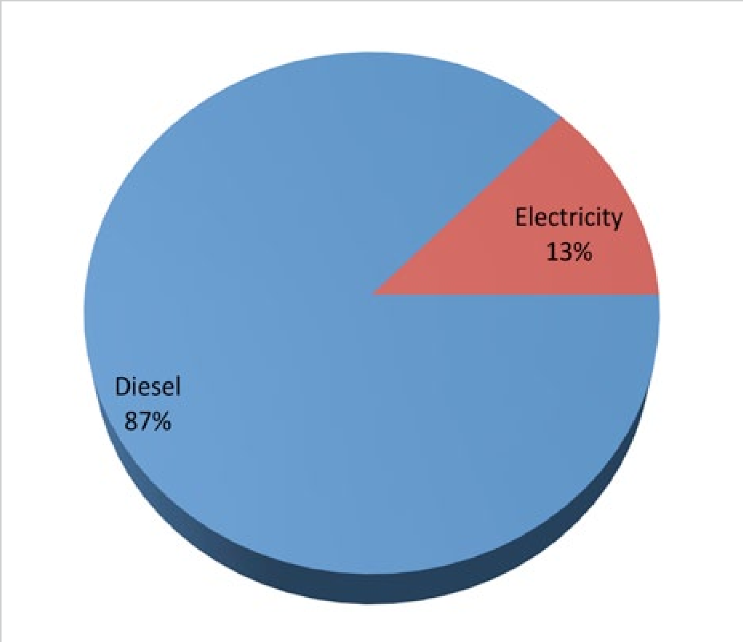


Figure 2 : The distribution of direct energy expenditure between diesel fuel and electricity from the sample of 158 data sets. On average roughly thirteen percent of the direct energy expenditure in this sample of Australian irrigated cotton growers was on electricity consumption.

The raw results indicate many instances of complete reliance on diesel as the energy source in the cotton production system. As this agricultural production system is heavily reliant on mobile diesel driven equipment and stationary diesel driven pumps, the greatest proportion of this electrical expenditure will be on electrically driven pumping plants, while smaller quantities will have been consumed on workshop and household functions.

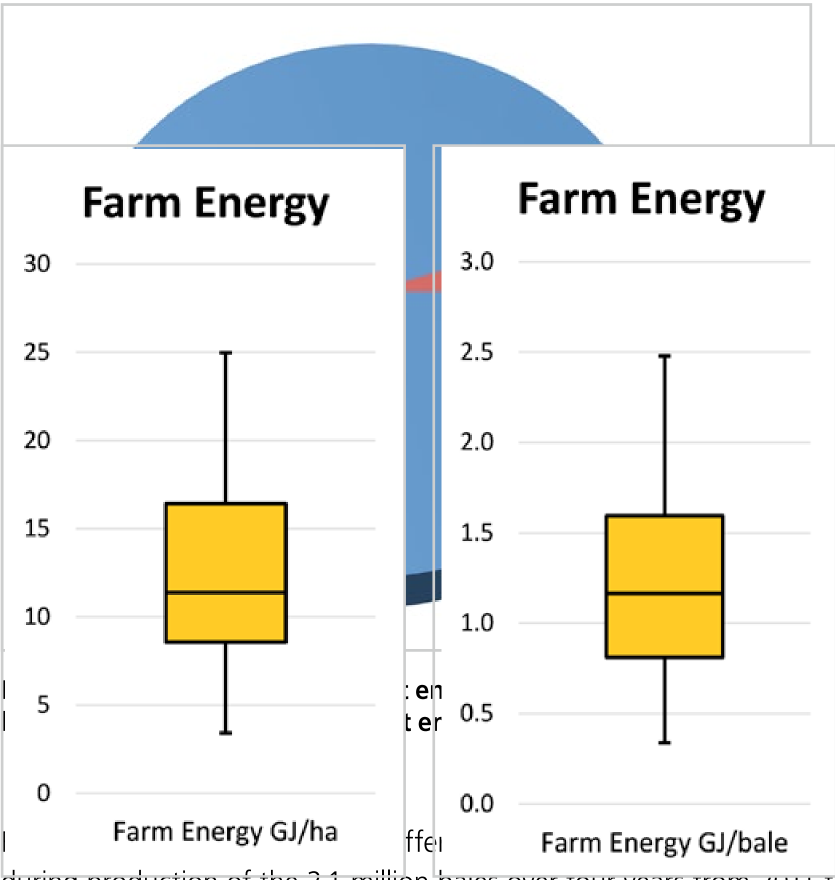
An analysis of 23 of the largest growers present in the total data set of 158 show that they have energy expenditure over $1 million per annum. These 23 growers account for nearly 1 million bales out of the total of 2.1 million bales of production over four years of production represented in the data. Their average production was 43,000 bales each.

Importantly, these 23 growers have an average annual expenditure of $1.55 million per annum on fuel and oil (range from $360,000 to $2.8 million per annum), while they only have an expenditure of $230,000 per annum on electricity, with a range from $17,000 to $693,000 per annum.

Of these 23 large producers, energy costs per hectare ranged from $150 to $750 per hectare, with an average of $450 per hectare, highlighting that the extreme ranges of energy consumption are evident in the data from larger producers with high levels of farm management input. This large range also suggests that substantial opportunity for improvement in energy use is possible within the industry.

The CRDC funded Boyce & Co. Cotton Comparative analysis from 2013 (CRDC & Boyce, 2014) reports that the three year average productions costs were $3627 per hectare and $358 per bale. The median direct energy expenditure from this data of $308 per hectare then represents 8.5% of the total crop production costs.

While growers on average expended 13% of their total direct energy budget on electricity, this only represented 5% of the actual total energy consumed on irrigated cotton farms in this study. This fact alone justifies the close scrutiny and high priority given to diesel engine performance and associated equipment, throughout the life of this project, and recent investigations of alternative fuels, and hybrid technologies.



n cotton production

irect energy consumption during production of the 2.1 million bales over four years from 2011 to 2014 was supplied by diesel fuel as presented in Figure 3.

The total of the direct energy quantity captured in the data from these 158 farms is 2.9 million GJs. The median energy consumption during irrigated cotton production from this data set, displayed in Figure 4, is 11.4 GJ per hectare and 1.2 GJ per bale. The middle 50% of growers had direct energy consumption between 8.6 and 16.4 GJ per hectare, roughly double the energy consumption of the upper quartile growers over the lower quartile energy users. These absolute results are sensitive to the unit prices of diesel fuel and electricity developed for this Level 1 analysis as presented in Table 1 and Table 2, but are not sensitive as relative measures of performance as these highlight opportunity for improvement, given the spread.

To provide a different view of the breadth of direct energy use across the sample of 158 data sets, Figure 5 displays the number of growers spread across increments of 2.5 GJ of energy per hectare increments.

On average growers in this study have paid $24.43 per GJ of liquid fuels like diesel, and $67.09 per GJ of electrical energy. While these costs might seem to provide a significant reason to favour diesel use over electricity, using published average efficiencies of diesel (33%) and electric (88%) motors, calculation of energy delivered at motor shafts amounts to $74 per GJ for diesel systems and $76 per GJ for electrical systems. So, as the costs of energy delivered by the motor shafts are about the same for both energy sources, electrical motor shaft energy delivered is only cheaper by the difference in the maintenance costs, and the capital cost for these different systems. This analysis is based on average energy costs per unit of $0.242 per kW.h and $0.938 per Litre of diesel.

Figure 4 : Energy consumption in GJ per hectare and per bale for irrigated Australian cotton production, with the box plots in yellow capturing the upper quartile, median and lower quartile with black lines, while the upper and lower "whisker" extremes represent the 95th percentile and the 5th percentile, respectively.

