National Centre for Engineering in Agriculture
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DEVELOPMENT OF ENERGYCALC - A TOOL TO ASSESS COTTON ON-FARM ENERGY USES

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A Report for the Cotton Research and Development Corporation (CRDC)

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EXECUTIVE SUMMARY

Within highly mechanised agricultural productions systems such as the Australian cotton industry, operational energy inputs represent a significant cost to growers. Overall, it has been estimated that machinery may contribute 40-50% of the cotton farm input costs. In this project, a framework to assess the operational energy inputs of various production systems and the relative performance of a grower within an adopted system is developed. This framework is later implemented and incorporated into a user-friendly energy assessment tool (a Betta version web-enabled online energy calculator, EnergyCalc).

EnergyCalc divides energy usage of cotton production into six broadly distinct processes, which includes fallow, planting, in-crop, irrigation, harvesting and post harvest. This enables both the total energy inputs and the energy usage of each production processes to be assessed. In addition to the default energy use data provided, the software also allows the user to enter their own site-specific data so that they can benchmark their performance with peer farmers and best practices to identify opportunities for reduced energy costs.

Seven case studies are presented. It is found that overall, the total energy inputs for these farms was significantly influenced by the management and operation methods adopted, and ranged from 3.7-15.2 GJ/ha of primary energy, at a cost of $80-310/ha and 275-1404 kg CO_2 equivalent/ha greenhouse gas emissions. Among all the farming practices, irrigation water energy use is found to be the highest and is typically 40-60% of total energy costs (wherever water is pumped). Energy use of the harvesting operation is also significant, accounting for 20% of overall direct energy use. If a farmer moves from conventional tillage to minimum tillage, there is a potential saving of around 10% of the fuel used on the farm. Compared with cotton, energy used in the production of other irrigated crops on these farms is generally half of cotton. This is due to less intensive management required for these crops, leading to the lower number of farming operations (passes) carried out (generally about 10, in comparison with 17-18 for cotton) and reduced irrigation requirements.

The opportunities for further work are also identified. EnergyCalc is currently being populated with generalised performance data obtained from various sources which may not be specific and accurate to the Australian conditions. Opportunities therefore exist to further test and improve the accuracy of the model. Wide promotion and use of this tool is also critical. Conceptually, EnergyCalc may also be extended to other Australian rural industries to conduct on-farm energy audits and recommend strategies to reduce energy input costs. This will provide an opportunity for co-investment from these industries for continuing development of the tool.

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1 INTRODUCTION

Cotton is a significant industry in Australia. Between 1987-88 and 2001-02, the gross value of cotton production in Australia more than tripled, while the value of exports has more than quadrupled. For over a decade up until 2005 Australia was consistently the third largest cotton exporter in the world and Australian cotton growers produced the highest yields in the world. The average area of cotton harvested in over the last decade is 380,000 hectares. Many Australian cotton farms are owned and operated by family farmers, with production spread across Queensland (30%) and New South Wales (70%).

The Australian cotton growing industry is highly mechanised and heavily reliant on fossil fuels (electricity and diesel). On-farm energy use is becoming increasingly important with rising energy costs and concern for greenhouse gas emissions. Within highly mechanised farming systems such as those used within the cotton industry, energy inputs represent a major cost to the grower. Overall, it has been estimated that machinery may contribute 40-50% of the cotton farm input costs.

Given the major dependence on direct energy inputs and rising energy costs, energy use efficiency is an emerging issue for the Australian Cotton Industry. Quantifying the operational energy costs for different cotton production systems through the development of an on-farm energy audit process / tool is fundamental in building the capacity to develop strategies to reduce energy inputs. In response to this need an on farm energy calculator i.e. EnergyCalc was used to evaluate energy use for alternative production systems and the impacts on greenhouse gas emissions. EnergyCalc was also used to identify opportunities to reduce operational energy inputs and associated greenhouse gas emissions.

2 REVIEW OF OPERATIONAL ENERGY USE IN AGRICULTURE

Extensive research has been conducted on energy use and conservation both in agriculture (Pellizzi et al, 1988; Stout, 1989; Tullburg and Wylie, 1994) and in other industries (Eastop and Croft, 1990; Nystrom and Cornland, 2002). Table 1 summarizes energy performance data for different cropping systems.

Table 1 Energy performance data from published literature

Crops	Total Energy Input (GJ/ha)	Direct Energy Input (GJ/ha)	Indirect Energy Input (GJ/ha)	Researchers	Country
Wheat		2.5 ~ 4.3		Pellizzi et al (1988)	Europe
Maize		4.7~5.0		Pellizzi et al (1988)	Europe
Cotton	49.73	21.14	28.59	Yilmaz et al (2005)	Turkey
Rice	64.89			(Pretty, 1995)	USA
Pea	2.5 ~5.4			Gulden & Entz (2005)	Canada
Dairy pasture	18.2	14.56	3.63	Wells (2001)	NZ

Pellizzi et al (1988) discussed the energy saving potential of various agricultural machinery and farming practices. Stout (1989) reviewed much of the early research on energy use in agriculture, both for developing and developed countries. A stock take of the existing information on energy efficiency measures was provided by Barber and Pellow (2005). This work also included an extensive list of energy efficiency measures and factors to be aware of when implementing these measures. Two special workshops on energy uses in agriculture were respectively held in NZ (2004) (http://www.maf.govt.nz/mafnet/rural-nz/sustainable-resource-use/climate/energy-and-agriculture-workshop/index.htm) and Australia (2006) (http://www.crdc.com.au/crdc_news-Onfarm_energy_use.htm) respectively.

Tullburg and Wylie (1994) provided a comprehensive review of energy use in agriculture in Australia and reported that for grain and cotton production, tillage on average used around 40% of on-farm energy, planting and harvesting 20%, and the remaining 40% for administration and cartage. In comparison, Pellizzi et al (1988) found that in Europe, for wheat-like cereals, 55-65% of the direct field energy consumption was accounted to soil tillage, while harvesting took about 25%. They also reported that the range of field energy consumption for wheat-like cereals varied from 2.5 GJ/ha to 4.3 GJ/ha. For maize, this was estimated to be between 12.6 GJ/ha to 16.2 GJ/ha including drying which alone would require 50 to 60% of the fuel consumption. They attributed the remaining energy use to tillage (30-40%), irrigation and other cultivation practices (30-40%), and harvesting (18-20%). The average percentage contribution of the direct energy input for different farming processes in Europe is shown in Fig.1 (Pellizzi et al, 1988).

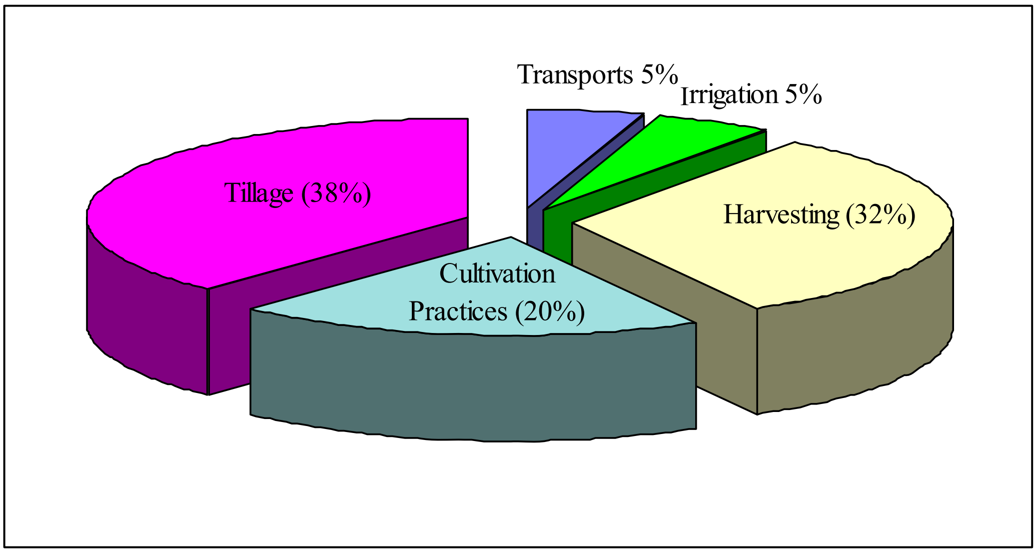


Figure 1 Direct on-farm energy inputs, Europe (Pellizzi et al, 1988)

Pellizzi et al (1988) showed that with improved management and operation, energy saving of around 12-15% of present consumption can be realistically obtained for tractors, 30% for soil tillage, and 10% for harvesting machines. Similar saving was found by Tullburg and Wylie (1994). Based on two year experiments in Croatia, Kosutic (2001) demonstrated that up to 82.6% of energy can be saved by the adoption of no-till conservation farming system (0.25 GJ/Ha) in comparison with the conventional tillage system (1.44 GJ/Ha). Gulden and Entz (2005) found that 36% of fuel was saved by the adoption of no-till conservation farming system in Canada. A comparative study of conventional tillage and conservation farming was carried out by Smith (2001) to compare the impact of these practices on soil characteristics, crop performance and economic outcomes. Brown and Elliot (2005) found that the largest on-farm energy savings are available in motorised systems, especially irrigation pumping.

In terms of irrigation, best management guidelines for sustainable irrigated agriculture were published by the New Zealand Ministry of Agriculture and Forestry (1997). A net margin calculator for costing and comparing the costs and returns from any two irrigation systems was also developed by Davies and Richards (2002). The amount of total life-cycle energy uses (i.e., both direct and indirect energy uses) and greenhouse gas (GHG) emissions due to different irrigation systems was analysed by Jacob (2006).

Overall, energy savings in cotton have received relatively little attention. Singh (2002) however, found that cotton has the highest energy usage among wheat, mustard, maize and cluster bean. Singh et al (1996) also reported that the cost of energy per unit area normally decreases with farm size because large farms have better capacity to manage energy use. Yaldiz et al. (1993) reported that fertilizers and irrigation energy dominate the total energy consumption in Turkish cotton production. Yilmaz et al (2005) showed that the energy intensity in agricultural production is closely related with production techniques. He estimated that cotton production in Turkey consumed a total of 49.73 GJ/ha energy, consisting of 21.14 GJ/ha (42.5%) direct energy input and 28.59 GJ/ha (57.5%) indirect energy input. By comparison, modern rice production in the United States requires a total energy input of 64.89 GJ/ha for a yield of 5.8t/ha or 11.19 GJ energy input for per tonne of grain produced (Pretty, 1995). Gulden and Entz (2005) found that legume crops (eg pea) use much less energy than other crops because of the low nitrogen fertilizer requirement.

Through the collection and analysis of energy data of 150 dairy farms, Wells (2001) determined the total energy inputs for dairy production in New Zealand. He estimated that the total energy requirements of the 'national average' dairy farm in NZ were about 18.2 GJ/ha, of which fuel contributes (20%), fertiliser (35%), electricity (25%), capital (13%) and other indirect (7%). He also found that (total) energy uses vary significantly between different farms. He attributed this variation to the differences in the use of fertilisers and the use of electricity for irrigation pumping. Several key sustainability indicators were also developed (Wells, 2001).

Overall, Murray (2005) showed that growing food and fibre accounts for approximately one fifth of total energy use in the U.S. food system, the other four fifths being used to move, process, package, sell, and store food after it leaves the farm. He estimated that of all the energy used in agriculture in the U.S., some 28 percent goes to fertilizer manufacturing, 7 percent goes to irrigation, and 34 percent is consumed as diesel and petrol by farm vehicles used to plant, till, and harvest crops. The rest (31%) goes to pesticide production, grain drying, and facility operations (Figure 2).

