Reducing Energy Use and Costs in Agriculture

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Abstract: Agriculture and the related primary industry is an increasingly energy demanding sector. Energy is needed to different extent in all the stages of the agri-food chain. In many cases, energy cost may represent a significant proportion of the total agricultural production cost, including the cost of manufacturing and transportation of various chemicals and fertilisers. A modified and standardized energy analysis and benchmarking process is described in this paper. It is shown that energy use in agriculture varies considerably, depending on the cropping enterprise and the farming systems. Opportunities to reduce energy use and costs and greenhouse gas emissions in agriculture are discussed.

Keywords: Agriculture, farming systems, energy, energy audit, life cycle assessment, greenhouse gas emissions.

1. INTRODUCTION

Farming is often an energy intensive operation (Table **1**). Within highly mechanised agricultural productions systems such as the Australian agricultural industry, energy inputs represent a significant cost to growers [1].

Table 1: Examples of Average Fuel Use for Different Tillage Methods [1]. A Ratio of 4.5:1 from the Highest to the Lowest Energy Use may be Found in Different Tillage Methods

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

Energy is used both on-farm and off-farm. It can be further divided into direct energy used, i.e., the fuel and electricity consumed, and the indirect energy (embodied energy) involved in the manufacturing of all other inputs such as equipment and agro-chemicals [2]. Direct energy may be consumed in three major forms on most farms: 1) general electricity usage for lighting, appliances, irrigation; 2) fuel use for machinery, tractors and vehicles; and 3) heating/cooling for industries such as dairy, horticulture, piggeries and poultry.

In the United States, it has been estimated that the operations of food systems, including agricultural production, food processing, packaging, and distribution, accounted for approximately 19% of America's national fossil fuel energy use [3]. In another study, it was found [4] that in the United States, about 1500 litres of oil equivalents are expended annually to feed each American (as of data provided in 1994). In many developed countries, fossil fuel consumption by food systems often rivals that of transport systems.

Energy efficiency is an important consideration for agriculture both in terms of rising energy costs and greenhouse gas (GHG) emissions [5, 6]. Overall, Australia's electricity prices have increased by 80% in the last 5 years (Figure **1**), which has far exceeded the increases in consumer price index (CPI) changes over the same period. Hence, there is increased importance in quantifying energy use, as an essential step toward encouraging efficient energy use on the farm. It is likely that farmers in the world may face either an energy, water or carbon constrained future.

Figure 1: Electricity price increases in NSW and Queensland, Australia, since 2004. (Source: http://www.theaustralian.com.au/national-affairs/return-power-gst-to-the-poor/story-fn59niix-1225938928090).

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In this paper, a modified and standardized energy assessment process is first described. This is then linked to the energy data requirements in life cycle assessment (LCA) for agriculture. Opportunities to reduce energy use and costs and greenhouse gas emissions are also discussed.

2. ENERGY AUDITS

Energy audits are a crucial part of farm energy management [7, 8]. Energy audits refer to the systematic examination of an entity, such as a firm, organization, facility or site, to determine whether, and to what extent, it has used energy efficiently. An energy audit determines how efficiently energy is being used, identify energy and cost saving opportunities and highlight potential improvements in productivity and quality. An energy audit may also assess potential energy savings through strategies such as fuel switching, tariff negotiation and demand-side management (e.g., by changing to alternative farming systems and farm layouts).

An energy audit may be undertaken as part of a broader plan to manage energy inputs on farm [7]. The objectives of energy audits include:

- Conserve energy inputs;
- Reduce greenhouse gas emissions;
- Achieve operational and cost efficiencies with improved productivity and profitability.

In order to obtain and compare with suitable energy benchmarks, it is necessary to:

- Define farm system types and characterize each farm system type;
- Collect energy and production data, analyze and benchmark energy use;
- Analyze and identify energy use pattern /mix and compare across industries (what, when, where and how much energy is used);
- Link the energy use data to the production processes/practices, sources and prices of energy supply, and characteristics of the region and the industry;
- Identify opportunities and best practices to increase energy efficiency, farm profitability and industry sustainability.

Energy audits may be conducted with different levels of detail (Figure **2**). The general methodology