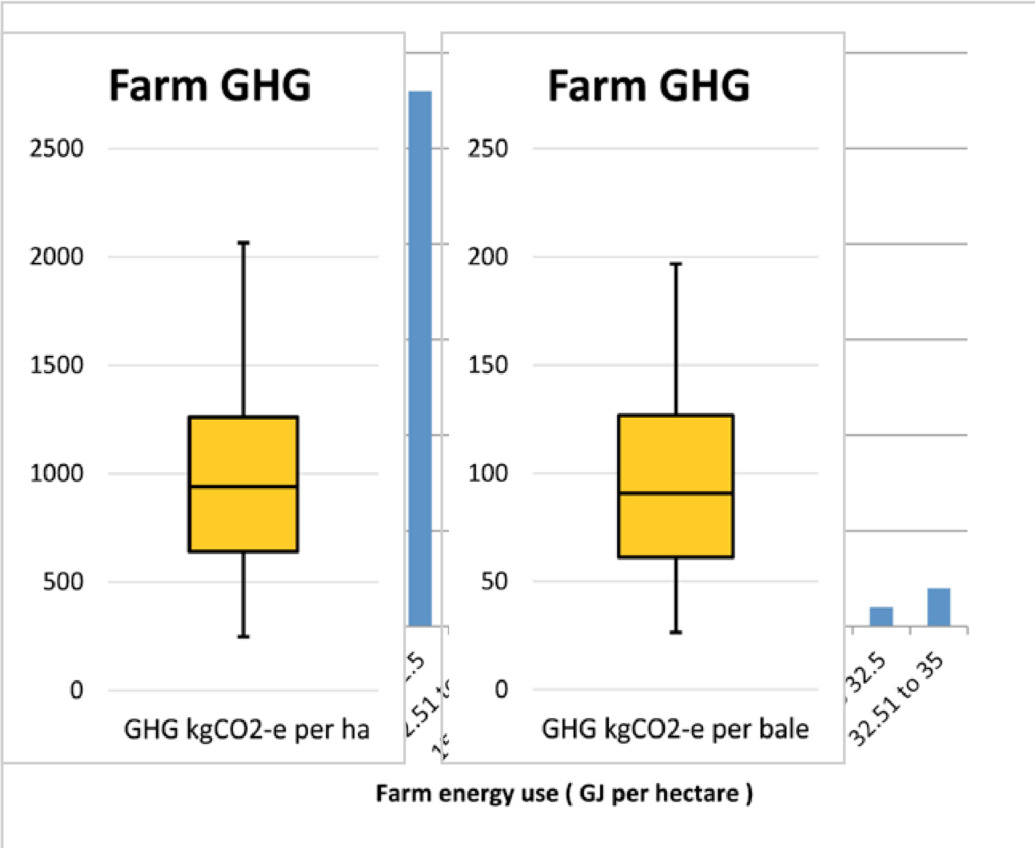


Figure 5 : Number of growers with total direct energy use in 2.5 GJ per hectare increments up to a maximum of 35 GJ per hectare. Fifty percent of growers used more than 11.4 GJ per hectare. The 158 data sets represented here, hold irrigated cotton farming operations from the Macquarie to the Condamine-Balonne valleys.

Greenhouse gas (GHG) is an inevitable output wherever carbon based energy forms are combusted through diesel engines and at electricity generation plants that supply our electrical networks. The common measure of these emissions is kilograms of carbon dioxide equivalent (kgCO_2-e), even though not all GHG emissions produced are solely carbon dioxide.

Figure 6 : Greenhouse gas production in kg of CO_2 equivalent per hectare and per bale, with the box plots in yellow capturing the upper quartile, median and lower quartile with black lines, while the upper and lower "whisker" extremes represent the 95th percentile and the 5th percentile, respectively.

The median greenhouse gas production during irrigated cotton production in this Level 1 analysis is 940 kgCO_2-e per hectare and 91 kgCO_2-e per bale, as shown in Figure 6. The middle 50% of irrigated cotton growers represented by this study had produced between 641 and 1261 kgCO_2-e of per hectare of irrigated cotton field. Importantly for this study, Figure 7 shows that 85% of the GHGs emitted were produced diesel engines.

5 Standard on-farm analysis at Level 2 of irrigated cotton farms

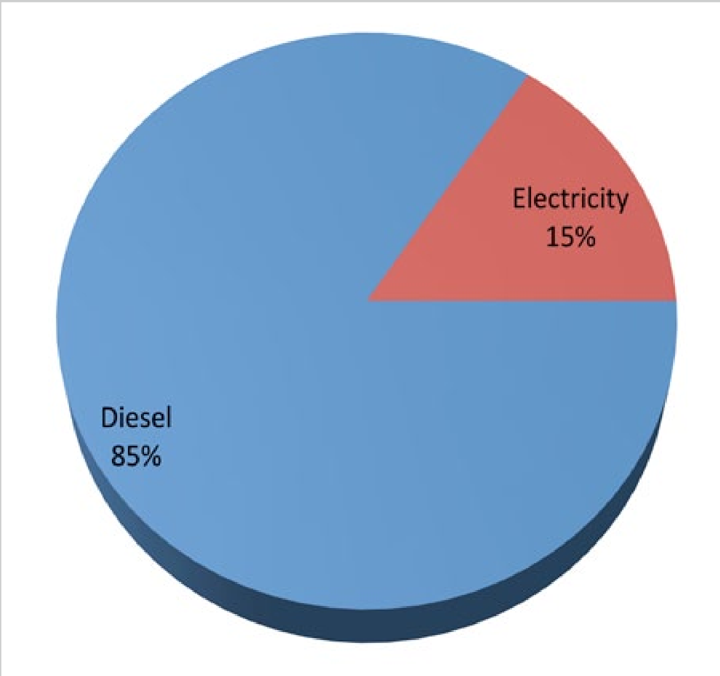


Figure 7 : The distribution of the greenhouse gas sources from the common direct energy sources in irrigated Australian cotton production showing that 15% of the greenhouse gasses represented in kilograms of CO_2 equivalent are produced by electricity generation across QLD and NSW.

4.5 Discussion and Lessons learnt

Overall, while this Level 1 analysis provides some reasonable results for energy consumption and GHG production across Australian irrigated cotton production, a number of limitations exist within the accuracy bounds of whole farm, across industry studies such as this. As detailed in Sandell et al (2013), it is important to clearly define the temporal boundary for any such analysis to reasonably define energy consumption for a particular crop in a particular year. This requires strict control and documentation of any stored fuels on-farm, and fuel used in tillage and other processes for one crop to the next. It is common practice to purchase fuel prior to end of financial year, and while accounting records like those used in the study would record energy purchase (interpreted here as energy consumption) in one year, this fuel would clearly be used in the production process for next year. In a similar manner, if weather conditions are favourable, it is common in cotton production to complete crop destruction after picking in the early autumn, and then proceed directly to tillage activities to prepare next season's fields. At the whole of farm scale, separating these out for a particular year's crop production is a challenge unless finely detailed accounting principles and record keeping are in practice which is uncommon.

In cotton production valleys, it is common to store significant quantities of water in on-farm storages for up to two years, after pumping from large river flood events. The most significant volume of water stored in on-farm water storages occurs in the northern Murray Darling Basin and this is a key feature of irrigated enterprises in the Cotton Industry. Generally these influences will be averaged over a 2 to 3 year period. This and the highly seasonal nature of energy use on farm suggests benchmarking activities for a particular enterprise needs to be conducted over at least 3 successive years to provide meaning for the enterprise. Energy expended in one year in water pumping into on-farm storages may not actually be used until the second of two consecutive crops. As water pumping is a major consumer of energy, this stored water represents significant stored energy, and carryover to successive crops is common wherever water is stored on-farm.

However challenging these studies are, the value of reportable measures captured is in the use of these to provide a benchmark to argue, discuss, define improvement strategies, and work towards improving in future years. In this respect, and with the knowledge of the accuracy limitations evident in the approach applied, benchmarks such as 11.4 GJ of energy use per hectare, 1.2 GJ per bale, 940 kgCO_2-e per hectare and 91 kgCO_2-e per bale can be reported from the analysis of this Level 1 data set.

