XVII[th] World Congress of the International Commission of Agricultural and Biosystems Engineering (CIGR)

Hosted by the Canadian Society for Bioengineering (CSBE/SCGAB)
Québec City, Canada June 13-17, 2010

ENERGY AND GREENHOUSE GAS EMISSIONS OF ASTRALIAN COTTON: FROM FIELD TO FABRIC

BORZOO GHAREEI KHABBAZ[1], GUANGNAN CHEN[1], CRAIG BAILLIE[1]

[1]B.G. KHABBAZ, National Centre for Engineering in Agriculture (NCEA), Faculty of Engineering & Surveying, University of Southern Queensland (USQ), Toowoomba, QLD 4350, Australia. khabbaz@usq.edu.au.
[1]G. CHEN, chengn@usq.edu.au.
[1]C. BAILLIE, craig.baillie@usq.edu.au.

CSBE100434 – Presented at Section IV: Rural Electricity and Alternative Energy Sources Conference

ABSTRACT Australian cotton production has seen vast changes in the past two decades, in both its on-farm and off-farm activities. The resource inputs include both the direct and indirect inputs. A Life Cycle Assessment (LCA) has been carried out in this project to evaluate the energy usage and greenhouse gas emissions of cotton production from field to fabric, which is from the real beginning i.e. tillage up to export shipping. It is found that on-farm indirect cotton-farming is the most energy consuming component (63%), consuming some 32.36 GJ/ha of energy. It is also found to be the most greenhouse gas emitting component (57%), emitting some 1.64 tonne of CO2/ha. This research also shows that on-farm direct stage uses 14.07 GJ/ha of energy and emits 0.78 tonne of CO2/ha. Energy use and the emissions by the off-farm direct section are calculated as 5.09 GJ/ha and 0.14 tonne CO2/ha respectively. Energy consumed by the off-farm indirect farming section is found to be 0.036 GJ/ha or 0.002 tonne CO2/ha. The total energy usage and greenhouse gas emissions in the Australian cotton farming system are estimated to be 46.43 GJ/ha and 2.42 tonnes CO2/ha for on-farm, 5.13 GJ/ha and 0.145 tonne CO2/ha for the off-farm sections. In total (after including the 300 kgCO2/ha soil emission caused by nitrogen based fertilisers), 51.57 GJ/ha of energy is used and 2.86 tonnes CO2/ha is emitted by a typical Australian cotton farming system from field to fabric.

Keywords: Energy, Greenhouse Gas Emissions, Life Cycle Assessment, Cotton.

INTRODUCTION There is currently a lack of data on the life cycle energy and greenhouse gas (GHG) emissions for Australian cotton production. Earlier researches were often only limited to on-farm direct energy usage (Yilmaz et al., 2005; Chen and Baillie, 2009) and did not cover the off-farm and indirect sections of Australian cotton farming and production systems.

Cotton is a significant crop in Australia. Between 1987-88 and 2001-2, gross cotton production was increased by 3 times and the related export value was raised more than 4 times. Yilmaz et al. (2005) found that total energy input of cotton-farming in Turkey was

49.73 GJ/ha, with 21.14 (GJ/ha) being attributed to direct energy input and the other 28.59 (GJ/ha) to indirect energy input. This research however only covered the on-farm section of cotton-farming, which already showed that the indirect energy usage was more than direct energy consumption in on-farm cotton-farming in Turkey.

Chen and Baillie (2009) investigated the on-farm energy usage of Australian cotton production and found that it ranged between 3.7 to15.2 GJ/ha or 275 to 1404 kgCO_2/ha GHG emissions. It was also found that results could vary by up to 300% due to different methods of tillage and irrigation. However, this study was again limited to on-farm direct section of Australian cotton production.