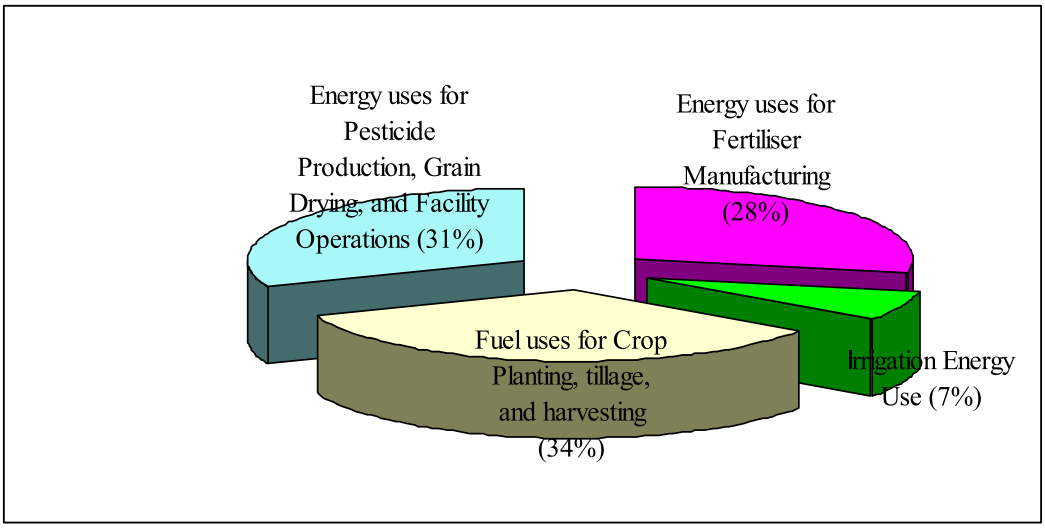


Figure 2 Total on farm energy inputs, USA (Murray, 2005)

In another study, Pfeiffer (2003) estimated that in the United States, about 1500 litres of oil equivalents are expended annually to feed each American (as of data provided in 1994). He broke the agricultural energy consumption (excluding packaging, refrigeration, transportation to retail outlets, and household cooking) in the USA as follows:

- 31% for the manufacture of inorganic fertilizer
- 19% for the operation of field machinery
- 16% for transportation
- 13% for irrigation
- 8% for raising livestock (not including livestock feed)
- 5% for crop drying
- 5% for pesticide production
- 8% miscellaneous.

Brown and Elliot (2005) found that although the currently available agriculture data may be sufficient for general policy development, the quality of existing energy end-use data is often unsatisfactory, therefore making it inadequate to predict where the largest opportunities for energy efficiency are. They suggested that further research be conducted to achieve a clear and consistent definition of farm types and energy end-uses. Individual energy end-uses will also need to be identified and quantified.

In order to increase energy awareness in agriculture and to help farmers identify where they can reduce their energy costs, four separate energy calculators were developed by United States Department of Agriculture (USDA) for estimating the energy uses in animal housing, irrigation, nitrogen, and tillage (http://energytools.sc.egov.usda.gov/). In this way, the average diesel fuel use and costs in the production of key crops in different parts of USA can be estimated and compared. These calculators however do not explicitly relate the energy use to the particular farming methods or per unit of work. It can only estimate the average energy use for a given region.

UK (2007) recently commenced a research project on "Direct energy use in agriculture: opportunities for reducing fossil fuel inputs", to quantify direct energy use in agriculture. The aim of this project is to provide a breakdown by sector and fuel type, and to recommend technologies that offer the best opportunities for reducing the current dependence of the agricultural sector on fossil fuels. A definition of appropriate indicators for 'on-farm' situations will also be developed (http://www2.defra.gov.uk/research/Project_Data/More.asp?I=AC0401&M=KWS&V=Energy).

The issue of managing carbon emissions in rural Australia is receiving increasing attention (Wilson, 2002). At present, the greenhouse gas emissions from the Australian agriculture represent approximately 16% of Australia's total national emissions. Several greenhouse gas calculators have now been developed to estimate the greenhouse footprint from fuel, soils and nitrogen, and to promote the awareness and action on this issue (http://www.greenhouse.crc.org.au/tools/; http://www.isr.qut.edu.au/tools/index.jsp). However, it is noted that these calculators all typically use national-average data to estimate emissions of the greenhouse gases which may change significantly with both time and locations. Chen et al (2007) highlighted the need to develop an economics model to facilitate cost-effective reduction of greenhouse gas emissions. Initial research to address this gap was also outlined. ABARE (2007) in its recent report highlighted the importance of energy-saving measures to greenhouse cuts in Australia.

3 OVERVIEW OF AUSTRALIAN COTTON PRODUCTION SYSTEMS

Depending on the prevailing market and soil conditions, cotton growers generally have a rotation that includes a winter crop following cotton, then a long summer/winter fallow for moisture conservation and then back to the next cotton crop or an alternate summer crop (Harris, 2007). In essence a "typical" cotton grower will most likely have other crops (grains) incorporated into the farming system and the crop rotation. With the advance of biotechnology and increasing awareness of water and energy conservation, conservation farming practices with reduced or zero tillage is becoming widely adopted.

Following the seedbed preparation, cotton is planted in spring (late September to mid November). Herbicide and other chemicals may be applied before planting and may be repeated several times after that. Frequent irrigations may also be applied between the hot months of December and February, depending on available rain fall and soil moisture levels. Cotton is harvested in late March/late May in most regions. The total cotton growing period is about 180 days.

Overall, the main cotton farming activities (events) in different months in Australia are broadly presented and categorised according to the following farming processes Table 9.

Table 2: Calendar of Cotton Operation

<table>
<tr><th>Month</th><th>Farming production activities</th><th>Farming Process</th></tr>
<tr><td>May</td><td>Soil deep ripping</td><td rowspan="4">Fallow</td></tr>
<tr><td>June</td><td>Hilling (bed forming)</td></tr>
<tr><td>July</td><td>Fertilising and hilling up (bed refining)</td></tr>
<tr><td>August</td><td>Fertilising</td></tr>
<tr><td>September</td><td>Pre-planting spraying and irrigation</td><td rowspan="2">Planting</td></tr>
<tr><td>October</td><td>Planting</td></tr>
<tr><td>November</td><td>Inter-row cultivation and spraying (pests & weeds)</td><td rowspan="4">Incrop</td></tr>
<tr><td>December</td><td>Inter-row cultivation, spraying, Fertilising</td></tr>
<tr><td>January</td><td>Inter-row cultivation, spraying</td></tr>
<tr><td>February</td><td>Defoliation</td></tr>
<tr><td>March</td><td>Harvesting</td><td>Harvesting</td></tr>
<tr><td>April</td><td>Mulching</td><td>Post Harvest</td></tr>
</table>

Machinery is integral to modern cotton farming systems. Overall, it has been estimated that machinery may contribute 40-50% of the cotton farm input costs. Inappropriate use of tractors and machinery, when the soil is too moist, is also a significant cause of soil structure degradation leading to reduced yield potential.

Machinery for cotton farming operations is characterised by relatively larger tractor horsepower (~150 to 200 kW) and high work rates (up to 8 Ha/hr). Machinery needs to have sufficient capacity for timely operations. For example, if rain falls on the cotton lint (in March), it can discolour (stain), resulting in a lower price. The typical acceptable time periods to complete various tasks for cotton are presented by Hughes, (2007) Table 2 and based on estimated work rates in Table 3.

Table 2 Acceptable time periods for various farming operations

Farming operations	Acceptable time periods
Planting	7 days
Spraying	2 days
Inter-row cultivation	7 days
Harvesting	21 days

Table 3 Machinery work rates

Machinery	Average work rate
Planter	6 ha/hr
Sprayer	16 ha/hr
Cotton picker (4 rows)	1.2 ha/hr
Cotton stripper (4 rows)	2.4 ha/hr

Typical machinery requirements (and capacity) for a 200-400 Ha cotton farm are normally associated with critical aspects of the farming process including planting, pest control, weed control and harvesting. Basis machinery requirements are presented in Table 4. Outside of these basic requirements other machinery options will vary depending on the adopted farming system.

Table 4 Typical machinery requirements

Machinery	Recommended capacity
Tractor	150 – 200 kW
Planter	8 to 12 row
Spray rig	24 m
Inter-row cultivator	8 to 12 row
Harvesting equipment	4 – 6 row cotton picker; module builder and boll buggies

4 FRAMEWORK TO ASSESS ON-FARM ENERGY USE

To assess on-farm operational energy inputs for cotton (and other crops) a framework was developed which conceptualises the major processes of a farming operation regardless of crop type. This framework consists of 6 major processes including:

1. Fallow
2. Planting
3. In-crop Operations
4. Irrigation
5. Harvesting
6. Post-harvesting

Each of the above farming processes may also be further divided into a number of common farming practices / operations such as tillage, spraying, fertilizing, and irrigation type etc. Each of these farming practices / operations may also appear in several farming processes (Figure 3). Implementation of the framework described in Figure 3 to assess on-farm energy use led to the development and implementation of an online energy calculator (EnergyCalc) which is described in section 5.

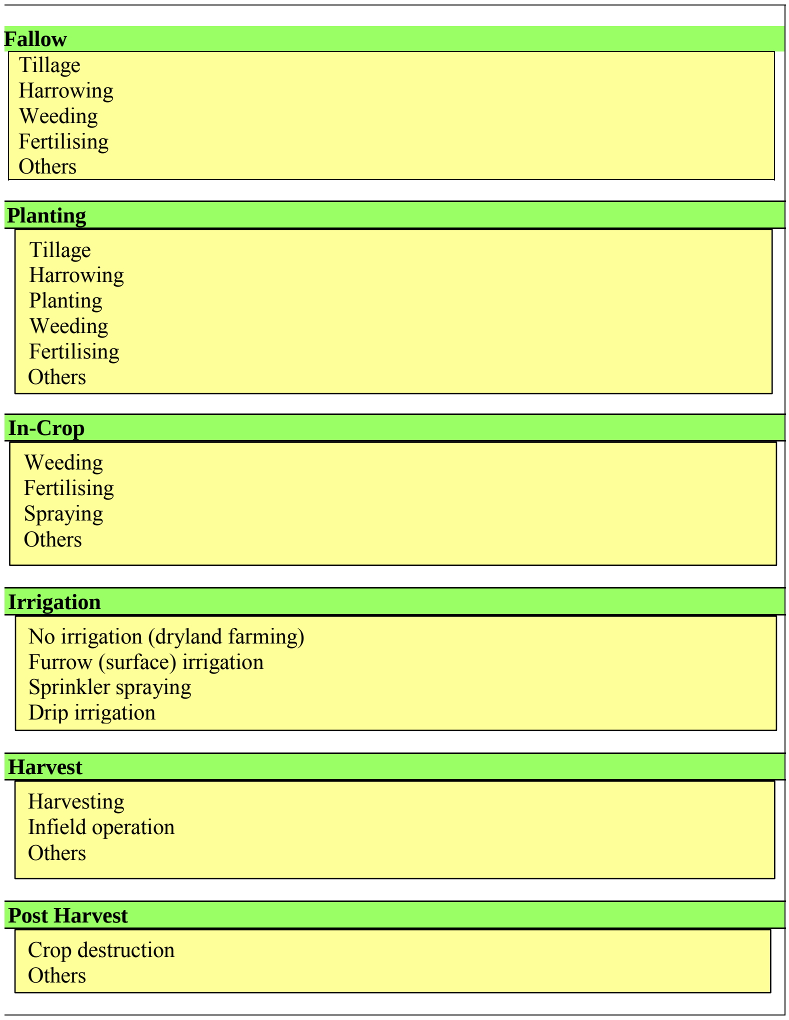


Figure 3 Farming processes (stages) in cotton production

4.1 Fallow

Fallow operations are normally weighted towards tillage however recent implementation of minimum tillage farming practices has placed greater emphasis on spraying (to reduce costs and conserve soil moisture). Fallow tillage operations include subsoiling, discing, chisel ploughing, or harrowing. Tillage operations performed prior to planting cotton is aimed to make a firm, well-drained seedbed that will provide a warm environment for seed germination and vigorous seedling growth. These tillage operations represent not only high energy, equipment and labour costs, but also can reduce soil organic matter, and contribute to environmental pollutions and soil erosion. Tillage operations can account for a significant proportion of overall cotton production costs and is one of the important management variables that producers can directly control.