On an energy basis, electricity consumed by irrigated cotton growers in this study was 12.2% of the total amount of energy consumed…

5. Standard on-farm analysis at Level 2 of irrigated cotton farms

5.1 Methodology and assumptions used in Level 2 assessments

The methodology employed through the level 2 process was individual audit style conversations with individual growers to detail the individual farm level energy consumption in diesel and electricity volumes used across seven different key processes (Chen & Baillie 2007, 2009), named as field preparation, plant establishment, in-season, irrigation, harvesting, post-harvest, and general and maintenance type activities, for irrigated cotton production. While many individual practices may contribute to a single one of these broad processes, these have all been accumulated during the audit process in EnergyCalc (Baillie et al 2009, Chen & Baillie 2009) and allocated to one of these seven separate process types. The analysis of individual auditor's results highlighted clear difficulty in capturing all of the practices that contribute sensibly to the total energy used in any process, and so the results have been reported in a different manner to overcome this limitation. When the opportunity arose, grower data sets for fully irrigated cotton cropping scenarios were selected in preference to those reporting partial or supplementary irrigation.

Results have been calculated for the median, upper and lower quartiles, and the 5th and 95th percentiles from the original energy use records of key farming processes entered by the auditors in the software EnergyCalc for each individual farm. These results have then been checked to determine any outliers, and where necessary individual follow up conversations and discussions were held with auditors to clarify data sets from original records.

As with the Level 1 results display, the main method of representing the data is in "box and whisker" plots that have a central box with three horizontal black lines that represent the lower quartile, median and upper quartile captured in any particular data set. The ends of the vertical black lines above and below this box are commonly referred to as "whiskers" and these have lower and upper end point values that represent the 5th and 95th percentiles, respectively.

All energy density values and emission factors used to develop results in this Level 2 analysis have been reported previously in Section 4.3. The "whole farm" energy use values reported for Level 2 results are the total of the accumulated direct energy uses captured in EnergyCalc for all of the separate farming practices throughout a full season of irrigated cotton production. The cost of diesel and electricity used to develop the energy expenditure results for Level 2 have been previously presented in Table 1 and Table 2 in Section 4.3.

5.2 Profile of captured Level 2 farm data for analysis of direct energy use on Australian irrigated cotton farms

The nature of the 40 enterprises captured in this study of Australian irrigated cotton grower's direct energy use is broad, being representative of the varied situations in which cotton is grown. Locations extend from the Murrumbidgee Valley in southern NSW to the north western Darling Downs in southern Queensland. This study of irrigated cotton farm direct energy use focussed on a sample of 40 enterprises selected to cover fully irrigated cotton scenarios, and does not include dryland or partially irrigated cotton cropping situations. Yield varies from 8.3 to 14.0 bales per hectare and represents an appropriate range of fully irrigated cotton scenarios. This sample of growers has cotton crop areas ranging from 16 to 5000 hectares. Analysis is completed at the green irrigated crop area level, in terms of the area of crop grown, and dryland or uncropped farm areas were not typically included in the analysis. Data sets for the enterprises included, range from FYE 2009 to 2015, with over 90% in the FYE's 2013 to 2015 years.

Importantly for this Level 2 study, the selected range of irrigation scenarios is from groundwater supplied surface irrigation systems through to surface water supplied centre pivots and lateral moves, and also includes a number of cases where irrigation water is supplied under gravity by a water supply authority with little or no pumping. These different irrigation scenarios are not represented in the same proportions as that occurring across the entire industry.

For this group the median area of cotton grown was 212 hectares and the middle 50% of areas of cotton was between 146 and 432 hectares. The middle 50% of growers had an average yield of between 11.0 and 12.1 bales per hectare, with the median yield for the forty enterprise sample being 11.5 bales per hectare. The total area of cotton grown that has contributed to this sample of 40 enterprises is 19,000 hectares and the total energy consumed in the production of 197,000 bales is 186,000 GJs. Twenty-one of the forty enterprises are based in NSW in this sample. Only five data sets are older than FYE 2013. This sample has captured direct energy use of 6.27 GW.h of electricity and 4.2 ML of liquid fuels, 99.5% of which are diesel, and is about 186,000 GJs of direct energy consumption. On an energy basis, electricity consumed by irrigated cotton growers in this study was 12.2% of the total amount of energy consumed, and this differs substantially from the Level 1 sample of 158 farm data where only 5% of the direct energy consumed was in electricity. Importantly for this study, electricity is only consumed in the irrigation pumping process and in no other irrigated cotton production processes, as all are mobile and stationary diesel motor based.

5.3 Results and Analysis for Level 2 Benchmarking of Direct Energy Use on Australian Irrigated Cotton Farms

Due to the nature of the results recorded by auditors, it is evident that auditors have had some difficulty in separating some practices into the most appropriate of the seven processes outlined initially by Chen and Baillie (2007) for irrigated cotton production. This is particularly evident for the field preparation and post-harvest field processes where heavy tillage practices that occur at the end of one season, may in fact be part of the field preparation for the next crop. To overcome this challenge with the existing captured results, energy use for "field preparation" and "post-harvest" processes have been grouped together as "heavy tillage". The field preparation and post-harvest phase of irrigated cotton production are the processes where all of the heavy tillage tractor operations occur. While the ability of auditors to capture practices associated with the "harvesting" and "plant establishment" process was good, the relatively low energy consumption during the plant establishment process has meant that it was appropriate to place the highly variable "in-season" and "general/maintenance" results together, and leave the higher average "harvest" energy results together. This then provides four simple grouped processes across irrigated cotton production that logically partition the energy consumption processes.

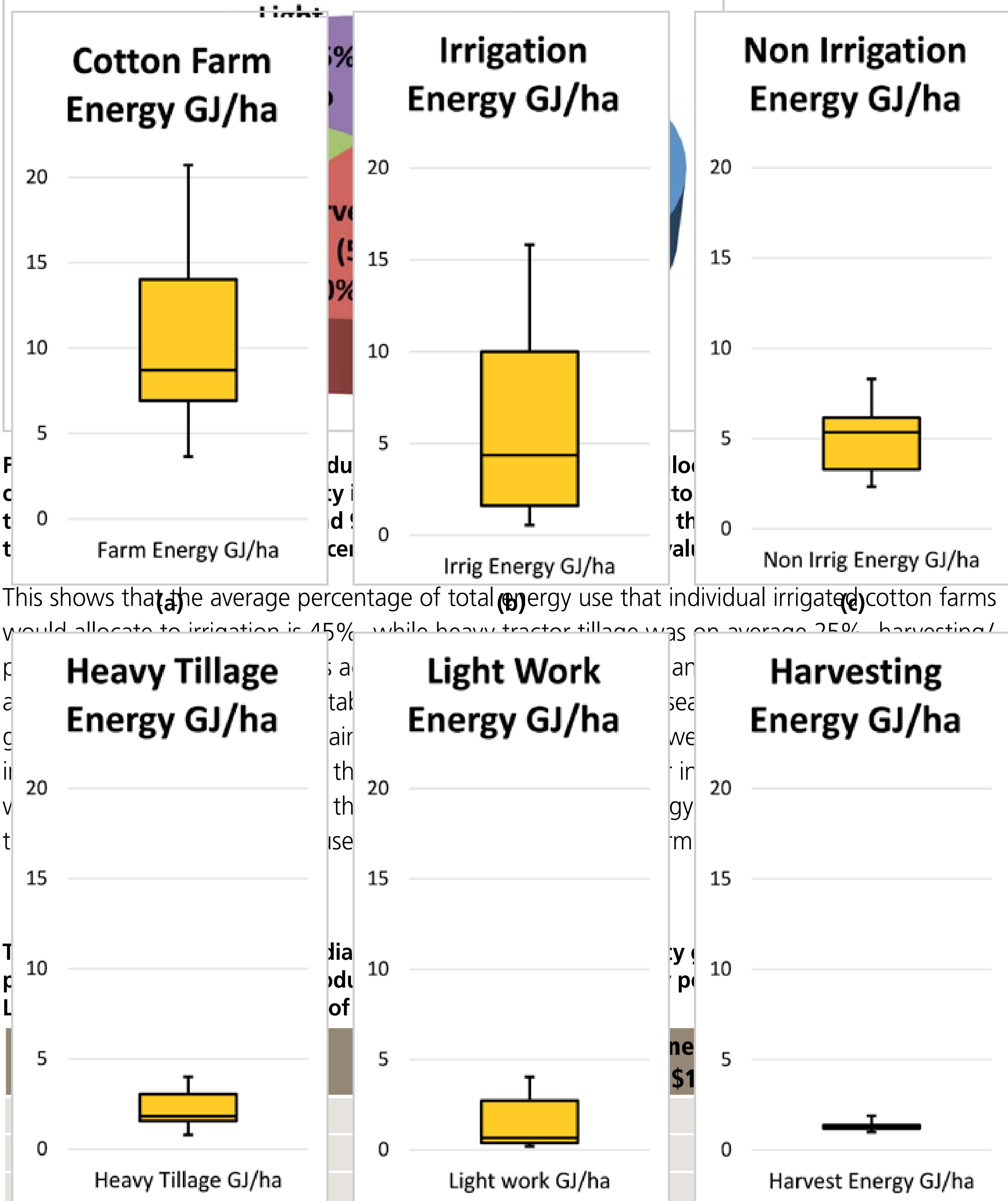
The "general and maintenance" process was least well attended of all of the seven processes in the irrigated cotton production process during this Level 2 audit process.