Grant and Beer (2008) published a paper on ‘Life cycle assessment of greenhouse gas emissions from irrigated maize and their significance in the value chain’. This study showed that the average total life cycle greenhouse gas emissions for different uses of maize are: 12.32 tonne CO_2/ha for corn chip manufacture, 7.65 tonne CO_2/ha for starch production, and 8.66 tonne CO_2/ha for ethanol production. In the case of corn chip manufacture, it was also found that pre-farm emissions comprised 6% of the total life cycle emissions, on-farm activities 36% and post-farm activities the remaining 58%.
The main objective of this research is to calculate energy usage and GHG emissions of Australian cotton production from the true beginning i.e. tillage, to the real end i.e. shipping to export destinations. Life cycle assessment (LCA) is used to determine and profile the energy and carbon footprints of different on-farm and off-farm applications (Chen et al, 2010). It is noted that over 98% of Australian produced cotton is for export purpose and only 2% is milled locally. This study will cover both on-farm and off-farm activities and will also include both direct and indirect sections of each farming stage.

MATERIALS AND METHODS A model has been developed to estimate energy usage and GHG emissions of cotton-farming system from field to fabric. This model was developed by Agricultural Engineering team at the National Centre for Engineering in Agriculture (NCEA) based at University of Southern Queensland (USQ), Australia.

This Excel-based model uses macro programming to separate cotton-farming into five different farming sections of:

- On-farm direct (e.g. tillage)
- On-farm indirect (e.g. manufacturing of fertilisers and on-farm machinery)
- Off-farm direct (e.g. ginning, and shipping)
- Off-farm indirect (e.g. manufacturing of processing machinery and storage facilities)
- Soil emissions (e.g. N_2O emissions from the application of nitrogen fertilizer)

By using specific energy and emissions conversion rates, the model is able to show the total energy usage and related GHG emissions for each of the sections detailed above.

Input data for the model was collected from several sources including the farm survey (farmer log book), cotton research organisations and the government departments. Wherever Australian data could be found/collected it was used; otherwise overseas data might be substituted.

Equations below are used to determine each section's energy and emissions:

Total used energy (MJ) = units used * energy conversion rate

Total GHG emissions (kg CO_2) = unit used * emissions conversion rate (kg CO_2/unit)

The tables below show the energy and emissions conversion rates for the different on-farm farming sections.

Table 1: Energy and Emissions Conversion rates used in cotton on-farm (direct section)

Activity	Energy Conversion Rate	Emissions Conversion Rate	Source
Tillage (L of Diesel)	39 (MJ/L)	2.89 (kgCO_2)/MJ	AGO (2004)
Harrowing (L of Diesel)	39 (MJ/L)	2.89 (kgCO_2)/MJ	AGO (2004)
Weeding (L of Diesel)	39 (MJ/L)	2.89 (kgCO_2)/MJ	AGO (2004)
Fertilising (L of Diesel)	39 (MJ/L)	2.89 (kgCO_2)/MJ	AGO (2004)
Planting	39 (MJ/L)	2.89 (kgCO_2)/MJ	AGO (2004)
Spraying (L of Diesel)	39 (MJ/L)	2.89 (kgCO_2)/MJ	AGO (2004)
Harvesting (L of Diesel)	39 (MJ/L)	2.89 (kgCO_2)/MJ	AGO (2004)
In Field Operations (L of Diesel)	39 (MJ/L)	2.89 (kgCO_2)/MJ	AGO (2004)
Crop Destruction (L of Diesel)	39 (MJ/L)	2.89 (kgCO_2)/MJ	AGO (2004)
Furrow or Flood irrigation (ha/year)	4600 (MJ/ha/year)	78.2 (kgCO_2)/ha/year	Jacobs (2005)
Centre Pivot irrigation (ha/year)	6200 (MJ/ha/year)	140 (kgCO_2)/ ha/year	Jacobs (2005)
Subsurface drip (ha/year)	10500 (MJ/ha/year)	175 (kgCO_2)/ ha/year	Jacobs (2005)

Table 2 shows the "indirect" energy and GHG emission rates that are used to manufacture machinery, fertilisers and other materials on a per year basis, noting that the machinery and input materials' energy conversion rates are calculated by using the following equation:

[Energy used to produce 1 kg of machinery or materials/Life period (years)] * Machinery or materials weight (kg)

Table 2: Energy and Emissions Conversion rates used in cotton on-farm (indirect section)