From the literature, the average fuel use for various tillage methods in Australia is estimated in Table 5.

Table 5 Average fuel use for different tillage methods (fallow)

Soil tillage methods	Average fuel use
Subsoiling	18 Litre/ha diesel use
Discing	12 Litre/ha diesel use
Chisel ploughing	7 Litre/ha diesel use
Power Harrowing	8 Litre/ha diesel use
Light Harrowing/rolling	4 Litre/ha diesel use
Hilling (bed forming)	No data currently available

(Source Tullburg and Wylie, 1994; Downs and Hansen, 2007)

It is noted that these figures assume typical conditions and average working depths. For some very heavy or light soils, these values may vary by up to 25% or more (Downs and Hansen, 2007). To save fuel costs, it is particularly important that:

- Avoid using machinery in wet soil
- Use minimum tillage when appropriate.

For some operations such as hilling (bed forming), there is currently no fuel use data available in the literature. In this case, the energy use may be estimated using the data of “similar” operations or based on the power (size) of the tractor engine, loading conditions (heavy, normal or light duty), and tractor work rate etc. This (alternative) method will be discussed later in the report.

4.2 Planting

For cotton production, there are essentially two methods of planting: conventional drilling or direct drilling. The average fuel use for these two methods is presented in Table 6:

Table 6 Average fuel use for planting

Planting methods	Average fuel use
Conventional drilling	5 Litre/ha diesel use
Direct drilling	10 Litre/ha diesel use

It is reported that by adopting the direct drilling and controlled traffic farming method, fuel saving of up to 50~70 % may be achieved over the whole season.

4.3 In-crop operations

After planting various in-crop operations will be performed to maintain the crop. These include weed control, and applications of various fertilizers and pesticides. Depending on the height of the crop, weed control may be done by either inter-row cultivation or shielded / boom spraying. Farm chemicals (herbicides and insecticides) may also be applied using tractors on the ground, or by an aircraft. With the advance of biotechnology and development of crop varieties, the number of crop spraying operations (insecticides) has been reduced from as much as 16 to 3 to 4 times on average. Similarly inter row cultivation has been reduced. The average fuel uses for each of these field operations are presented in Table 7. [I assume a comparison of conventional vs Bollgard II crops would be possible using Energy Calc?]

Table 7 Average fuel use for in crop operations

In-crop operations	Average fuel use
Fertiliser spreading	3 Litre/ha diesel use
Spraying (by aircraft)	0.035 Litre/ha diesel use
Boom spraying (by tractor)	1.5-3 Litre/ha diesel use
Inter-row cultivation	4-6 Litre/ha diesel use

From the above table, it can be seen that the (direct) fuel use for spraying is significantly lower than that used for cultivation. The energy used to manufacture the pesticides has however not been included in the above table. For these in-crop operations, the range of energy use variation is typically around 10%.

4.4 Irrigation

Cotton may be rain-grown (dryland farming) or watered by irrigation. Farm irrigation systems include surface irrigation, sprinkler systems, and drip (trickle) systems.

It is estimated that in Australia, about 92% of the total cotton production and 85% of the total area is surface irrigated. Sprinkler irrigation (6-7%), consists of either Centre

Pivot or Lateral Moves. These pressured irrigation systems are often powered by diesel engines or electric motor (when the electricity is readily available). Due to the high cost of installation, the occurrence of drip irrigation is relatively much less than other irrigation systems (i.e. 1-2% of the irrigated area).

Compared with other on-farm operations, pumping energy use is highly variable. Wells (2001) found that energy use for irrigation was highly correlated to choice of irrigation system, and total pumping head pressure, which includes the energy required for both lifting water several meters higher and pushing against the pressure of the sprinklers and friction loss.

The energy consumed by pumping system is determined by:

Flow rate × Pressure head/ Pump efficiency

This may be represented by the following equation (for electric pump):

Pumping Electricity Use (kWh/ha) = $(g/3.6)\ V\ H\ /\eta$

Where: g = gravity acceleration constant = 9.81 (m/s^2)
η = pump efficiency %
V = volume of water pumped (ML/ha)
H = head pressure (m)

Typical electric pump efficiency is between 50-70%. When diesel engine is used, the pump efficiency would be lowered to 25-30%. Because the energy content of diesel is taken as 38 MJ/L, and 1 kWh is equal to 36 MJ, the corresponding equation for diesel pump is:

Pumping Diesel Use (Litre/ha) = $g\ V\ H\ /\ (38\ \eta)$

Irrigation may have 10-40 m head pressure, with the “typical” values for various systems presented in Table 8

Table 8 Head pressures for pressurised systems

Irrigation method	Typical head pressure (meter)
Surface irrigation	8
Sprinkler spraying	20
Trickle irrigation	35

Pressurised irrigation systems when compared with furrow irrigation will generally save water at the expense of increased energy costs. Where surface irrigation supplies are pumped more water (eg, 5~10 ML/ha in comparison 3~7 ML/ha) may have to be pumped to make up for lower irrigation efficiency. Typical irrigation efficiency for surface, sprinklers and trickle irrigation are 50-70%, 75%, and 90% respectively. The capital cost of pressurised systems is also significantly higher. The typical setup costs and life expectancy of various irrigation systems is shown in Table 9. The comparison of life cycle energy consumption and costs of alternative irrigation systems is shown in Table 10 (Jacobs, 2006). In recent years, there is a strong move towards the adoption of pressurized sprinkler irrigation systems within the Australian cotton industry.

Table 9 The typical setup costs and life expectancy of various irrigation systems

Irrigation System	Setup Cost ($/ha)	Life Expectancy (years)
Furrow irrigation	$1800-$2500	10-20
Sprinkler spraying	$2500-$4000	15-25
Trickle irrigation	$4500	7-10

Table 10 Total life cycle energy consumption for different irrigation systems

Irrigation methods	Total life-cycle energy consumption
Surface irrigation	4.6 GJ/ha/year
Centre Pivot	6.2 GJ/ha/year
Sub-surface Drip	10.5 GJ/ha/year

Assuming the electricity cost of 16¢ per kWh (44¢ per MJ) and a diesel cost of $1.20 per Litre (32¢ per MJ), Smith (2006) showed that the pumping energy costs may be between $0.6 to $1.2/ML/m respectively. This is corresponding to 4 KWh of electricity and 1 Litre of diesel use for per ML water per meter pumped. Similar linear relationships were also found by the research at Queensland Department of Natural Resources (1996) http://www.dnr.qld.gov.au.

4.5 Harvesting

Several units of work are involved in mechanical harvesting of cotton including, harvesting, module building, infield transport (i.e. boll buggies) and road cartage. The average fuel use for these operations is presented in Table 11.

Table 11 Average fuel use for harvesting

Machinery	Average fuel use
Cotton picker	45 Litre/ha diesel use
Cotton stripper	11 Litre/ha diesel use
Module builder	No data currently available
Infield trailers	3 Litre/km
Road cartage	0.08 Litre/km*tonne

It can be seen here that a cotton picker uses nearly 4 times of the energy that is used by a cotton stripper.

4.6 Post-harvesting

After harvest crop residue and stubble is removed to prepare for the next season's crop. This usually involves the actions of slashing, stalk pulling and mulching etc. The average fuel use for each of these field operations is presented in Table 12.

Table 12 Average fuel use for post harvesting operations

Crop destruction	Average fuel use
Slashing	10 Litre/ha diesel use
Stalk pulling	5 Litre/ha diesel use
Mulching	No data currently available

4.7 Others

From time to time, farmers may need to carry out certain tasks that are not discussed above. For these unspecified "others" operations, their energy uses may have to be estimated based on the power (size) of the tractor engine, loading conditions (heavy, normal or light duty), and tractor work rate. For this project, the rule of thumb as suggested by Harris (2005) is adopted:

Average tractor fuel usage (L/hr) = PTO power rating (kW)/4

Note that the above equation is only applicable for normal (medium) loading conditions. For either heavy or light condition, adding or subtracting 20% fuel use would be appropriate. A special calculator has been designed and incorporated into EnergyCalc to assist the user in this calculation.

4.8 Total energy use and greenhouse gas emissions

By adding up all the energy uses discussed above, we may be able to estimate the total (primary) energy use of the farm as

Total (primary) energy use of the farm (GJ) =
0.0386 * Total diesel use (Litre) + 0.036 * Total electricity use (kWh)/0.35

Here we have assumed that the diesel heat content is 38.6 MJ/L, and the electricity generation efficiency is 35%. In the current market condition, 1 GJ of fuel energy would cost around $25-30.

With the increased community concern on global warming and climate change, the greenhouse gas emissions from the cotton production will also need to be monitored. In this report, the algorithms as outlined in the AGO's Factors and Methods workbook (2005) will be adopted http://www.greenhouse.gov.au/workbook/index.html:

GHG Emissions (kg CO_2 equivalent) = Q × EF

in which Q is the quantity of fuel (L) or electricity (kWh) used. EF is the relevant emission factor given below (Table 13) assuming the emission factor for diesel is 74.9 kg CO_2 /GJ.

Table 13 CO_2 Emission factor for diesel and electricity

Energy sources	Emission Factor kg CO_2 equivalent per litre diesel or per kWh electricity
Diesel	2.89
Electricity	1.051

Therefore

Total greenhouse gas emissions of the farm due to energy use (kg CO_2)
= 2.89 * Total diesel use (Litre) + 1.051 * Total electricity use (kWh)

Note that the above calculation has only included the direct greenhouse gas emissions from the energy use, and has not included the effect due to soil tillage/disturbance and nitrogen fertilizer applications (http://www.isr.qut.edu.au/tools/index.jsp). The latter may change significantly with both time and locations.

5 ENERGYCALC - ONFARM ENERGY USE CALCULATOR

5.1 Design and Implementation

A significant aim of this project is to develop a framework and a software tool to assess on-farm operational energy uses. As outlined previously, this calculation will be based on the energy use by units of activities. The software will therefore have a hierarchal structure as shown in Figure 4, which assumes that the faming activities will be arranged in the order of six farming processes of fallow, planting, in-crop, irrigation, harvesting and post harvest. Each of these processes will then be further divided into a number of farming practices such as tillage, harrowing, spraying, fertilising, and irrigation etc. The detailed formulae used in the calculation of energy uses are summarized in Appendix A.