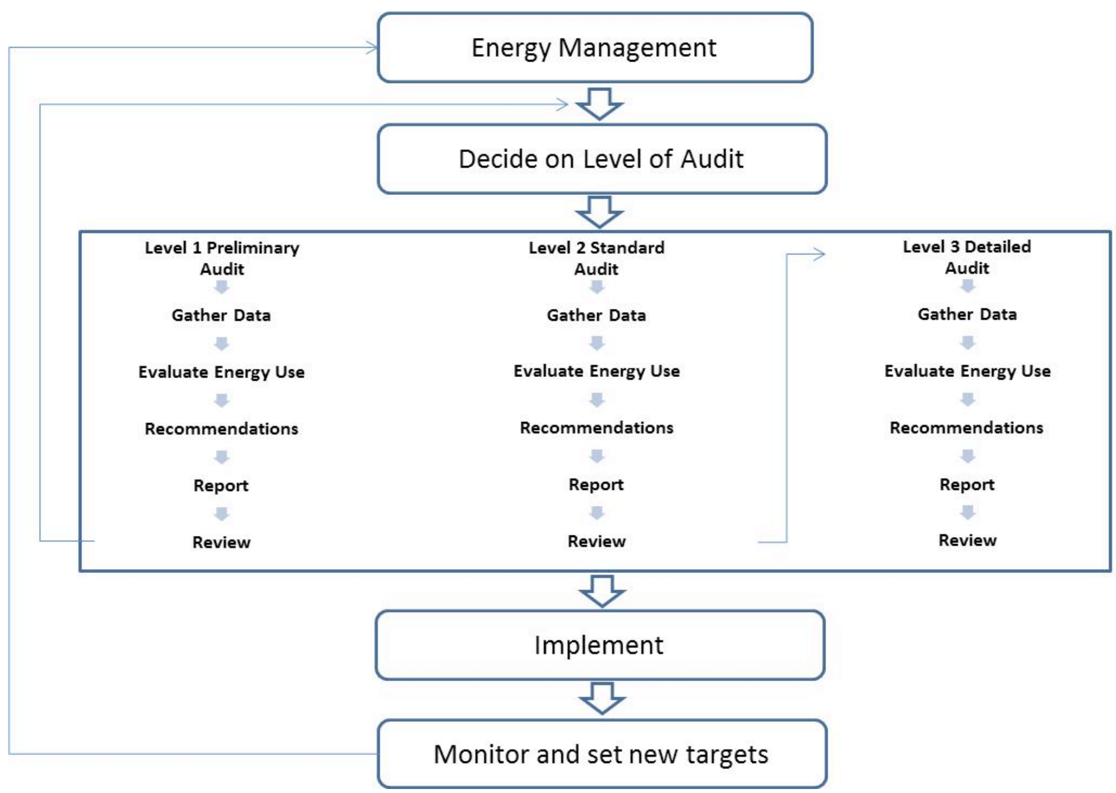

Figure 2: Energy assessment and management process [8].

follows the Australian/New Zealand Standards for Energy Audits – AS/NZS 3598:2000 [9]. Three levels of structured energy audits are also defined:

- The level 1 is the simplest and usually utility-bill based for a “whole” site, to determine an overall index and if there is a need to go down to the next levels. A summary of the total production and energy used for different crops / products at the site will be collated.
- A level 2 audit is referred to as a standard/ general audit and is effectively process-based. Its purpose is to provide an itemised account of energy usage across the site/facility so that energy saving opportunities can be prioritized and ranked. Data will be collated and analysed to determine performance indicators such as the percentage of energy use for key production processes and the intensity based performance indicators for energy, GHG emissions and costs per unit area or production.
- The level 3 audit is the highest and is an investment-grade audit for detailed cost-effectiveness assessment. It is usually carried out by specialists.

The level of audit will depend on factors such as:

- The potential energy or energy cost saving strategies,
- The level of detail and accuracy required to evaluate proposed changes,
- The total annual energy cost,
- Size of the site.

A user may decide to conduct any single level of audit or may conduct a level one audit and then progress to a level two audit and possibly to a level three audit. Each level of audit has its own time and monetary cost.

3. ENERGY USE AND LIFE CYCLE ASSESSMENT

Life Cycle Assessment (LCA) is an internationally recognised approach for evaluating the environmental impacts of products and services [2]. It analyses and quantifies the environmental impacts of the whole process of making, using and disposing a product. LCA is able to provide a rigorous, comprehensive, and multi-dimensional analysis of all relevant factors. It is therefore potentially a very useful and powerful tool for the process improvement and evaluation of environmental impacts of complex systems such as agriculture. A comprehensive LCA analysis would in particular have the advantage of being able to quantify the magnitude of potential environmental saving in each (environmental) category, and to avoid the pitfall of just shifting from one category to another category. LCA is often used to compare the environmental damages assignable to products and services, and further to choose the least burdensome one. It is also able to inform industries of areas of inefficiency, particularly regarding energy and water use, which can lead to significant economic savings. LCA has been successfully used for product-labelling and marketing by relevant industries and public policy development and environmental reporting by the government agencies.

The quality of a LCA project is strongly dependent on the quality of inventory data. A simple LCA analysis may be performed manually. But when the complexity of the analysis increases, a computer based tool with a comprehensive data library may be required.

Energy data for LCA may include direct measurement of actual performances in the field, or alternatively by a proxy based protocol and / or a combination of both methods. A proxy based protocol is where energy inputs are assumed or estimated based on practices or tools as opposed to direct measurement. A proxy based protocol is generally more economic, but its accuracy may be lower. Research has been conducted to compare the values of energy use in different operations and different regions between default values and direct measurements. Preliminary research results [10] indicated that the percentage difference between measured results and practice-based (default) results for tractor operations may often be within 10-20%. This suggested that default and calculation based techniques were found to be an acceptable method of performing an energy and LCA analysis. It was also found that there is less variation in fuel use of in-field operations and pumping has often the most potential for saving energy and money.