Energy Type	Energy Conversion Rate	Emissions Conversion Rate	Source
Herbicides (L/ha)	310 (MJ/L)	0.06 (kgCO_2/MJ)	Saunders (2006)
Fungicides (L/ha)	210 (MJ/L)	0.06 (kgCO_2/MJ)	Saunders (2006)
Insecticides (kg/ha)	315 (MJ/kg)	0.06 (kgCO_2/MJ)	Saunders (2006)
Plant Growth Regulator (kg/ha)	175 (MJ/kg)	0.06 (kgCO_2/MJ)	Saunders (2006)
Nitrogen (kg/ha)	65 (MJ/kg)	0.05 (kgCO_2/MJ)	Saunders (2006)
Ammonia	28.82 (MJ/kg)	N/A	Saunders (2006)
Urea	33.8 (MJ/kg)	N/A	Saunders (2006)
Diammonium Phosphate	15 (MJ/kg)	0.06 (kgCO_2/MJ)	Saunders (2006)
Potassium	10 (MJ/kg)	0.06 (kgCO_2/MJ)	Saunders (2006)
Sulphur (kg/ha)	5 (MJ/kg)	0.06 (kgCO_2/MJ)	Saunders (2006)
Lime	0.6 (MJ/kg)	0.06 (kgCO_2/MJ)	Saunders (2006)
Manufacturing of Seeds (kg/ha)	33 (MJ/kg)	0.17 (kgCO_2/MJ)	USDA (2009)
Post Rammer (kg/ha)	80 (MJ/kg)	0.04 (kgCO_2/MJ)	Wells (2001)
Grader Blade (kg/ha)	80 (MJ/kg)	0.04 (kgCO_2/MJ)	Wells (2001)
Mower (kg/ha)	80 (MJ/kg)	0.04 (kgCO_2/MJ)	Wells (2001)
Trailer (kg/ha)	160 (MJ/kg)	0.08 kgCO_2/MJ)	Wells (2001)
Silage Feed Wagon (kg/ha)	160 (MJ/kg)	0.08 (kgCO_2/MJ)	Wells (2001)
Bale Feeder (kg/ha)	80 (MJ/kg)	0.04 (kgCO_2/MJ)	Wells (2001)
Front End Loader (kg/ha)	80 (MJ/kg)	0.04 (kgCO_2/MJ)	Wells (2001)
Fertiliser Spreader (kg/ha)	80 (MJ/kg)	0.04 (kgCO_2/MJ)	Wells (2001)
Sprayer (kg/ha)	80 (MJ/kg)	0.04 (kgCO_2/MJ)	Wells (2001)
Hay Rake (kg/ha)	80 (MJ/kg)	0.04 (kgCO_2/MJ)	Wells (2001)
Hay Baler (kg/ha)	80 (MJ/kg)	0.04 (kgCO_2/MJ)	Wells (2001)
Drill (kg/ha)	80 (MJ/kg)	0.04 (kgCO_2/MJ)	Wells (2001)
Farm Implements (kg/ha)	80 (MJ/kg)	0.04 (kgCO_2/MJ)	Wells (2001)
Plough (kg)	80 (MJ/kg)	0.04 (kgCO_2/MJ)	Wells (2001)
Discs (kg/ha)	80 (MJ/kg)	0.04 (kgCO_2/MJ)	Wells (2001)
Cultivator (kg/ha)	80 (MJ/kg)	0.04 (kgCO_2/MJ)	Wells (2001)
Harrows (kg/ha)	80 (MJ/kg)	0.04 (kgCO_2/MJ)	Wells (2001)
Roller (kg/ha)	80 (MJ/kg)	0.04 (kgCO_2/MJ)	Wells (2001)
Harvester (kg/ha)	160 (MJ/kg)	0.08 (kgCO_2/kg)	Wells (2001)
Tractors (kg/ha)	160 (MJ/kg)	0.08 (kgCO_2/kg)	Wells (2001)
In-field transportation of chemicals and fertilisers (kg/ha)	0.03 (MJ/kg)	1.35 (kgCO_2/kg)	Wells (2001)
In-field transportation of seeds (kg/ha)	0.03 (MJ/kg)	1.35 (kgCO_2/kg)	Wells (2001)