Significant vehicular diesel consumption was included by some auditors as a necessary component of cotton production, accounting for up to 20% of energy consumed for some farms. It is evident from discussions with auditors that there was inconsistency in the way utility vehicle energy consumption was captured.

...in-field irrigation systems must take the greatest proportion possible of the delivered water and place it into the crop root zone

While stored energy in any form has presented difficulties through this energy audit process for irrigated cotton production, the two most relevant to this cropping situation are the stored diesel liquid diesel carried over from cropping year to the next year through end of season's fuel stocks and pumped water stored in on-farm storages. The practice of monitoring or examining individual tractor operations and generating total fuel consumed from that basis is not always practiced in the audit process. Auditors will often utilise existing financial records or energy supplier accounts to determine energy consumption and this is only valid when "closing" and "opening" fuel stocks are accurately recorded. It is fortunate that in the electrical supply process, billing and electrical energy use for direct irrigation to field is reasonably simply accounted for, and it is only when electrical pumps supply water to storage and that stored water is carried over from crop season to crop season that this provides difficult auditing conditions. Future energy audits at the separate crop production process level should more rigorously apply a clearly defined process whereby individual motor operations are accounted for with hours of operation through the season and typical energy demand at normal operating conditions when under load and travel conditions for mobile equipment.

The averages across forty farms of the individual percentages of energy use in irrigation, heavy tillage, light and general work, and harvesting, each as part of the total energy farm energy use,



This shows that the average percentage of total energy use that individual irrigated cotton farms

In-season in-field	0.41	10.66	4.7
General / Maintenance	0.47	12.22	5.4
Harvesting process	1.2	31.20	13.8
Post Harvest crop destruction	1.2	31.20	13.8
Total for green cotton area	8.7	226.20	100

When the median "Direct Energy Use" of the separate processes in irrigated cotton production are examined (Table 1) across the seven separate processes usually accounted for in irrigated cotton production (Chen & Baillie 2009), it is perhaps clearer to understood how large the irrigation direct energy use component is with respect to other farming processes.

The energy use per hectare across the forty data sets in the Level 2 analysis was accumulated for a variety of processes and combinations, and these have been plotted in a matrix of six separate "box and whisker" plots in Figure 9 labelled as (a) through to (f). The three black horizontal lines in the central box represent the upper quartile, the median and lower quartile values, from top to bottom. Fifty percent of growers will have an energy use per hectare in this central box of each plot. The upper and lower extremities of the vertical "whiskers" represent the 95th and 5th percentile, and 90% of growers will have an energy use between those two extremes. The height of each central box indicates the variation across the middle 50% of cases, and the height between the ends of each set of "whiskers" indicates the variation in the middle 90% of results.

Figure 9(a) displays the whole farm energy use per hectare, as accumulated in EnergyCalc from the addition of the energy used for the many individual farm practices within the entire cotton season on each farm. Figure 9(a) shows the two-fold range containing 50% of the growers between the lower quartile value of 6.9 GJ per hectare and the upper quartile value of 14 GJ per hectare in whole farm energy use results from these forty growers.

...the harvesting process is the third highest energy consuming activity in irrigated cotton production in Australia

The range of irrigation energy use captured in this forty grower sample as shown in Figure 9(b) for the middle 50% of growers is between 1.6 and 10 GJ per hectare. The middle 90% of grower results for irrigation energy use have a 25 fold variation from 5th to 95th percentile. This very wide range in irrigation energy use is due to variation across four main factors. These four factors are the volume of water pumped, the static lift (water surface to water surface) involved in "lifting" the water, and the remaining components of the total dynamic head, the friction and minor headloss through pumped pipelines, while the fourth is related to the pump, drive-train and motor efficiencies of the system.

The volume of irrigation water pumped on cotton farms is dependent on the crop water requirement at that particular site under a particular set of climatic conditions, and the additional water lost in conveying the water from the source to the crop root zone. The latter of these two is completely dependent on the level of irrigation management skill brought to bear on this task of irrigation. Smaller quantities of water pumped mean smaller energy bills overall. Every effort should be expended by growers in ensuring that storage losses through evaporation and seepage are as small as possible, that delivery systems do not lose water, and that in-field irrigation systems take the greatest proportion possible of the delivered water and place it into the crop root zone.

The second factor, the static lift, is predominantly a matter dominated by the natural lay of the land, or the depth of the groundwater. These are not normally something that is under the daily control of any grower.

Figure 9 : Energy consumed in GJ per hectare from forty grower data sets captured as part of the Level 2 analysis for all the total of all key processes in cotton production (a), for irrigation (b), for all non-irrigation (c), for heavy tillage (d), for light work (e) and for harvesting/picking (f).

At the design stage of any open channel or pipeline system, friction and minor headloss can be reduced by ensuring channels, culverts and pipe sizes are large enough for the design flowrate, so that the resultant velocities are low.

The fourth and final factor determining the energy used in the irrigation process on farm is the efficiency of the individual components in the pump, drive-train, engine combination in the pump station. For each of these three components, the efficiency is high when the majority of the energy that is put into the component, is converted into energy or useful work on the output side of that component.

The non-irrigation energy consuming processes for the sample of forty growers have been combined in Figure 9(c) in irrigated cotton production. This data simply highlights the less than two-fold variation across the middle 50% of grower results for all farm activities excluding irrigation, in stark contrast to the greater than six-fold increase shown in Figure 9(b).

Due to the difficulty in capturing all field preparation and post-harvest processes in appropriate ways in this study, a box and whisker plot of the energy consumed in all practices during field preparation and the post-harvest phase of this work is capture in Figure 9(d) under the heading of “Heavy Tillage”. While not all field practices in these crop production processes are heavy tillage with high work rates on high capacity tractors, these phases do contain the majority of the heavy load tillage where high energy consumption is recorded. Half of the grower result report energy use greater than 1.8 GJ per hectare from this data set of forty irrigated cotton growing operations.

Figure 9(e) captures processes such as planting, in-season spraying and light inter-row cultivation, general vehicle activity and light maintenance earthwork, and these are typically done with light work rates and low loads on mobile diesel engine driven machinery. The variation evident in the height of the central yellow box plot is a fact due to the consistency in the audit process and the wide variation in the number of activities such as spraying, and whether or not vehicular activity has been recorded by the auditor. Fifty percent of the grower results are less than 0.7 GJ per hectare in this combination “Light work” activity.