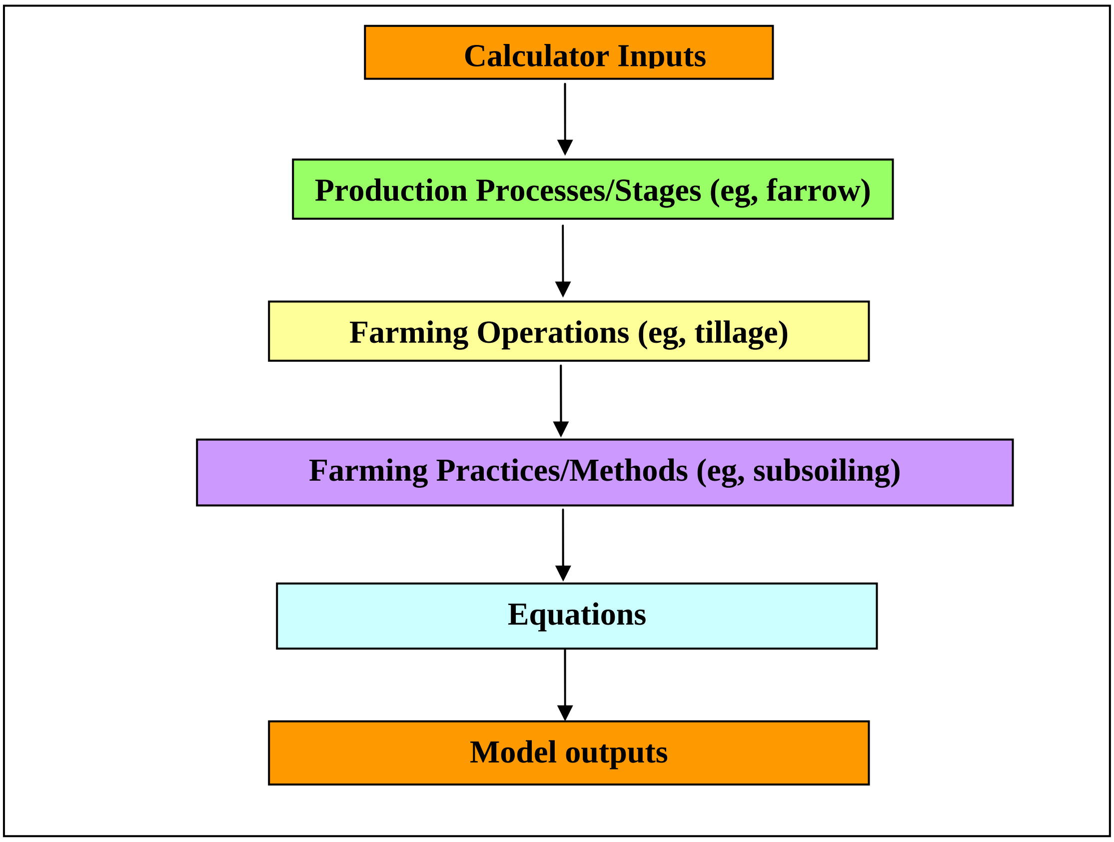


Figure 4 EnergyCalc flow chart

To enter the data into the software, the user will need to select the appropriate farming and sub-farming actions such as subsoiling, discing, chisel ploughing, or harrowing etc, and then enter the specific number of operations (passes) performed. The calculator will then be able to (automatically) convert these input data into estimated energy use based on the default benchmarking energy use data built into the software. If a specific action is not listed in the table, the user can enter the data in the special cell ("others") provided (under each farming practice). The fuel use for these "others" operations can be either entered directly by the farmers or are estimated based on the tractor size and also the tractor work rate. This will then be further adjusted by the loading conditions such as heavy, medium or light. A separate "tractor calculator" is available to assist this calculation.

For most of these input data, default values have been supplied, but the user has been given the option to override these values using his own site-specific data. This may be obtained for example by measuring the amount of fuel used and the area of crop covered for specific operations over a specific time, such as two or three days. This will allow a grower to benchmark his real performance and identify opportunities to reduce costs.

EnergyCalc also gives an excellent feedback on both the estimated total energy use on the farm, as well as in the individual production processes. For this purpose, the software outputs are grouped into four broad categories related to fuel use, electricity use, total on-farm energy use and carbon emissions. A number of normalised energy use indices (energy intensity) such as GJ/ha or $/ha are also included to allow farmers to directly compare and benchmark his energy performance.

All the above input and output data are automatically stored in a central location (web server). This accumulation of data will eventually provide a wealthy source of data for the industry, and may be used for fuel use monitoring and for policy development.

For widespread use and delivery to the Australian cotton industry, the software has been implemented on a web enabled platform for online uses.

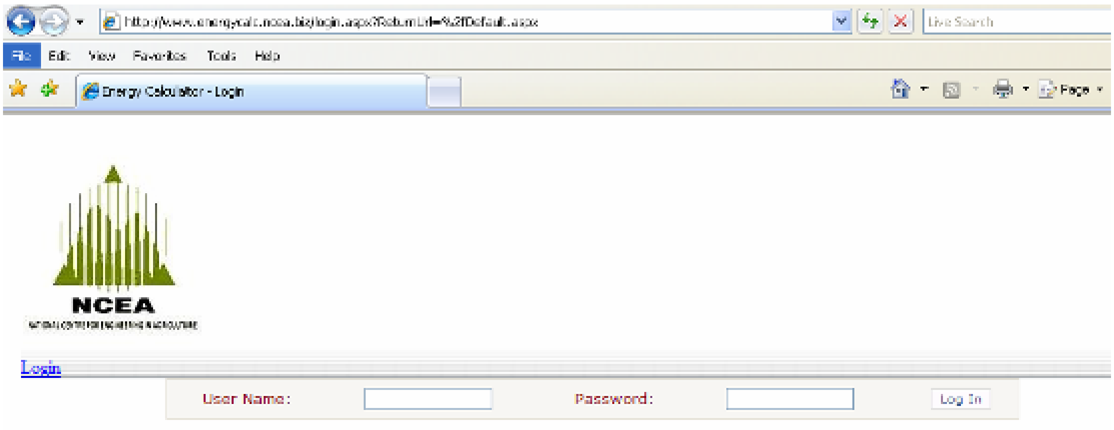
Overall, it will be found that the software (EnergyCalc) is user-friendly, and has also a number of unique and important features. First, this is a world-first energy calculator specifically designed for property and process level energy end-use calculations. It is also self-explanatory, and quick and easy to use – essentially just follow the prompts and enter the number of farming operations (passes) performed, the area covered, the water used, and you're away.

In addition to total farm-level energy inputs, EnergyCalc is also able to store and identify the (historical) energy usage data in each of the six production processes including: fallow, planting, in-crop, irrigation, harvesting and post harvest. Total greenhouse gas emissions are also calculated. This information may become important in the future if the carbon-trading system is introduced into agriculture.

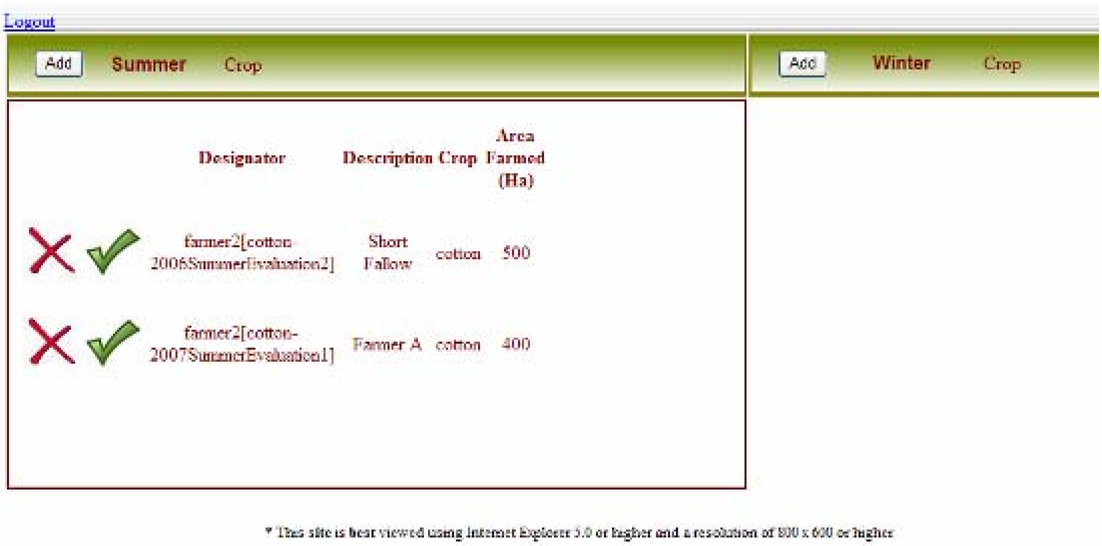
5.2 Operation and Use

5.2.1 Log in

The software (EnergyCalc) will first require the user to enter User Name and Password, and then click "Log in".



The user then has the options to "Add" (create) a new record of crop listing, or "Select (√)" or "Delete (X)" the old records from previous interrogations.



5.2.2 Entering farm-level (global) input data

To create a new record of crop listing, the user will need to first enter a number of basic farm-level (global) data in the drop-down menu. These include: Crop type (eg, cotton), Area under crop (Ha), Year of the production, and a short description (maximum 15 characters) of the investigation (eg Farm B). The user then needs to select the type of investigation (ie, using actual data or evaluation default data for fuel use rate estimation). Then click “Finish”. In this way, a new record of crop listing has been created. The user will also be returned to the previous page with this new record.

5.2.3 Entering operation-related input data

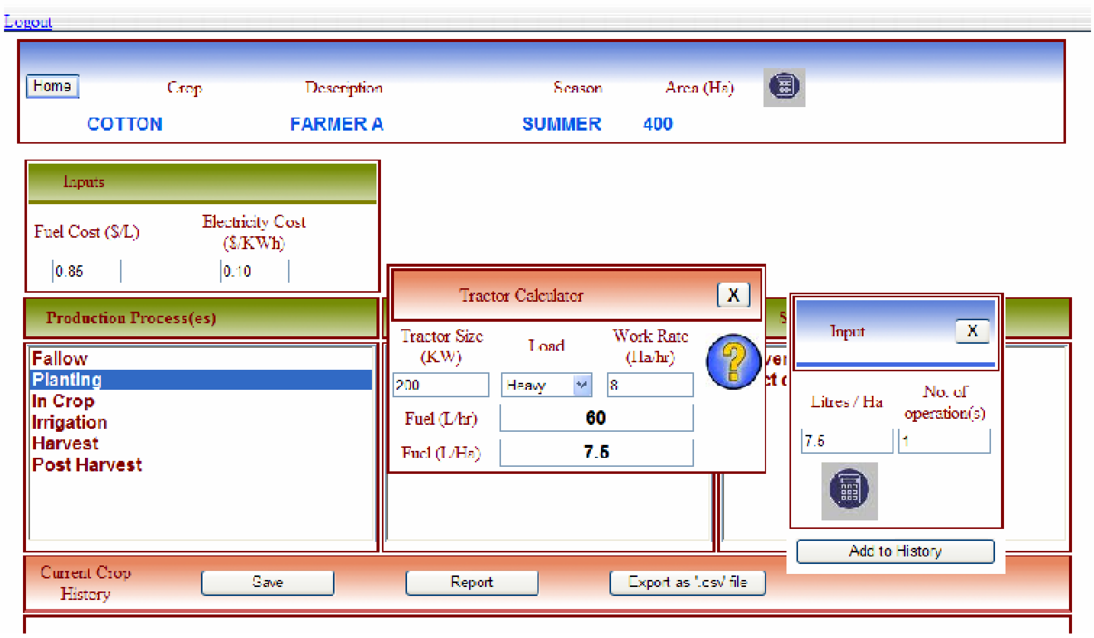
First, the user will need to enter (or modify) another two basic data for the farm, including the cost of fuel (default value $0.85/L), and cost of electricity (default value $0.10/kWh).