Because the machinery is mostly steel based, the carbon emission coefficient for vehicles is calculated by multiplying the energy coefficient (160 MJ/kg) with 0.07 kg CO_2/MJ and adding 1.6 kg CO_2/kg. The reason for adding this number is that the IPCC (1996) guidelines recommend allowing additional emissions of 1.6 kg CO_2/kg for steel and iron products due primarily to the oxidisation of coke during the smelting process. As a result, an emissions factor of 12.8 kg CO_2/kg vehicle weight or 0.08 kg CO_2/MJ is used in this study. The energy conversion rate is assumed to be 80 MJ/kg for farm implements. This equals 0.04 kgCO_2/MJ of the emissions (Wells, 2001).

Table 3 shows the energy usage and related emissions rate for cotton off-farm (direct section).

Table 3: Energy and Emissions Conversion rates used in cotton off-farm (direct section)

Activity	Energy Conversion Rate	Emissions Conversion Rate	Source
Trucking (kg Cotton)	0.5 (MJ/kg)	0.09 (kgCO_2/MJ)	Wells (2001)
Lubricants (L)	38.5 (MJ/L)	0.073 (kgCO_2/MJ)	Wells (2001), AGO (2004)
Ginning (kg Cotton)	2 (MJ/kg)	0.25 (kgCO_2/ kg Cotton)	Ismail (2009)
Shipping (tonne Km)	0.114 (MJ/tonne km)	0.007 (kg/CO_2 per tonne km)	Wells (2001)

The energy used to process 1 kg of cotton in Australian gins is estimated to be 2 MJ/kg with the CO_2 emissions being 0.25 kgCO_2/kg of cotton (Ismail, 2009).
Table 4 shows the emission rates per year for production of machinery that are used in off-farm indirect section of cotton-farming. Motor bikes and light vehicles may be used. Building area is needed for storage and ginning purpose.
It is assumed that 29.5 MJ/m^2 of energy is used to build 1 m^2 of gin building and storage area (Saunders et al, 2006).
N_2O is also found to be one of the main soil emissions sources in cotton-farming. In this paper, it is assumed to be 300 kgCO_2/ha of cotton fields (Grace, 2009).

Table 4: Energy and Emissions Conversion rates used in cotton off-farm (indirect section)

Energy Type	Energy Conversion Rate	Emissions Conversion Rate	Source
Heavy Vehicles (kg/year)	10.67 (MJ/kg)	0.85 (kgCO_2)/Kg	Wells (2001)
Light Vehicles (kg/year)	10.67 (MJ/kg)	0.85 (kgCO_2)/Kg	Wells (2001)
Motor Bikes (kg/year)	10.67 (MJ/kg)	1.28 (kgCO_2)/Kg	Wells (2001)
Buildings (m^2/year)	29.5 (MJ/m^2)	0.01 (kgCO_2/MJ)	Saunders (2006)

RESULTS AND DISCUSSIONS

Application rates Table 5 shows the average application rate for Australian genetically modified (GM) cotton. Average farm size is assumed to be 300 ha. All data and numbers in that table are based on 300 ha of cotton land.

As the most common irrigation system in Australia for cotton farming is furrow irrigation, it is used as the base irrigation method in this study.

Building average life is assumed to be 30 years with 100 m^2 per year used in this research (Total of 3000 m^2 for gin and storage). Normal life time for all farm implements such as tractors and harvesters are assumed as 15 years and 20 years respectively. Average mass for each tractor used in this study was John Deere 7030 series that weight 6967 kg which equals to 464 kg per year. Three tractors were needed for the 300 ha of cotton land (4.64 kg/ha). The average weights of motorcycles, heavy vehicles and Ford falcon Ute are respectively 99 kg, 9320 kg and 1620 kg over their 15 years of life. In this research empty vehicle weights are used to calculate manufacturing energy usages and their related emissions.