In contrast to the 1.5 to 2 GJ per hectare range of energy use in plots Figure 9(d) and (e) for the middle 50% of cases, Figure 9(f) highlights how some industry processes such as harvesting have very tight ranges of energy use across the forty cotton growing operations. This is due to the dominance of a single picking technology in the industry, using highly experienced contractors, as opposed to different cropping practices. The variation in energy use in the middle 50% of growers is a very small range of 0.21 GJ per hectare, with the median value of 1.22 GJ per hectare. As a proportion of the whole farm energy use, the harvesting process is the third highest energy consuming activity in irrigated cotton production in Australia.

When examining the energy use in the different irrigated cotton farming processes across Figure 9, around 80 out of 100 cases, have picking energy consumption less than the irrigation energy use of 80% of growers. Half of all growers use more energy with irrigation than all growers do with heavy tillage. While there is a 25 fold variation in irrigation energy use in the middle 90%

of grower results, there is only a six-fold variation in heavy tillage energy use across the same

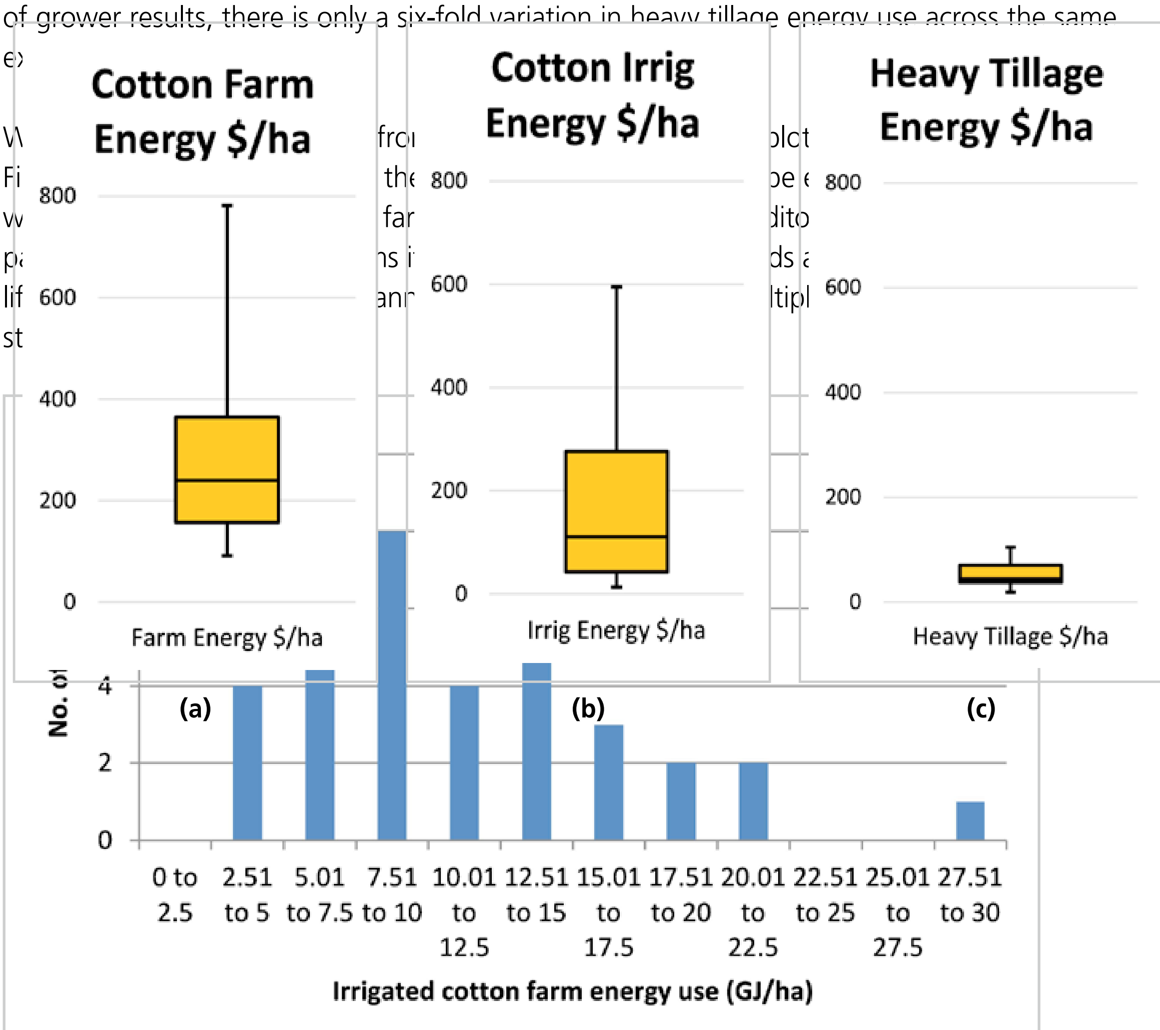


Figure 10 : The number of growers from the Level 2 analysis of forty irrigated cotton growers whose overall whole farm energy consumption fall in separate 2.5 GJ per hectare increments. The significant variation of grower energy consumption above the median is similar to results shown in Figure 5 for 158 growers.

Another way of displaying the variation in irrigation energy in Australian irrigated cotton production is shown in Figure 11. The irrigation energy use for each of the forty growers is allocated to 2 GJ per hectare increments up to the maximum recorded near to 20 GJ per hectare.

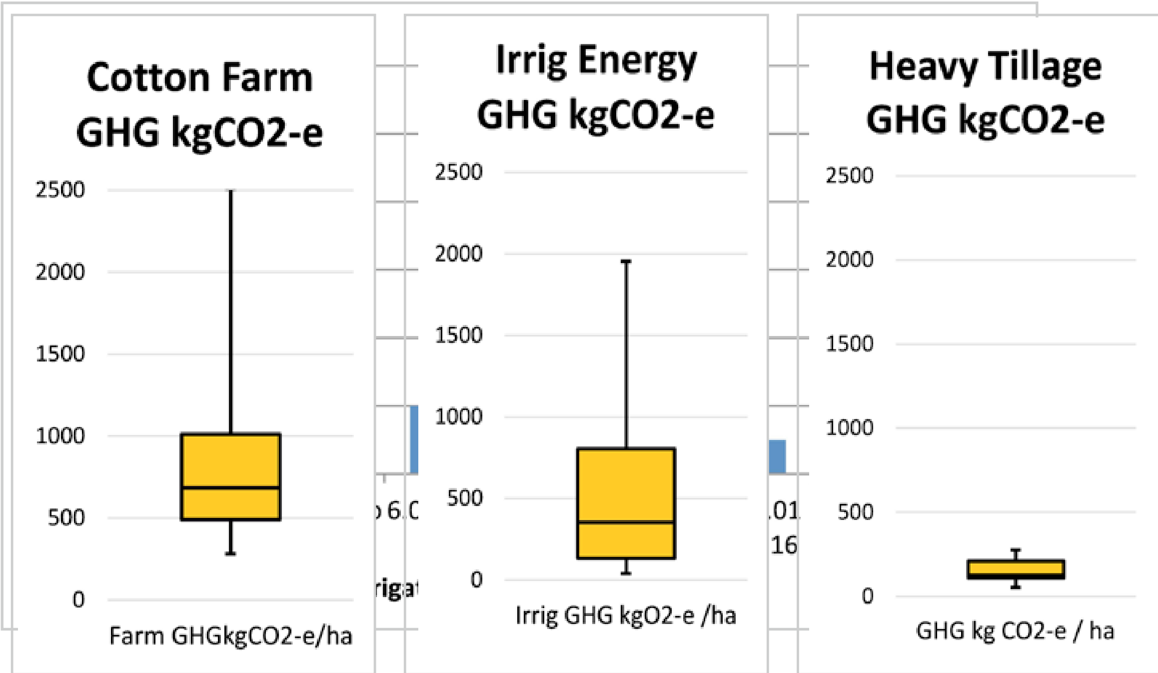


Figure 11 : Distribution of grower numbers for 2 GJ per hectare increments of irrigation energy consumed up to the 20 GJ per hectare maximum level of irrigation energy consumption found across the forty growers in the Level 2 analysis. The upper half of growers above 4.4 GJ/ha report irrigation energy use up to 20 GJ/ha, highlighting in another form the wide variation in irrigation energy consumed.