Now the user is ready to start entering operation-related input data for his specific farming system. This is achieved by “Select” (indicated by colour change of the cell) appropriate Production Process, and Farming Operation, and Sub-Farming Operation, and then enter (or change) the fuel use rate and the number of particular operations (passes) performed, and click the button “Add to History” to finish and store the entered data.

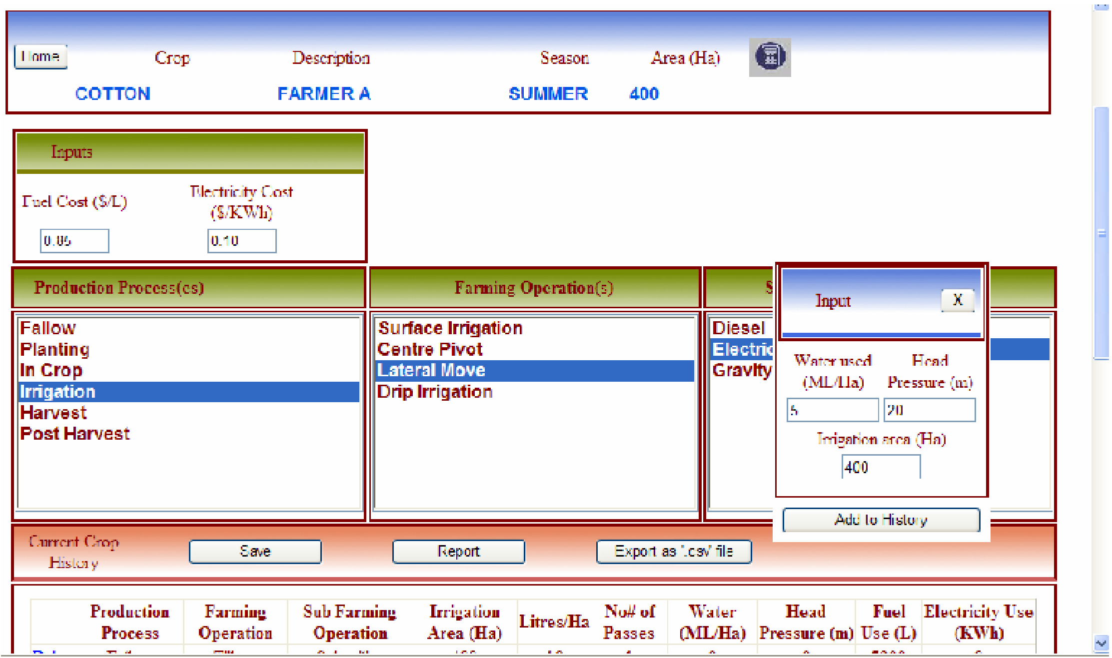
Repeat the above operations as many as necessary to enter all the data.

A special "Tractor Calculator" module (shown as a blue calculator icon) is also available. This module is needed when the user wishes to calculate his site-specific fuel use rate based on the tractor size and work rate.

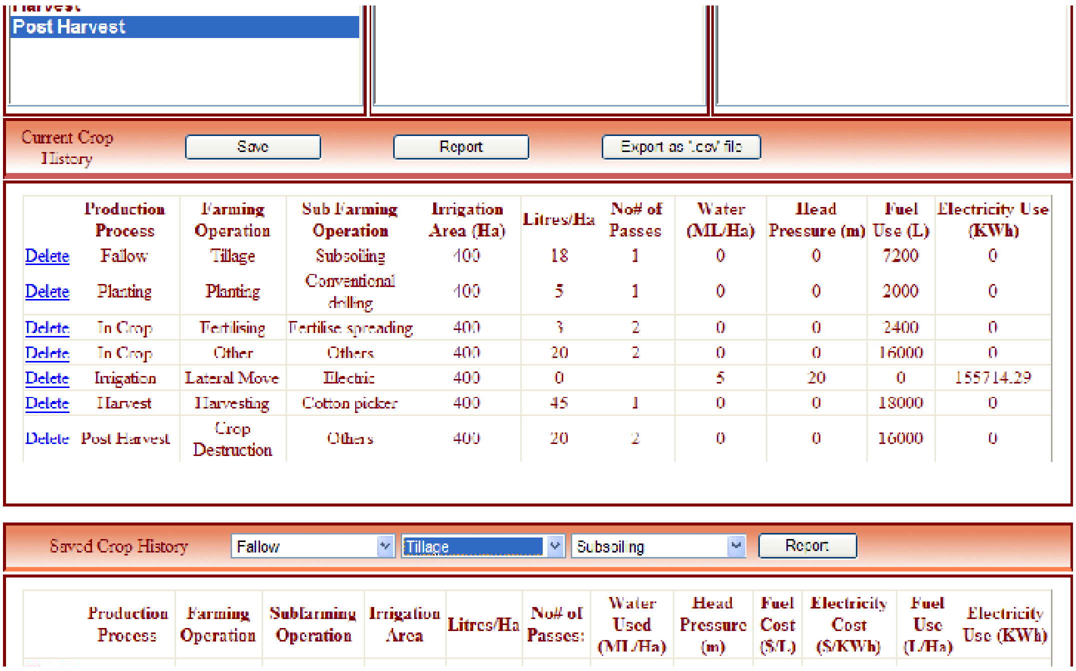
Click the blue calculator icon, and enter the Tractor Size (kW), and then select either "Heavy", "Medium" or "Light" loading condition, and enter the appropriate "Work Rate" and click the blue-circled yellow "?" button in the far right. The calculator will then automatically convert these just-entered data into fuel use rate (L/ha) and show up in the fuel use calculation.



The user will then also need to specify the irrigation method used (Surface irrigation, Centre Pivot Irrigation, Lateral Move Irrigation or Drip irrigation), and the pump motor type (Electric motor or Diesel motor, or Gravity feed). For estimating the energy use by irrigation, the user will need to specify the parameters of Head Pressure (m), and Water Used (ML/ha) for his system. The software then will be able to calculate the energy use based on these information. Then click the button "Add to History" to store the data.



The stored data for the current crop history (ie, the current investigation) can be viewed in the table just beneath the operation data entry module. If a lot of operations are involved, it may be necessary to scroll down to look at all the data. Incorrectly entered data can also be deleted here too.



	Production Process	Farming Operation	Sub Farming Operation	Irrigation Area (Ha)	Litres/Ha	No# of Passes	Water (ML/Ha)	Head Pressure (m)	Fuel Use (L)	Electricity Use (KWh)
Delete	Fallow	Tillage	Subsoiling	400	18	1	0	0	7200	0
Delete	Planting	Planting	Conventional drilling	400	5	1	0	0	2000	0
Delete	In Crop	Fertilising	Fertilise spreading	400	3	2	0	0	2400	0
Delete	In Crop	Other	Others	400	20	2	0	0	16000	0
Delete	Irrigation	Lateral Move	Electric	400	0		5	20	0	155714.29
Delete	Harvest	Harvesting	Cotton picker	400	45	1	0	0	18000	0
Delete	Post Harvest	Crop Destruction	Others	400	20	2	0	0	16000	0

To look at all the current and past data entries and energy performance, the "Saved Crop History" in the module below the "Current Crop History" is available to show you all the work previously performed and the stored results for that specific process.

Saved Crop History | Fallow | Planting | Subsoiling | Report

	Production Process	Farming Operation	Subfarming Operation	Irrigation Area	Litres/Ha	No# of Passes:	Water Used (ML/Ha)	Head Pressure (m)	Fuel Cost ($/L)	Electricity Cost ($/KWh)	Fuel Use (L/Ha)	Electricity Use (KWh)
X	Fallow	Tillage	Discing	400	12	2	0	0	1.0	0.70	9600	0
X	Fallow	Tillage	Subsoiling	400	18	3	0	0	0.85	0.10	21600	0
X	Planting	Planting	Conventional drilling	400	5	1	0	0	0.85	0.10	2000	0
X	In Crop	Other	Others	400	15	2	0	0	0.85	0.10	12000	0

5.2.4 Software output data

To see the calculation results from the EnergyCalc, click the "Report" in the "Current Crop History". You will be shown a summary of the performance indicators grouped into four broad categories related to fuel use, electricity use, total energy use and carbon emissions. From here, you can also return to previous (data-entering) page by clicking "Hide Report" or return to the beginning page of "crop listing" by clicking "Home" .

Hide Report

CURRENT CROP HISTORY REPORT

Fuel

Total Fuel Use (Litres)	Total Fuel Cost ($)	Fuel Use (L/Ha)	Fuel Cost ($/Ha)
7200	6120	18	15.3

Electricity

Total Electricity (KWh)	Total Electricity Cost ($)	Electricity Use (KWh/Ha)	Electricity Cost ($/Ha)
155714.29	15571.43	389.29	38.93

Energy

Total Energy Use (GJ)	Total Energy Cost ($)	Energy (GJ/Ha)	Energy Cost ($/Ha)
1835.06	21691.43	4.59	54.23

Greenhouse Gas Carbon Emission (Kg)

176530.5

* This site is best viewed using Internet Explorer 5.0 or higher and a resolution of 800 x 600 or higher

Finally, the data you have just entered can be saved onto the central server by clicking "Save" button in the "Current Crop History". This will however also move all the data init to the database and clear (from the screen) the current crop history to avoid data redundancy. To avoid this "loss of data", the user will need to confirm this before continuing.

The data can also be downloaded as a csv spreadsheet file for further analysis. To logout, click the “lock” icon in the upper left corner of the screen.

6 CASE STUDIES

EnergyCalc was used to determine the direct energy use for seven case studies (Farm A to G) in the cotton industry. The data for cotton farms A and B are extracted from Chudleigh, et al (2007), while data for the other case studies (Farms C to G) was obtained from farmer interviews. These farms cover a range of farming regions and farming practices (eg, conventional tillage, minimum tillage, dryland farming, and irrigation) in both NSW and Queensland.

Key elements of each case study include the following and are presented in Table 14. For some of the case studies, basic farm data (eg, irrigation head pressure) was used to reflect the operating costs recorded by the grower and may not reflect physical setup depending on pump efficiency.

- Case Study C entirely gravity fed surface irrigation (no pumping cost),
- Case Study F and G utilised electric power plants for pumping irrigation,
- Case Study A, B, D and E utilised diesel power plants for pumping irrigation,
- Case Study B uses sprinkler irrigation,
- Case Study D, E and G source ground water (high pumping costs) and
- Case Study C, E and G practice minimum tillage (low tillage costs).