Table 5: Application rate in average for Australian GM cotton per annum (300 ha)

Activity	Unit Used	Activity	Unit Used
Direct On-farm		**Indirect On-farm Continues**	
Tillage	18000 L Diesel	**Harvester**	20 kg
Harrowing	2400 L Diesel	**Silage Feed Wagon**	80 kg
Weeding	1500 L Diesel	**Bale feeder**	25 kg
Fertilising	900 L Diesel	**Front end loader**	25 kg
Planting	3000 L Diesel	**Fertiliser spreader**	10 kg
Spraying	900 L Diesel	**Sprayer**	5 kg
Furrow or flood irrigation	300 ha/year	**Hay rake**	100 kg
Centre Pivot	N/A	**Hay baler**	25 kg
Sub Surface irrigation	N/A	**Tractors * 3**	1392 kg
Harvesting	16500 L Diesel	**Plough**	75 kg
Crop Destruction	4500 L Diesel	**Disk**	75 kg
Direct Off-farm		**Cultivator**	50 kg
		Harrows	10 kg
Trucking	611400 kg (cotton)	**Roller**	75 kg
Ginning Machinery	611400 kg/300 ha	**Drill**	100 kg
Shipping	611.4 tonne km/300 ha	**Trailer**	50 kg
		Post rammer	25 kg
Indirect On-farm		**Grader blade**	25 kg
Herbicide	3480 L	**Mower**	25 kg
Insecticide	3570 kg	**Transport of Seeds**	3000 kg
Fungicide	11520 L	**Indirect Off-farm**	
Nitrogen	65490 kg	**Heavy vehicles**	621.3 kg
Phosphate	21210 kg	**Light vehicles**	108 kg
Potassium	15240 kg	**Motor bikes**	6.6 kg
Man. of Seeds	3000 kg	**Buildings**	100 m^2
Transport of Chemicals	117000 kg		

Average mass used in Table 5 for agricultural machinery and implements are gathered by dividing the average mass of each implement or vehicle into its life duration (the numbers used are based on per year per vehicle).The direct off-farm section weight of 611,400 kg is related to weight of the cotton that enters into the gin produced from 300 ha of cotton land.

RESULTS By using the data from Table 5 in our model, the average amount of energy used per cotton-farming section and relevant emissions was calculated. This is shown in the pie charts in Figures 1 and 2. Each of these sections shows the amount of energy used and GHG emitted as percentage of total energy and emission.