The expenditure on direct energy use across the seven processes in irrigated cotton production was accumulated across the forty farm sample, and is represented in Figure 12 (a). This records that the middle 50% of growers in the study were spending between $160 and $360 per hectare, and that 25% of growers were spending more than $360 per hectare, as indicated by the upper quartile (top line of central yellow box) in Figure 12. The median expenditure on energy in this sample was $240 per hectare. Around $800 per hectare is spent by a small number of cotton growing operations on diesel and electricity.

The expenditure on diesel and electricity in the irrigation process as captured in this study ranged from $45 to $280 per hectare for the middle 50% of growers, with a median result of $110 per hectare. Some growers are spending about $600 per hectare on diesel and electricity for irrigation alone.

Figure 12 : Expenditure on direct energy per hectare across all farming processes on forty Australian cotton farms (a), for direct energy expenditure per hectare for irrigation, (b) and for heavy tillage in (c). At least 20 growers are spending more than $240 per hectare on energy, and the same number are spending at least $110 per hectare on irrigation energy.

From Figure 12 (c), the heavy tractor activity during the field preparation and post-harvest phases of irrigated cotton production had a median energy expenditure of $44 per hectare.
The middle 50% of growers spent between $38 and $70 per hectare on energy during heavy tillage. From the other results captured as part of this study, about $30 per hectare was the median expenditure on picking energy.

One of the important outcomes of this work has been to establish an understanding of emissions from direct energy consumption. Figure 13 (a) illustrates greenhouse gas emissions (GHG) in kgCO_2-e per hectare from direct energy use across the whole farm for the forty farms in this study. Figure 13 (a) displays the quantity of emissions directly attributable to irrigation per hectare across the forty irrigated cotton farms in this study. Twenty per cent of the farms in the sample were emitting between 1 and 2.5 tonnes of CO_2-e per hectare across the farming operation. Fifty per cent of farms in this sample were producing 0.5 and 1.0 tonnes of GHG per hectare from direct energy consumption of diesel and electricity. In other words from Figure 13 (a) we can see that three-quarters of all farms in the sample were emitting more than 500 kgCO_2-e per hectare.

6 Level 3 measurements and analysis

Figure 13 : Irrigated cotton farm greenhouse gas (GHG) production per hectare across the forty Level 2 grower results in (a), GHG production per hectare for irrigation only, (b), and for heavy tillage, (c). A couple of very high GHG emission results in (b) extend the 95th percentile, and come as a consequence of large volumes of deep groundwater pumped with electrical motors powered by electricity from coal-fired power stations.

The irrigation direct energy use emissions, in comparison on Figure 13 (b), highlight that half of the farms are producing 350 kg CO_2-e per hectare or more. In around 5% of cases, more than 2 tonnes of CO_2-e emissions are being produced as a result of direct energy use in irrigation. Approximately 40% of farms are producing more than 500 kg CO_2-e per hectare as a result of irrigation alone. The high emission results in irrigation will occur due to the majority of electricity on a farm being used in the irrigation process. From the example laid out in Section 2 previously to pump 1 ML into on-farm storage with a pump TDH of 7 metres for each hectare, you would use 6.72 Litres of diesel and 28 kW.h of electricity. These would produce emissions of 18 kg CO_2-e with diesel or 24.4 kg CO_2-e on average with electrical energy from the electricity grid. For 10 ML pumped per hectare of crop in a season, these would produce emissions of 180 kg CO_2-e per hectare with diesel, and 244 kg CO_2-e per hectare with grid electricity.

In contrast, Figure 13(c) displays the GHG emissions per hectare from "Heavy Tillage" processes in the field preparation and post-harvest phase. These will be solely from diesel engines in tractors, and the combined impact of the small energy use per hectare for heavy tillage and lower relative emissions from diesel combustion as compared to network supplied electricity, produces a result much lower than level of emissions from irrigation. Ninety percent of growers would produce emissions between 53 and 278 kg CO_2-e per hectare around a median value of 126 kg CO_2-e per hectare with heavy tillage.

5.4 Discussion and Lessons Learnt

The standard energy audit of the separate farming processes on irrigated cotton farms was conducted in a variety of ways by a highly diverse group of industry personnel with highly varied levels of motivation and enthusiasm in engagement with cotton growers on the topic of energy use. Appropriate motivation for the grower was not always provided and the level of trust required with industry personnel was not developed to the point where the grower would readily provide access to a significant quantity of personal financial information.

Great success occurred in obtaining data from growers once separate contracts were put in place with local consultants in cotton growing districts, who already hold the confidence of their client base on related farming and irrigation matters. Their prior interactions meant success in extracting detailed information about actual practices across the seven processes in irrigated cotton production systems, and represented the majority of Level 2 audits.

It would appear that the Level 2 audit process proposed through earlier research activity in agricultural energy consumption was not appropriately utilised. In the process auditors do not have to find cost and energy expenditure information for each and every individual practice in the grower's cotton farming process. The process is held within the software EnergyCalc and contains informed "aids" or "tools" to assist in the calculation of energy use for individual farming operations, and allows an accumulation of the entire set of farming operations through a conversation or interview style session with book-keepers and those with some financial understanding of the enterprise.

There were a number of legitimate questions from auditors about the bounds of the Level 2 energy use for cotton production, during the data collection in the project. These questions concentrated on utility and other vehicular energy use during the cotton season from preparation to post harvest, and whether or not these should be included as legitimate energy use for cotton growing purposes. Some auditors included all vehicular energy use in the energy assessment capture, and others did not. Energy use expended on-farm in the cotton production process within the bounds of the farm gate, is reasonable, but should only be included in the assessment process if it represents a significant proportion that can be captured.

The median direct energy use captured across this sample of forty growers was 8.7 GJ per hectare, a lower result than expected and probably one skewed by the Level 2 audit process on farm. During normal extended interview processes it is likely that not all appropriate energy use across the full cotton growing season have been captured. This is because each and every practice should be accounted for, and this can be an extended process. It is imagined that in some instances not all data would have been captured leading to results lower than actual at the whole farm level.

The very wide range of irrigation energy use captured across the forty data sets in this study should dominate any discussion in regard to this energy assessment data set.

While it is not possible with this data set to adequately differentiate between separate irrigation type groups, close examination of the data shows that the top four results for irrigation energy use per hectare are equally split between farms that pump river water into storages across multiple pump stations, and those pumping water from deep groundwater systems.

The next largest opportunity to reduce energy consumption on irrigated cotton farming enterprises is in relation to heavy tillage. Operating on wet ground during picking is the quickest way to compact ground so that high fuel consuming heavy tillage operations are necessary. With the advent of significant shift to a single picking technology that is very heavy, significant tillage remediation of picked fields is common. Opportunities for dry picking are sometimes low, and care should then be taken to ensure that only the depth required is set-up on the implement during the ensuing heavy tillage operations, so to minimise fuel use. The appropriate selection of gear ratios, tractor ballasting and tyre pressure settings are important in reducing energy use.

6. Level 3 measurements and analysis

6.1 Introduction

The detailed assessments of energy audit activity were included in this project and named as Level 3 analyses. This activity was included in this project to more broadly understand the energy efficiency of the Australian irrigated cotton industry, and consisted of a series of detailed pump assessments and tractor tillage tests. These detailed assessments of a particular component of the farming system were used to confirm the common energy saving potential possible in the two largest energy consuming activities in the Australian cotton industry that had been previously highlighted in other studies. The two separate types of detailed testing and analysis completed in this project were the pump testing of large low-head mixed-flow pumps, and tractor tests under heavy tillage.