Table 14 Key farming methods (cotton production only)

	Tillage method	Irrigation method	Water Sources
Farm A	Conventional tillage	Diesel pump	Surface water
Farm B	Conventional tillage	Diesel pump	Surface water
Farm C	Minimum tillage	Gravity feed	Surface water
Farm D	Conventional tillage	Diesel pump	Ground water
Farm E	Minimum tillage	Diesel pump	Ground water
Farm F	Conventional tillage	Electric pump	Surface water
Farm G	Minimum tillage	Electric pump	Ground water

To demonstrate and compare the relative energy uses for different crop rotation practices, three case studies (Farms E, F, G) of mixed farms (producing cotton and other crops) are also included. Dryland farming is also practiced in farms B, E and G (for other crops only, not for cotton).

6.1 Case Study A (furrow irrigated farming system)

Case Study A is a 450 hectare irrigated property growing cotton in the Emerald irrigation area. It typically irrigates 400 hectares of cotton per annum. Cotton production is based on furrow irrigated Bollgard II with 5% of the area available to be planted allocated to a refuge area for insect control.

The basic input data for this farm are:

Crop type: cotton
Area for cotton farm: 400 ha
Cost of fuel (diesel): $0.85/L
Cost electricity: $0.10/kWh
Tractor size: 200 kW
Irrigation method: furrow irrigation
Pump motor type: diesel motor

Number of subsoiling operation: 1
Number of fertilizing operation: 3
Number of (boom) spraying operation: 1
Number of inter-row cultivation operation: 3
Number of (conventional drilling) planting operation: 1
Number of (cotton picker) harvesting operation: 1
Number of “others” operation (heavy load): 1
Number of “others” operation (medium load): 1
Number of “others” operation (light load): 1

Water Used: 9 ML/ha
Irrigated area: 400 ha
Head pressure: 8 m.

6.2 Case Study B (sprinkler irrigation)

Case Study B is a 2000 hectare irrigated property growing cotton, sorghum and wheat in the Goondiwindi area. It has a 4500 ML allocation from the McIntyre River with a 70% reliability. This allocation typically irrigates 480 hectares of cotton and 240 hectares of sorghum each year. The remaining 1200 hectare is used for rain-grown (dryland) cropping with four year-rotation, working of three years wheat and one year sorghum. Cotton production is based on lateral-move irrigated Bollgard II and is Roundup Ready.

Crop type: cotton
Area for cotton farm: 480 ha
Cost of fuel (diesel): $0.85/L
Cost electricity: $010/kWh
Tractor size: 200 kW
Irrigation method: lateral move irrigation

Pump motor type: diesel motor

Number of chisel ploughing operation: 2
Number of fertilizing operation: 3
Number of (boom) spraying operation: 3
Number of inter-row cultivation operation: 1
Number of (conventional drilling) planting operation: 1
Number of (cotton picker) harvesting operation: 1
Number of "others" operation (heavy load): 1
Number of "others" operation (medium load): 1
Number of "others" operation (light load): 1

Water Used: 3.1 ML/ha
Irrigated area: 480 ha
Head pressure: 20 m.

6.3 Case Study C (min till furrow irrigated farming system)

Case Study C is a 500 hectare irrigated property growing cotton (250 Ha) in rotation with wheat (190 Ha) and chickpeas (60 Ha) in the Lower Namoi Valley (NSW). The farm is divided into 8 fields. One field is laser levelled and worked each year. Minimum tillage is practiced with wide permanent beds.

The basic input data for the cotton production of this farm are:

Crop type: cotton
Area for cotton farm: 250 ha
Cost of fuel (diesel): $0.85/L
Cost electricity: $0.10/kWh
Tractor size: 200 kW
Irrigation method: furrow irrigation
Pump motor type: gravity feed

Number of (direct drilling) planting operation: 1
Number of (boom) spraying operation: 9
Number of (aircraft) spraying operation: 1
Number of inter-row cultivation operation: 1
Number of (cotton picker) harvesting operation: 1
Number of slashing operation: 1
Number of stalk pulling operation: 1
Number of "others" operation (light load): 3

Water Used: 5 ML/ha
Irrigated area: 250 ha
Head pressure: 5 m.

6.4 Case Study D (furrow irrigated farming system)

Case Study D is a 248 hectare irrigated property growing cotton in rotation with sorghum on the Darling Downs (Queensland).

The basic input data for the cotton production of this farm are:

Crop type: cotton
Area for cotton farm: 150 ha
Cost of fuel (diesel): $0.85/L
Cost electricity: $0.10/kWh
Tractor size: 150 kW
Irrigation method: furrow irrigation
Pump motor type: diesel motor

Number of subsoiling operation: 1
Number of (direct drilling) planting operation: 1
Number of (boom) spraying operation: 5
Number of (aircraft) spraying operation: 3
Number of inter-row cultivation operation: 2
Number of (cotton picker) harvesting operation: 1
Number of “others” operation (heavy load): 1
Number of “others” operation (medium load): 1
Number of “others” operation (light load): 3

Irrigated area: 150 ha
Water Used: 2 ML/ha
Head pressure: 100 m.
Water Used: 6 ML/ha
Head pressure: 8 m.

6.5 Case Study E (min till furrow irrigated farming system)

Case Study E is a 840 hectare property growing cotton (40%, irrigation) in rotation with wheat (20%, dryland) and sorghum/corn (40%, irrigation) on the Darling Downs (Queensland). Mminimum tillage is practiced with 2 m wide beds (single row cotton; dual row sorghum and corn).

The basic input data for the cotton production of this farm are:

Crop type: cotton
Area for cotton farm: 336 ha
Cost of fuel (diesel): $0.85/L
Cost electricity: $0.10/kWh
Tractor size: 200 kW
Irrigation method: furrow irrigation
Pump motor type: diesel motor

Number of fertilizing operation: 2
Number of (direct drilling) planting operation: 1
Number of (boom) spraying operation: 8

Number of (cotton picker) harvesting operation: 1
Number of slashing operation: 1
Number of stalk pulling operation: 1
Number of “others” operation (light load): 3

Irrigated area: 336 ha
Water Used: 7.5 ML/ha
Head pressure: 5 m.
Water Used: 2.5 ML/ha
Head pressure: 55 m.

The basic input data for the wheat production of this farm are:

Crop type: wheat
Area for wheat farm: 168 ha
Cost of fuel (diesel): $0.85/L

Number of discing operation: 1
Number of (conventional drilling) planting operation: 1
Number of (boom) spraying operation: 2
Number of harvesting operation (20 litre/ha): 1
Number of “others” operation (medium load): 1
Number of “others” operation (light load): 2
Irrigated area: 0 ha (dryland farming practiced)

The basic input data for the sorghum/corn production of this farm are:

Crop type: sorghum/corn
Area for sorghum/corn farm: 336 ha
Cost of fuel (diesel): $0.85/L

Number of inter-row cultivation operation: 1
Number of (direct drilling) planting operation: 1
Number of (boom) spraying operation: 7
Number of harvesting operation (20 litre/ha): 1
Number of “others” operation (medium load): 1
Number of “others” operation (light load): 2

Irrigated area: 336 ha
Water Used: 1.5 ML/ha
Head pressure: 55 m.
Water Used: 3 ML/ha
Head pressure: 5 m.

6.6 Case Study F (furrow irrigated farming system)

Case Study F is a 800 hectare surface irrigated property growing cotton ((200 Ha) in rotation with Chickpeas (500 Ha) and Sorghum (100 Ha) in Central Queensland.

The basic input data for the cotton production of this farm are:

Crop type: cotton
Area for cotton farm: 200 ha
Cost of fuel (diesel): $0.85/L
Cost electricity: $0.10/kWh
Irrigation method: furrow irrigation
Pump motor type: electric motor

Number of subsoiling operation: 1
Number of power harrowing operation: 1
Number of fertilizing operation: 1
Number of (direct drilling) planting operation: 1
Number of (boom) spraying operation: 3
Number of inter-row cultivation operation: 1
Number of (cotton picker) harvesting operation: 1
Number of "others" operation (Large load): 1
Number of "others" operation (medium load): 2
Number of "others" operation (light load): 4

Water Used: 13 ML/ha
Irrigated area: 200 ha
Head pressure: 8 m.

The basic input data for the Chickpeas production of this farm are:

Crop type: Chickpeas
Area for Chickpeas farm: 500 ha
Cost of fuel (diesel): $0.85/L
Cost electricity: $0.10/kWh
Irrigation method: furrow irrigation
Pump motor type: electric motor

Number of power harrowing operation: 1
Number of (direct drilling) planting operation: 1
Number of (boom) spraying operation: 3
Number of inter-row cultivation operation: 1
Number of harvesting operation (20 litre/ha): 1

Number of "others" operation (medium load): 1
Number of "others" operation (light load): 2

Water Used: 4 ML/ha
Irrigated area: 500 ha
Head pressure: 8 m.

The basic input data for the sorghum production of this farm are:

Crop type: sorghum
Area for sorghum farm: 100 ha

Cost of fuel (diesel): $0.85/L
Cost electricity: $0.10/kWh
Irrigation method: furrow irrigation
Pump motor type: electric motor

Number of power harrowing operation: 1
Number of inter-row cultivation operation: 2
Number of (direct drilling) planting operation: 1
Number of (boom) spraying operation: 3
Number of harvesting operation (20 litre/ha): 1
Number of “others” operation (medium load): 1
Number of “others” operation (light load): 2

Irrigated area: 50 ha
Water Used: 4 ML/ha
Head pressure: 8 m.

6.7 Case Study G (furrow irrigated farming system)

Case Study G is in the Upper Namoi Valley (NSW), and has 968 hectare of irrigation area and 240 hectare of area of dryland farming. The irrigated area grows Cotton (506 Ha) in rotation with wheat (341 Ha) and chickpeas (74 Ha).

Crop type: cotton
Area for cotton farm: 506ha
Cost of fuel (diesel): $0.85/L
Cost electricity: $0.10/kWh
Irrigation method: furrow irrigation
Pump motor type: electric motor

Number of (direct drilling) planting operation: 1
Number of (boom) spraying operation: 5
Number of (aircraft) spraying operation: 4
Number of inter-row cultivation operation: 1
Number of (cotton picker) harvesting operation: 1
Number of “others” operation (Large load): 5
Number of “others” operation (medium load): 0
Number of “others” operation (light load): 3

Irrigated area: 506 ha
Water Used: 2.76 ML/ha
Head pressure: 25 m.
Water Used: 1.84 ML/ha
Head pressure: 110 m.

The basic input data for the <u>wheat</u> production of this farm are:

Crop type: wheat
Area for wheat farm: 341 ha

Cost of fuel (diesel): $0.85/L

Number of discing operation: 1
Number of chisel ploughing operation: 1
Number of (conventional drilling) planting operation: 1
Number of (boom) spraying operation: 2
Number of harvesting operation (20 litre/ha): 1
Number of “others” operation (large load): 1
Number of “others” operation (light load): 1.

Irrigated area: 341 ha
Water Used: 1.98 ML/ha
Head pressure: 25 m.
Water Used: 1.32 ML/ha
Head pressure: 110 m.

The basic input data for the Chickpeas production of this farm are:

Crop type: Chickpeas
Area for Chickpeas farm: 74 ha
Cost of fuel (diesel): $0.85/L
Cost electricity: $0.10/kWh
Irrigation method: furrow irrigation
Pump motor type: electric motor

Number of fertilizing operation: 1
Number of (boom) spraying operation: 5
Number of (direct drilling) planting operation: 1
Number of harvesting operation (20 litre/ha): 1
Number of “others” operation (light load): 1

Irrigated area: 74 ha
Water Used: 1.98 ML/ha
Head pressure: 25 m.
Water Used: 1.32 ML/ha
Head pressure: 110 m.