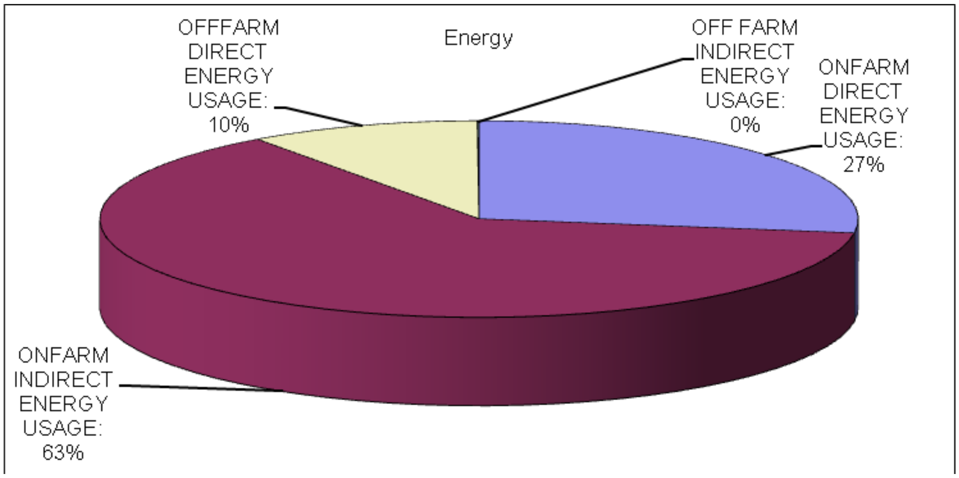

Figure 1: Total Energy Usage Rates

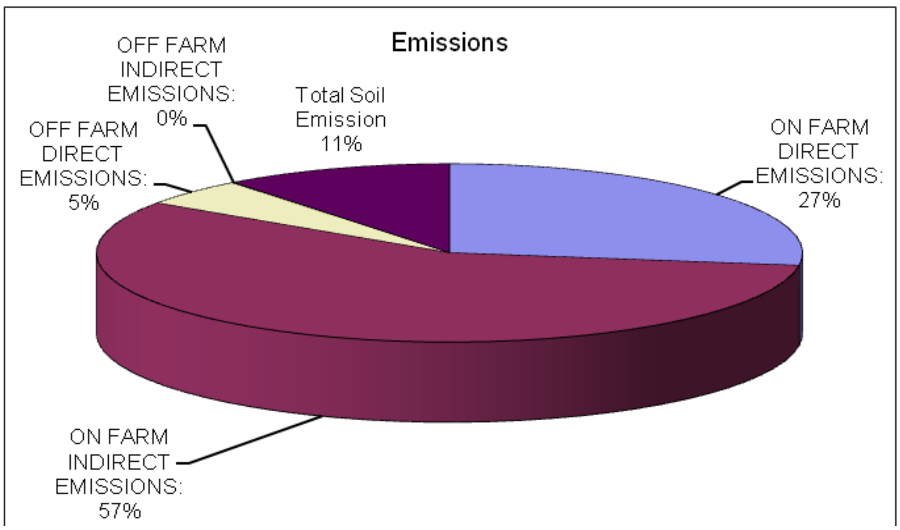

Figure 2: Total Greenhouse Gas Emission Rates

It was found that for 300 ha of GM cotton-farming in Australia the total on-farm direct energy usage is 4223 GJ/300 ha while related emissions amount to 234 tonne CO_2/300 ha. These numbers are equal to 14.07 GJ/ha and 0.78 tonne CO_2/ha.

On-farm indirect energy usage is found to be 9708 GJ/300 ha or 32.36 GJ/ha and relevant emissions are 491.1 tonne CO_2/300 ha or 1.64 Tonne CO_2/ha.

Energy used by off-farm direct section in this study is 1528 GJ/300 ha or 5.09 GJ/ha. The relevant emissions are 42.8 tonne CO_2/300 ha or 0.14 tonne CO_2/ha.

Finally, energy used by off-farm indirect cotton-farming section is calculated to be 10.8 GJ/300 ha or equivalent to 0.036 GJ/ha with CO_2 emissions of 0.66 tonne CO_2/300 ha or 0.002 tonne CO_2/ha. This is very small and negligible in comparison with other sections of the cotton production system.

DISCUSSION The above results show that there is a very significant difference between energy and emissions values for different farming stages.

Yilamz et al. (2005) showed that direct on-farm energy consumption was 21.14 GJ/ha in Turkey and Chen and Baillie (2009) estimated the number may be up to 15.2 GJ/ha for the Australian cotton-farming system. The energy usage that is determined by this model is 14.07 GJ/ha. This difference is caused by different tillage and irrigation methods modelled by different researchers.

Yilamz et al. (2005) reported an indirect energy input of 28.59 GJ/ha for the on-farm section, while our model gives a different value of 32.36 GJ/ha. The main reason for this difference is that our study also included the energy used to manufacture agricultural machinery, farm implement, fertilisers and seeds etc. This can amount to almost 90% of the total inputs by the indirect on-farm section. The other 10% is variable cost associated with casual workers, drivers and ergonomics, all of which were not covered in this study.

This study shows that energy inputs from field to fabric can significantly affect total energy and emission results. Unfortunately there is no relevant data currently available to do a direct comparison with these results.

Grant and Beer (2008) showed that the average total life cycle greenhouse gas emissions for different uses of maize are: 12.32 tonne CO_2/ha for corn chip manufacture, 7.65 tonne CO_2/ha for starch production, and 8.66 tonne CO_2/ha for ethanol production. Our model gave us a number of 2.86 tonne CO_2/ha for a typical Australian GM cotton production system.