6.2 Profile of tests conducted

The tests on large mixed flow pumps were a strong focus of this project activity through the early to middle stages, and came from a strong held belief of low actual efficiency levels, as compared to the published data sets from overseas based manufacturers. This was further compounded by early preliminary test results that indicated particular issues at sites offered to us for testing. While these sites were convenient and provided simple access, they had peculiar and inherent issues that meant that they were not representative of the typical performance levels of the very large number of large mixed flow pumps that dominate the irrigation pumping activity in the Australian cotton industry. One of the major reasons for such large quantities of diesel being used through large diesel-driven mixed-flow pump stations was believed to be due to the low level of efficiency actually occurring in the very common large 26" mixed flow pumps. Pump curves from the overseas manufacturer were perceived to be speculative in nature due to pump efficiency results in the low 90% range for a 50 year old design from foundries that have operated for more than 60 years. This level of efficiency is not possible for many larger pump types manufactured under rigorous control in modern factories in the western developed world. From this testing, it is clear that this is not the case, and these pumps are capable of excellent pump efficiency levels when managed appropriately and integrated into appropriately sized pump stations.

Two test sites for tractor tillage trials were established in this project and multiple tests were completed at each of these. Both sites had soil and field conditions that were representative of the majority of the soil conditions through the Australian cotton industry. These were heavy cracking clay soils that had been under cotton production and had been subject to normal cotton production traffic processes.

Overall, twenty-six Level 3 test sites were initiated throughout the project and at these, fifteen detailed assessments were completed. Typically, multiple tests were completed at each of these sites to produce a large quantity of information from which one detailed assessment was captured, described and reported.

6.3 Methodology and assumptions

The broad methodology at each of these sites involved common elements typical of detailed energy audit processes. The first of these was to capture the rate of energy consumption, as either kW.h or Litres of diesel, over an appropriate duration with recognition of the precision of the measurement equipment. This was often completed for diesel fuel use using off the shelf positive displacement oval lobe pumps that produce an electrical pulse for a very small fuel volume passed. This electrical pulse is either recorded by a logger, or accumulated and displayed on the flowmeter. Electricity consumption was always recorded using in-situ billing meters. Typically these were the EDMI digital type, and appropriate durations were selected according to the quantity and precision of the electrical energy values displayed. These results were always manually recorded. Generally, irrigated cotton growers were accepting of fuel supply pipe modification during testing, and at no sites were electrical metering installations and switchboards opened to gain access to wiring and connections of such things as electrical energy meters and ancillary equipment.

In the case of tractor testing under heavy tillage, the methodology also involved measurement of wheel slip, ground speed, the engine speed and the gear ratio selected, along with tillage depth and width. It was not necessary that the actual three-point linkage or drawbar draft of the implement itself was measured.

In the case of detailed pump testing, suction and discharge pressures, pump shaft and motor shaft speeds, static elevations, water discharge, and pipe, pump and motor details were all manually recorded. Pressure readings were measured using test gauges (typical accuracy level ±0.5%) installed on pump flanges, shaft speeds were measured with laser or optical tachometers, elevations with a dumpy level, water discharge with calibrated ultrasonic transit-time flowmeters, and pipe and pump dimensions with a standard retractable builder's tape, vernier calipers and ultrasonic thickness gauges, where necessary.

Analysis of the pump test results was typically completed with combinations of manual calculations and the software package IPERT (Raine et al, 2009) that is available for use on hand-held mobile devices and computers and has been specifically developed as an Irrigation Pump Evaluation and Reporting Tool (IPERT). Reports are generated by the tool and provide a common format and database storage mechanism for record keeping and multiple pump performance analyses. Common to all analyses of pump tests is a requirement to use the affinity laws for homologous systems to re-model the pump manufacturer's performance results for the particular pump shaft speed and impeller size of the test completed.

7

Overview and important lessons learnt

6.4 Results and analysis of detailed testing

While the earlier analysis from Level 2 energy assessments clearly highlighted in Figure 8 that heavy tillage is a major energy use on irrigated cotton farms in Australia, there was a genuine reluctance of the grower to engage in anything other than irrigation pump testing.

A particular focus of the detailed pump assessments performed was the large 26HBC-40 mixed flow pump. This pump is so common across the Australian cotton industry that it could be responsible for 30 to 40% of all direct energy use in this industry. While at least nine test sites were initiated for testing of this particular pump type, only six test sites were tested to complete an evaluation and develop a full assessment of the pump performance. The analysis of the pump performance across multiple test sites, with the wide variety of system components, was completed by homologising (normalising) the test results to a single speed of 470 rpm using the pump affinity laws, and assessing this conformity with the pump manufacturer's performance curve. Figure 14 provides the individual test points across these six sites and displays some of the issues that arose at these sites. In the main, the individual test results in purple crosses conform to the factory pump curve outlined in blue. Certainly, not all results do, and a range of issues have been identified and will be discussed at a later stage in the document. However, from the conformance of the majority of this test data with the original manufacturer's pump curve, it is clear that this pump can operate as described by the manufacturer.

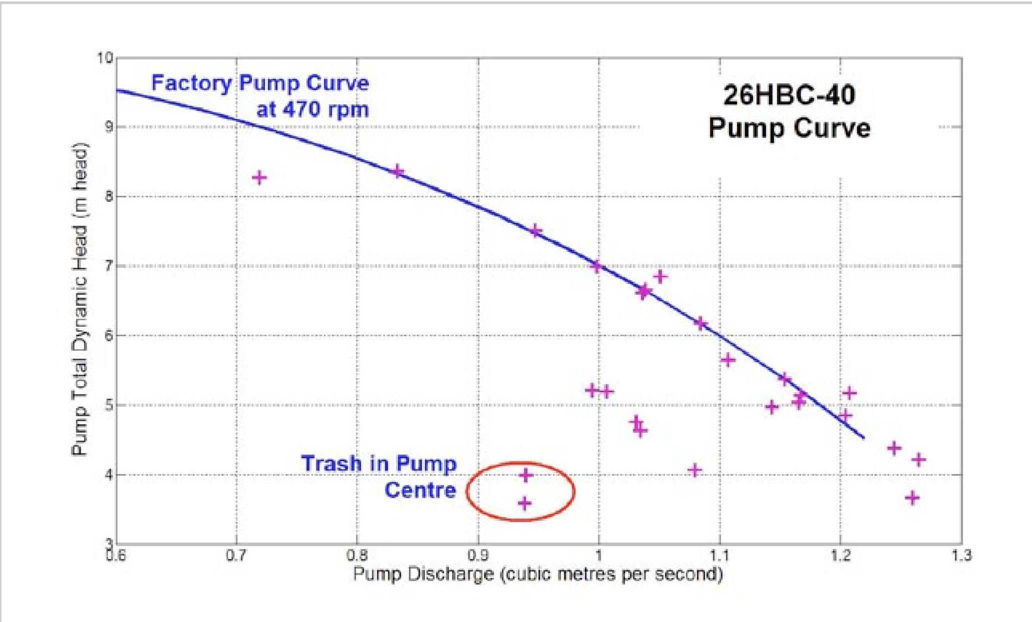


Figure 14 : Homologised individual test results of pump Total Dynamic Head and Discharge (purple crosses) at 470 rpm, in comparison to the blue factory pump curve. The impact of approximately nine Litres of cotton trash (stems and roots) at the eye of the impeller has reduced TDH and discharge by 20%.

Importantly for this study, the pump efficiency for a number of test results has been independently analysed using energy consumption rates measured on-site, along with published data for motor efficiency from manufacturers, and then compared to pump manufacturer data. After thorough and repeated checks of the recorded data, when test results conform to the factory curve in Figure 14 near to the best efficiency point of the curve between 0.9 and 1 cubic metre per second at 5 to 7 metres of TDH, the pump efficiency levels have been around 88%.