7 RESULTS AND DISCUSSION

Based on the calculated results for each case study (Appendix B) which has been summarised in Figure 5, the total energy inputs ranged from 3.7-15.2 GJ/ha of primary energy, corresponding to 275-1404 kg CO_2 equivalent/ha greenhouse gas emissions. Diesel energy inputs ranged from 95 to 365 liters/ha, with most farms using 120 to 180 liters/ha. This is broadly consistent with that reported in the literature.

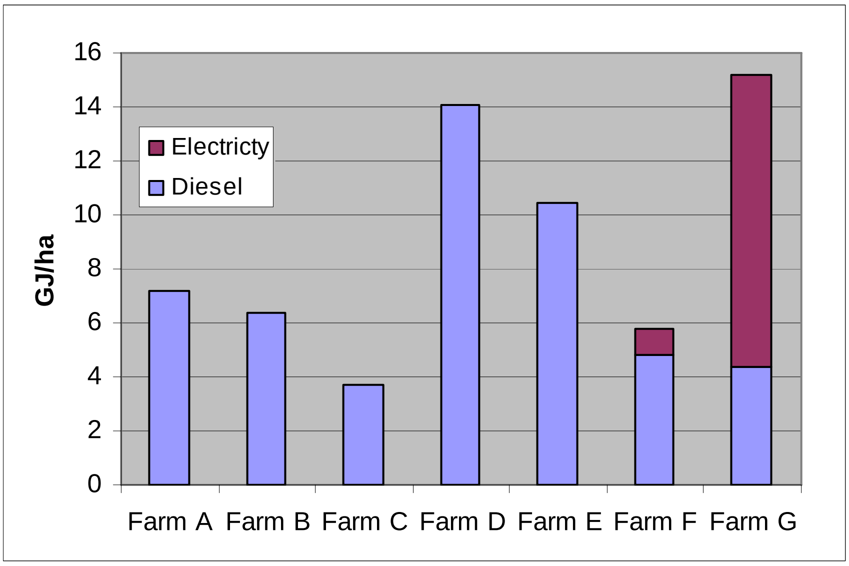


Figure 5 (Primary) energy inputs of case study farms (cotton production only)

The results also show that values for energy inputs vary widely (300%). Farm C uses the smallest amount of diesel energy (95 litres/ha, or 3.7 GJ/ha) due to gravity fed surface irrigation and minimum tillage. Farm D uses the largest amount of diesel energy (365 liters/ha) due to irrigation water which is double pumped. That is, the water is first pumped out of a bore and into an on farm storage and then pumped out of the on farm storage and onto the field. This significantly increases the irrigation energy use (70% of the total energy cost) for this farm (Table 6). A similar situation also occurs for farm E (62%) and G (51%). The total energy costs for different farms for cotton production are shown in Figure 6.

Compared with cotton, the total energy use by other crops are generally much lower (wheat $42-130/ha, sorghum $60-130/ha, chickpeas $50-130/ha). Lower energy use is due to less farming operations (generally 10 passes, compared to 17-18 for cotton) combined with reduced irrigation requirements. The energy use by the cotton harvester (45 L/ha) is another factor, as it uses much more energy than the other types of crop harvesters which use 10-20 L/ha of diesel. As a result, obtaining accurate measurements for harvesting energy use is important in the context of the cotton production system.

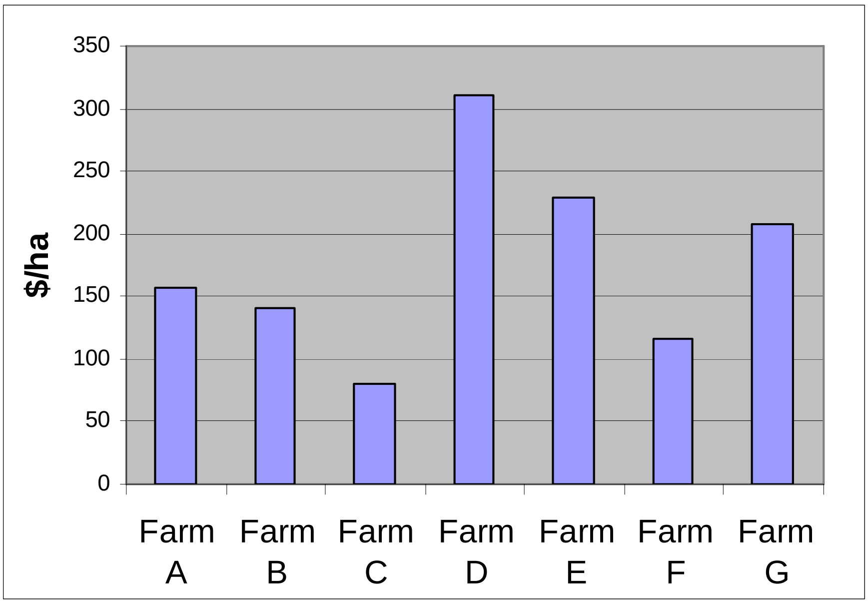


Figure 6 Total direct energy costs of case study farms (cotton production only)

The calculated results also show that the energy use by tillage and other on-farm operations vary due to the number of tillage operations between different farmers (particularly if minimum tillage is practiced or not). It is shown that if a farmer moves from conventional tillage to minimum tillage (eg Farms C and E), there is a potential saving of around 10% of the fuel used on the farm. This can also be seen in the proportion of energy spent on fallow management which reduces significantly from typically 12-15% to 4-5% of the total cost (Table 15). In comparison Farm F spent the highest proportion of energy inputs (32%) on fallow operations due to the use of both a rotary hoe and ripper (Table 15).

Table 15 Percentage of total energy costs for different cotton farming processes

	Fallow	Harvest	In Crop	Irrigation	Planting	Post Harvest
Farm A	15%	24%	8%	40%	4%	9%
Farm B	14%	27%	3%	39%	7%	10%
Farm C	4%	54%	21%	0%	5%	16%
Farm D	7%	14%	4%	70%	1%	3%
Farm E	5%	19%	4%	62%	2%	7%
Farm F	32%	38%	7%	9%	7%	7%
Farm G	12%	21%	4%	51%	4%	8%
All farm average	8%	20%	5%	57%	3%	7%

It can also be seen from Table 15 that values of the energy use by irrigation vary significantly between individual farms, typically between 40-60% of total energy costs for most farms. Farm G produced the highest greenhouse gas emissions (1404 kg CO_2 equivalent /ha) because it used electricity to pump ground water from a bore. These results show that effective water management is critically important, particularly when pumping costs are quite high (i.e. extracting water from bores).

8 CONCLUSION / RECOMMENDATIONS

With increasing concern for fuel cost and maximising energy conservation, there is an increasing need for Australian cotton farmers to be able to understand and calculate the amount of fuel used to perform farming operations. By knowing the amount of fuel and electricity required, farmers are empowered to fine tune and select the best farming practices that will allow them to reduce costs by becoming more energy use efficient.

In this project, a framework to assess the operational energy inputs of various production systems and the relative performance of a grower within an adopted system has been developed and incorporated in a Betta version web enabled online energy calculator (EnergyCalc). EnergyCalc examines energy usage in six different processes of the production system, including fallow, planting, in-crop, irrigation, harvesting and post harvest.

Through the development of an on-farm energy audit tool, the operational energy costs for different cotton production system can be determined and compared. It has been shown that this tool is not only useful to identify total energy inputs for the overall production system, but also allows growers to compare alternative farming practices or the effect of improvements at the process level. EnergyCalc is a world-first energy calculator designed for farm and process level calculation. All the input and output data can also be automatically stored in a central location (eg secure web server) for further use and benchmarking by the grower.

Seven simplified case studies have been presented. It has been found that overall, depending on the management and operation methods adopted, the total energy inputs for these farms may range from 3.7-15.2 GJ/ha of primary energy, corresponding to $80-310/ha and 275-1404 kg CO_2 equivalent/ha greenhouse gas emissions. This is broadly consistent with that reported in the literature and the experience of the Australian farmers.

It has also been found that energy use of harvesting is significant, because it usually contributes around 20% of overall direct energy use. It has been shown that if a farmer moves from conventional tillage to minimum tillage, there is a potential saving of around 10% of the fuel used on the farm, plus other production advantages. Compared with cotton, the energy use by other crops are generally much smaller (approximately half).

The model has also shown that water management on irrigated cotton properties is critically important; particularly those with high pressure spray irrigation systems or where "double pumping" from bores to storages and then to fields is practised. For surface furrow irrigation, the energy use by irrigation may vary between 40-60% of total energy costs for most farms.

In terms of future work, it has been identified that one of the major limitations of the current tool is its heavy reliance on published data from various sources. Consequently, estimates for both emissions and energy costs in this report could be (occasionally) at either extreme (under or over-estimated) relative to actual scenarios. Users are therefore advised that the accuracy level of the developed tool in the current form requires some caution. However, this should not devalue its use as a benchmarking tool to compare different farming operations, changes in practice and other farms with similar management systems.

Furthermore, because there is currently no consistent definition of farm types and energy end-uses in the literature, this can sometimes lead to confusion of the data reported. This suggests that further research needs to be conducted to ensure the accuracy and consistency of data, and to reconcile the model with real measured data and farmer expenditure records so that the accuracy of the model can be assured (in different types of farms and in different circumstances in Australia).

This research is limited to on-farm energy use, excluding ginning, drying and other off-farm activities. It is envisaged that additional features of EnergyCalc could include the capacity to extract data from existing grower records and to link with other Greenhouse Gas Calculators.

This project also focuses on "traditional" energy sources, such as electricity, and fossil fuels. The use of renewable energy has therefore been excluded. Indirect embodied energy of fertiliser and machinery has also been excluded, which may account for up to 50-70% of the total energy input in agricultural production. In particular, it is noted that the cost of manufacturing nitrogen fertiliser is mostly a reflection of energy cost.

It is further suggested that the concept of this work is potentially applicable to other Australian agricultural industries so that in the future this tool could be modified and extended to these industries. This would provide an opportunity for co-investment from these industries for continuing development. It would also be useful if this tool is further developed and integrated into an overall suite of environmental assessment tool or star-rating tool for the agriculture sector, to promote awareness, and practical and cultural changes.