There are a number of limitations in this study. Principally, the calculated results are highly dependent on previous work and in most cases a further farm survey would be necessary to confirm that accuracy of data. The main implications from this research for the Australian cotton-farming industry are: we have to reduce both on-farm direct and indirect energy usage in order to save energy and reduce unnecessary waste while facilitating a cleaner and more sustainable farming system.

CONCLUSION This research has shown that among different cotton-farming sections, on-farm indirect energy usage occupies about 63% of total energy consumption, and emits 57% of the total CO_2 equivalent emissions. The second biggest energy user section is found to be the on-farm direct cotton-farming section. 27% of the total energy is used by the direct on-farm section while on-farm direct emissions play the second biggest role at 27% of the total greenhouse Gas emissions.

Future work is planned to progress this study by comparing different farming systems to estimate the actual difference between GM and conventional cotton or different irrigation and/or tillage systems. It is also worth noting that our model is capable of comparing these differences.

REFERENCES

Australian Greenhouse Office. (2004). AGO Factors and Methods Workbook. Australian National Greenhouse Gas Inventory, Emissions Analysis Team, International Land and Analysis Division, Australian Greenhouse Office, ISBN: 1920840 37 0.

Chen, G. and Baillie, C. (2009). "Development of a Framework and Tool to Assess On-Farm Energy Uses of Cotton Production", Energy Conversion & Management, Vol. 50, No.5, pp.1256-1263.

Chen, G., Maraseni, T., and Yang, Z. (2010). "*Life-Cycle Energy and Carbon Footprint Assessments: Agricultural and Food Products*". In: Capehart, B. (Editor). *Encyclopedia of Energy Engineering and Technology*, Taylor & Francis Books, London, UK (Accepted for publication).

Cotton Seed Distributors (CSD). (2008). "Summer Crops Gross Margin Analysis". Cotton Seed Distributors, Australia.

Department of Climate Change. (2006). "Australian Methodology for the Estimation of Greenhouse as Emissions and Sinks 2006 ENERGY (Stationary Sources) & (Transport) ". National Greenhouse Gas Inventory Committee, Australian Government, Department of Climate Change.

Grace, P. (2009).”Life Cycle Assessment of 100% Australian Cotton T-shirt”, Institute for Sustainable Resources (ISR), Queensland University of Technology, Brisbane, Australia.

Grant, T. and Beer, T. (2008). “Life cycle assessment of greenhouse gas emissions from irrigated maize and their significance in the value chain”, Australian Journal of Experimental Agriculture, 48, pp.375–381.

Ismail, S, A. (2009). "Assessment of Energy Usage for Cotton Gins in Australia". Faculty of Engineering and Surveying, University of Southern Queensland, Toowoomba, Australia.

Jacobs, S. (2006). “Comparison of Life Cycle Energy Consumption of Alternative Irrigation Systems". Faculty of Engineering and Surveying, University of Southern Queensland, Toowoomba, Australia.

Navarro, F. And Grace, P. (2009). “Preliminary Life Cycle Analysis of Cotton Production and Manufacturing”. Institute for Sustainable Resources (ISR), Queensland University of Technology, Brisbane, Australia.

Saunders, C., Barber, A., and Taylor, G. (2006). " Food Miles – Comparative Energy/Emissions Performance of New Zealand’s Agriculture Industry". ISSN: 1170-7682, ISBN: 0-909042-71-3, Research Report No. 285, Agribusiness and Economics Research Unit, Lincoln University, New Zealand.

United States Department of Agriculture (USDA). (2009). "Life Cycle Inventory for Cotton (Field to Bale – Version 1.0 – 19 June 2009) ". USDA.

Wells, C. (2001). “Total Energy Indicators of Agricultural Sustainability: Dairy Farming Case Study". ISBN: 0-478-07968-0, ISSN: 1171-4662 Department of Physics, University of Otago.

Yilmaz, I., Akcaoz, H., and Ozkan, B. (2005). "An Analysis of energy use and input costs for cotton production in Turkey". Journal of Renewable Energy 30 (2005) 145-155, ELSEVIER.