There were a number of homologised test results that did not conform to curve, and there were four main reasons why this was the case. Small rates of air entry, of the order of 2% by volume, reduce pump performance by up to 20%, as reported in the formal literature. The encumbrance of cotton trash on the eye of the pump impeller eye has been recorded as producing a 20% reduction in TDH and discharge for this 26HBC-40 pump. The quantity of cotton trash involved was estimated as a nine Litre volume from photographic evidence recorded during the test. This "bird's nest" of trash was involved on the eye of the impeller at a test site where clear entrainment of trash was seen, noted, and removed during a consecutive series of tests at the site of a freshly refurbished pump installation. The third reason that this particular pump type produced results that did not conform to curve was due to pump cavitation from excessive suction lift. This occurred in a small number of cases. The fourth and more common issue from the test results was impeller wear or damage, in which the recorded data lie on a curve below the factory curve, as can be seen in Figure 14.

Ensuring appropriate screening of trash and air at the suction entrance will eliminate the first two of these issues. In those instances where pump cavitation has been noted, solutions are to reduce the elevation difference between pump shaft and supplied water surface for this particular pump type, or reduce the flowrate. In cases where the recorded data plots on a curve parallel to the

8

Conclusions

factory curve, nothing but impeller replacement can solve the existing wear issue for this mixed flow pump type.

Across a number of other detailed pump tests at these larger water harvesting pump stations, it became evident that none of these issues were evident and sole reason for the high energy use per MegaLitre (ML) of water pumped was the high headloss in friction and minor losses. In a number of instances energy savings of up to 40% could be achieved through capital outlay for larger fittings such as check valves and suction entries. Without exception the very high velocities in these stations was directly contributing to the large energy loss in fittings. Payback on these alterations was possible in three to four years when simple economic analysis was completed. In addition, other tests on these large pumps stations clearly indicated that while the 26HBC-40 pump was inappropriately matched to the site conditions, higher pump efficiency levels (10 to 15%) could be achieved by adjustment of the discharge at which the pumps were operating. Under high flow demand conditions during water harvesting events, this additional cost was happily borne by the grower, but future investment in these sites would see alterations to reduce irrigation energy consumption rates. Payback on these alterations is highly dependent on availability of water during the coming years.

The tractor tests completed as part of the detailed assessments included tests conducted on the black cracking clay soils of a large irrigated cotton farm on Queensland's Darling Downs using a 4.5 metre wide fixed-tyne ripper behind a 2010 John Deere 8220 tractor. This unit contains an 8.1-Litre electronically controlled and turbo charged engine with a rated power of 225kW (168 hp). It was put through a series of tillage runs with varying depths, across a range of engine speeds and gear selections to compare ground speed and fuel consumption.

Figure 15 shows the effect on hourly fuel burn rate of changing engine speed and gear selection for two ripping depths. Two different ripping depths are shown: 350 mm (triangles) and 250 mm (solid circles). For each ripping depth, two engine speeds were tested: 2300 rpm (lighter, solid lines) and 1830 rpm (darker, dotted lines).

9 Recommendations

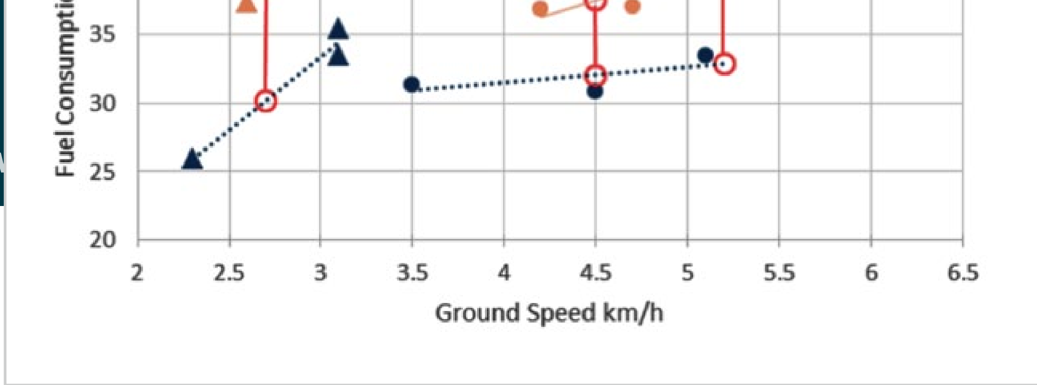


Figure 15 : Fuel consumption for different ground speeds of 2300 rpm (lighter coloured solid lines) and 1830 rpm (darker coloured dotted lines). Two different ripping depths are plotted : 350 mm (triangles) and 250 mm (solid circles).

Results indicate that reducing the engine speed of the tractors from around 2300 rpm to 1830 rpm reduced fuel use by 6 and 9 Litres per hour across three selected pairs of equal ground speed and ripping depths (shown by red circles and bars in Figure 15) with an average reduction of 7 Litres per hour. This shows that throttling back and gearing up reduces fuel consumption.

For a heavy tillage trial, at a work rate of 2.0 hectares per hour and a depth of 250 mm, shifting gears from 5th up to 7th, and throttling back the engine speed from 2200 to 1830 rpm, reduced fuel consumption by 6.7 Litres per hour while maintaining the same ground speed and work rate. On a per hectare basis this equated to a reduction in fuel use of 3.6 Litres per hectare, or about 20%, which represented a reduction of 0.14 GigaJoule of energy per hectare reduction and 10 kg per hectare less emissions. Tests also showed that for every 25mm increase in the depth of heavy tillage, tractor fuel consumption increased by 2.0 Litres per hectare. A 10 per cent reduction in energy costs and emissions per hectare was possible if tillage depth can be reduced by 25mm.

7. Overview and important lessons learnt

Overall, the median total energy use for the major practices involved in irrigated cotton production was 11.4 GJ per hectare median captured in the study of 158 growers at the whole of farm Level 1 type analysis, and lower for the 8.7 GJ per hectare in the Level 2 study of forty growers. The mean of the farm yield averages in the Level 1 study was 10.2 bales per hectare and is lower than the Level 2 mean of the individual farm yield averages of 11.4 bales per hectare. While these suggest widely different base populations, the limited number of results captured in each of the Level 1 and 2 audit processes in combination with the nature and accuracy levels of the audit processes employed, point to these results being within the error bounds of the study. Auditors in the Level 2 assessments may have naturally gravitated to growers with a keener interest in energy assessment and hence lower energy use rates and higher yields.

The financial data used in the Level 1 Benchmarking of direct energy use show that direct energy costs had a median of $308/ha (2011 to 2014), while the results from the Level 2 analysis record a median energy expenditure rate of $240 per hectare found across the 40 enterprises.

On analysis of the data sets captured through both of the benchmarking exercises, it would appear that in the process of capturing Level 1 data more farm activity, other than cotton growing may have been captured within the total diesel volume and the total diesel cost records. In contrast, during the Level 2 process, data from separate processes may be left out (e.g. vehicles), such that not all processes in irrigated cotton production are included in the direct energy use of the whole farm.

From analysis of the Level 2 data sets from individual auditors, it is clear that the boundaries for this study on individual farms were not clearly nor consistently applied and will contribute to relative error between the Level 2 assessments.

The diesel purchasing tactics of Australian cotton growers are less than optimal. Industry representatives would serve their grower base well, by investing effort in understanding and developing a text messaging alert systems for terminal gate prices, at Brisbane and Sydney. Separately building a text messaging based system for grower input of delivered diesel price “just paid” to central live database that updates all registered text message receivers of latest diesel prices would be of industry benefit given the very heavy reliance of the industry on diesel.

It is also clear, from extensive work over the last 15 years in water use efficiency (Roth et al, 2013), that every effort should continue to be made to ensure that any water extracted from a water source (e.g. groundwater aquifer or river system) is not lost to seepage and evaporation in the storage, delivery and in-field application systems (Smith et al 2005). On-farm storage losses can be between 20 and 40%, while in-field irrigation losses can be between 10 and 20%.

Improving Energy Efficiency on Irrigated Australian Cotton Farms

Farm level benchmarking report of direct energy consumption in Australian irrigated cotton production

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