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APPENDIX A FORMULAE USED IN ENERGYCALC

Fallow		
Tillage	***Subsoiling***	Fuel use (Litre) = 18 * Area * Number of operation
	Discing	Fuel use (Litre) = 12 * Area * Number of operation
	Chisel ploughing	Fuel use (Litre) = 7 * Area * Number of operation
Harrowing	***Power Harrowing***	Fuel use (Litre) = 8 * Area * Number of operation
	Light Harrowing	Fuel use (Litre) = 4 * Area * Number of operation
Weeding	***Weed Chipping***	Fuel use (Litre) = 0 * Area * Number of operation
	Inter-row Cultivating	Fuel use (Litre) = 5 * Area * Number of operation
Fertilising	***Fertilise spreading***	Fuel use (Litre) = 3 * Area * Number of operation
Others	***Others***	
Planting		
Tillage	***Subsoiling***	Fuel use (Litre) = 18 * Area * Number of operation
	Discing	Fuel use (Litre) = 12 * Area * Number of operation
	Chisel ploughing	Fuel use (Litre) = 7 * Area * Number of operation
Harrowing	***Power Harrowing***	Fuel use (Litre) = 8 * Area * Number of operation
	Light Harrowing	Fuel use (Litre) = 4 * Area * Number of operation
Planting	***Conventional drilling***	Fuel use (Litre) = 5 * Area * Number of operation
	Direct drilling	Fuel use (Litre) = 10 * Area * Number of operation
Weeding	***Weed Chipping***	Fuel use (Litre) = 0 * Area * Number of operation
	Inter-row Cultivating	Fuel use (Litre) = 5 * Area * Number of operation
Fertilising	***Fertilise spreading***	Fuel use (Litre) = 3 * Area * Number of operation
Others	***Others***	
In Crop		
Weeding	***Weed Chipping***	Fuel use (Litre) = 0 * Area * Number of operation
	Inter-row Cultivating	Fuel use (Litre) = 5 * Area * Number of operation
Fertilising	***Fertilise spreading***	Fuel use (Litre) = 3 * Area * Number of operation
Spraying	***Boom spraying***	Fuel use (Litre) = 2 * Area * Number of operation
	Airplane spraying	Fuel use (Litre) = 0035 * Area * Number of operation
Others	***Others***	
Irrigation		
Head pressure (m)		
Water used (ML/ha)		
Electric motor		Electricity use (KWh) = (981/36) * Water used * Area * Head pressure / (070)
Diesel motor		Fuel use (Litre) = 981 * Water used * Area * Head pressure / (38*025)

Harvest		
Harvesting	Cotton picker	Fuel use (Litre) = 45 * Area * Number of operation
	Cotton stripper	Fuel use (Litre) = 11 * Area * Number of operation
Infield operation	Module builder	
	Infield trailer	
	Road cartage	
Others	Others	
Post Harvest		
Crop destruction	Slashing	Fuel use (Litre) = 10 * Area * Number of operation
	Stalk pulling	Fuel use (Litre) = 5 * Area * Number of operation
Others	Others	

APPENDIX B ENERGYCALC RESULTS FOR CASE STUDIES

Calculation results for case study A (furrow irrigated farming system, cotton)

Hide Report

REPORT BASED ON - -

Fuel

Total Fuel Use (Litres)	Total Fuel Cost ($)	Fuel Use (L/Ha)	Fuel Cost ($/Ha)
74139.79	63018.82	185.35	157.55

Electricity

Total Electricity (KWh)	Total Electricity Cost ($)	Electricity Use (KWh/Ha)	Electricity Cost ($/Ha)
0	0	0	0

Energy

Total Energy Use (GJ)	Total Energy Cost ($)	Energy (GJ/Ha)	Energy Cost ($/Ha)
2861.8	63018.82	7.15	157.55

Greenhouse Gas Carbon Emission (Kg)

214348.51

Calculation results for case study B (sprinkler irrigation, cotton)

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REPORT BASED ON - -

Fuel

Total Fuel Use (Litres)	Total Fuel Cost ($)	Fuel Use (L/Ha)	Fuel Cost ($/Ha)
79211.12	67329.45	165.02	140.27

Electricity

Total Electricity (KWh)	Total Electricity Cost ($)	Electricity Use (KWh/Ha)	Electricity Cost ($/Ha)
0	0	0	0

Energy

Total Energy Use (GJ)	Total Energy Cost ($)	Energy (GJ/Ha)	Energy Cost ($/Ha)
3057.55	67329.45	6.37	140.27

Greenhouse Gas Carbon Emission (Kg)

229010.44

Calculation results for case study C (furrow irrigated farming system, cotton)

Hide Report

REPORT BASED ON - -

Fuel

Total Fuel Use (Litres)	Total Fuel Cost ($)	Fuel Use (L/Ha)	Fuel Cost ($/Ha)
23758.75	20194.94	95.04	80.78

Electricity

Total Electricity (KWh)	Total Electricity Cost ($)	Electricity Use (KWh/Ha)	Electricity Cost ($/Ha)
0	0	0	0

Energy

Total Energy Use (GJ)	Total Energy Cost ($)	Energy (GJ/Ha)	Energy Cost ($/Ha)
917.09	20194.94	3.67	80.78

Greenhouse Gas Carbon Emission (Kg)

68689.87

Calculation results for case study D (furrow irrigated farming system, cotton)

Hide Report

REPORT BASED ON - -

Fuel

Total Fuel Use (Litres)	Total Fuel Cost ($)	Fuel Use (L/Ha)	Fuel Cost ($/Ha)
54779.65	46562.7	365.2	310.42

Electricity

Total Electricity (KWh)	Total Electricity Cost ($)	Electricity Use (KWh/Ha)	Electricity Cost ($/Ha)
0	0	0	0

Energy

Total Energy Use (GJ)	Total Energy Cost ($)	Energy (GJ/Ha)	Energy Cost ($/Ha)
2114.49	46562.7	14.1	310.42

Greenhouse Gas Carbon Emission (Kg)

158375.64

Calculation results for case study example E (furrow irrigated and dryland farming system, cotton, wheat and sorghum/corn)

Cotton (case study E)

Hide Report

REPORT BASED ON - -

Fuel

Total Fuel Use (Litres)	Total Fuel Cost ($)	Fuel Use (L/Ha)	Fuel Cost ($/Ha)
90653.69	77055.64	269.8	229.33

Electricity

Total Electricity (KWh)	Total Electricity Cost ($)	Electricity Use (KWh/Ha)	Electricity Cost ($/Ha)
0	0	0	0

Energy

Total Energy Use (GJ)	Total Energy Cost ($)	Energy (GJ/Ha)	Energy Cost ($/Ha)
3499.23	77055.64	10.41	229.33

Greenhouse Gas Carbon Emission (Kg)

262092.51

Wheat (case study E)

Hide Report

REPORT BASED ON - -

Fuel

Total Fuel Use (Litres)	Total Fuel Cost ($)	Fuel Use (L/Ha)	Fuel Cost ($/Ha)
8232	6997.2	49	41.65

Electricity

Total Electricity (KWh)	Total Electricity Cost ($)	Electricity Use (KWh/Ha)	Electricity Cost ($/Ha)
0	0	0	0

Energy

Total Energy Use (GJ)	Total Energy Cost ($)	Energy (GJ/Ha)	Energy Cost ($/Ha)
317.76	6997.2	1.89	41.65

Greenhouse Gas Carbon Emission (Kg)

23799.86

Sorghum (case study E)

Hide Report

REPORT BASED ON - -

Fuel

Total Fuel Use (Litres)	Total Fuel Cost ($)	Fuel Use (L/Ha)	Fuel Cost ($/Ha)
51637.01	43891.46	153.68	130.63

Electricity

Total Electricity (KWh)	Total Electricity Cost ($)	Electricity Use (KWh/Ha)	Electricity Cost ($/Ha)
0	0	0	0

Energy

Total Energy Use (GJ)	Total Energy Cost ($)	Energy (GJ/Ha)	Energy Cost ($/Ha)
1993.19	43891.46	5.93	130.63

Greenhouse Gas Carbon Emission (Kg)

149289.83

Calculation results for case study example F (furrow irrigated farming system, cotton, chickpeas and sorghum)

Cotton (case study F)

Hide Report

REPORT BASED ON - -

Fuel

Total Fuel Use (Litres)	Total Fuel Cost ($)	Fuel Use (L/Ha)	Fuel Cost ($/Ha)
24800	21080	124	105.4

Electricity

Total Electricity (KWh)	Total Electricity Cost ($)	Electricity Use (KWh/Ha)	Electricity Cost ($/Ha)
20242.86	2024.29	101.21	10.12

Energy

Total Energy Use (GJ)	Total Energy Cost ($)	Energy (GJ/Ha)	Energy Cost ($/Ha)
1159.71	23104.29	5.8	115.52

Greenhouse Gas Carbon Emission (Kg)

91943.13

Chickpeas (case study F)

Hide Report

REPORT BASED ON - -

Fuel

Total Fuel Use (Litres)	Total Fuel Cost ($)	Fuel Use (L/Ha)	Fuel Cost ($/Ha)
29000	24650	58	49.3

Electricity

Total Electricity (KWh)	Total Electricity Cost ($)	Electricity Use (KWh/Ha)	Electricity Cost ($/Ha)
6228.58	622.86	12.46	1.25

Energy

Total Energy Use (GJ)	Total Energy Cost ($)	Energy (GJ/Ha)	Energy Cost ($/Ha)
1181.69	25272.86	2.36	50.55

Greenhouse Gas Carbon Emission (Kg)

90071.64

Sorghum (case study F)

Hide Report

REPORT BASED ON - -

Fuel

Total Fuel Use (Litres)	Total Fuel Cost ($)	Fuel Use (L/Ha)	Fuel Cost ($/Ha)
6300	5355	63	53.55

Electricity

Total Electricity (KWh)	Total Electricity Cost ($)	Electricity Use (KWh/Ha)	Electricity Cost ($/Ha)
6228.58	622.86	62.29	6.23

Energy

Total Energy Use (GJ)	Total Energy Cost ($)	Energy (GJ/Ha)	Energy Cost ($/Ha)
305.47	5977.86	3.05	59.78

Greenhouse Gas Carbon Emission (Kg)

24442.76

Calculation results for case study example G (furrow irrigated farming system, cotton, wheat and chickpeas)

Cotton (case study G)

Hide Report

REPORT BASED ON - -

Fuel

Total Fuel Use (Litres)	Total Fuel Cost ($)	Fuel Use (L/Ha)	Fuel Cost ($/Ha)
60781.98	51664.68	120.12	102.1

Electricity

Total Electricity (KWh)	Total Electricity Cost ($)	Electricity Use (KWh/Ha)	Electricity Cost ($/Ha)
534599.84	53459.98	1056.52	105.65

Energy

Total Energy Use (GJ)	Total Energy Cost ($)	Energy (GJ/Ha)	Energy Cost ($/Ha)
7692.18	105124.66	15.2	207.76

Greenhouse Gas Carbon Emission (Kg)

710329.05

Wheat (case study G)

Hide Report

REPORT BASED ON - -

Fuel

Total Fuel Use (Litres)	Total Fuel Cost ($)	Fuel Use (L/Ha)	Fuel Cost ($/Ha)
20460	17391	60	51

Electricity

Total Electricity (KWh)	Total Electricity Cost ($)	Electricity Use (KWh/Ha)	Electricity Cost ($/Ha)
258457.29	25845.73	757.94	75.79

Energy

Total Energy Use (GJ)	Total Energy Cost ($)	Energy (GJ/Ha)	Energy Cost ($/Ha)
3374.33	43236.73	9.9	126.79

Greenhouse Gas Carbon Emission (Kg)

317610.01

Chickpeas (case study G)

Hide Report

REPORT BASED ON - -

Repo

Fuel

Total Fuel Use (Litres)	Total Fuel Cost ($)	Fuel Use (L/Ha)	Fuel Cost ($/Ha)
3478	2956.3	47	39.95

Electricity

Total Electricity (KWh)	Total Electricity Cost ($)	Electricity Use (KWh/Ha)	Electricity Cost ($/Ha)
56087.51	5608.75	757.94	75.79

Energy

Total Energy Use (GJ)	Total Energy Cost ($)	Energy (GJ/Ha)	Energy Cost ($/Ha)
695.13	8565.05	9.39	115.74

Greenhouse Gas Carbon Emission (Kg)

66142.89