4. OPPORTUNITIES TO REDUCE ENERGY USE IN AGRICULTURE

Extensive research has been conducted on both energy use and conservation in agriculture. The library of energy use benchmarks provides a foundation to

Table 2: Energy Performance Data from Published Literature

Crops	Direct Energy Input (GJ/ha)	Indirect Energy Input (GJ/ha)	Total Energy Input (GJ/ha)	Country	References
Wheat	2.5 ~ 4.3	-	-	Europe	[11]
Cotton	-	-	82.6	Greece	[12]
Cotton	21.14	28.59	49.73	Turkey	[13]
Cotton	3.7 ~ 15.2	-	-	Australia	[1]
Cotton	1.6~ 7.9	-	5.5~20.5	USA	[14]
Cotton	11.5~13.2	21.9~112.2	47~128	Australia	[15]
Sugarcane	100.6	47.4	148.0	Iran	[16]
Sugarcane	2.5	-	35.7	South Africa	[17]
Rice	-	-	64.89	USA	[18]
Pea	-	-	2.5 ~5.4	Canada	[19]
Dairy pasture	14.56	3.63	18.2	New Zealand	[20]

perform energy audits and also life cycle assessments. Recent results of energy efficiency programs have shown considerable variation in energy use between different farms of similar production types.

Table **2** summarizes energy performance data for several different crops in different counties [11-20]. Pellizzi *et al*. [11] found that in Europe, the range of field energy consumption for wheat-like cereals varied from 2.5 GJ/ha to 4.3 GJ/ha. For cotton, a study by Chen and Baillie [1] showed that the direct energy inputs for cotton production in Australia ranged from 3.7 to 15.2 GJ/ha (Figure **3**). Diesel energy inputs

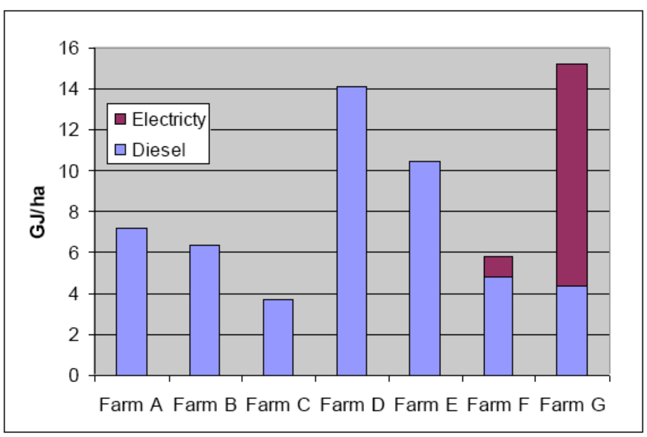

Figure 3: Direct on-farm energy inputs of seven cotton farms in Australia [1]. Electricity in Farm F and G was used for irrigation water pumping.

ranged from 95 to 365 liters/ha, with most farms using 120 to 180 liters/ha. Dryland cotton was at the lower end of this range. Results by Nelson *et al*. [14] also indicated that direct on-site energy use and total energy use for US cotton in 2004 ranged from 1.6 to 7.9 GJ/ha and from 5.5 to 20.5 GJ/ha respectively. It is also noted that in 2006/07, Australia yielded an average 1,792 kg/ha (7.89 cotton bales per hectare). This Figure was almost two and a half times the world average of 747 kg/ha. In Australia, 1 GJ of energy is currently worth $10 (coal) ~ $80 (electricity), depending on the fuel type being used.

Singh [21] found that cotton has the highest energy usage among wheat, mustard, maize and cluster bean. Compared with cotton, Baillie and Chen [1] also suggested that the energy use of other rotational crops (grain) is usually lower, because cotton generally has a greater number of farming operations, more intensive energy use associated with harvest (i.e. picking) and higher irrigation demands. Yaldiz *et al*. [22] reported that fertilizers and irrigation energy dominate the total energy consumption in Turkish cotton production. Yilmaz *et al*. [13] showed that the energy intensity in agricultural production was closely related with production techniques. They 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. Total sequestered energy in Greece was found to be 82.6 GJ/ha with irrigation and fertilizers as major inputs. Cotton yield was 1024 kg/ha lint and 2176 kg/ha seed.

Analyses of relevant data (eg, Table **2**) also indicate that in many cases, the embodied energy of agricultural inputs can be equal to or substantially greater than the direct energy [23]. The role of embodied energy and trade-offs between embodied and direct energy inputs are therefore important in discussing the impact of system change on overall energy budgets. Such examples include the trade-off between water and energy resulting from irrigation system selection and performance, and trade-off between reduced on-farm energy by conservation farming practice and the increased indirect energy use by fertilizer and weed control. The increased water-use efficiency of pressured irrigation systems will need to be balanced against the higher cost of the energy needed.

Overall, Pimentel *et al.* [4] showed that fossil energy use in the US food system could be reduced by about 50% by appropriate technology changes. Using corn production as an example, they estimated that total energy in corn production could be reduced by more than 50% with the following changes of practices: (1) using smaller machinery and less fuel; (2) replacing commercial nitrogen applications with legume cover crops and livestock manure; and (3) adopting alternative tillage and conservation techniques.

For cotton operations, it is suggested that energy audits should first focus on high-energy use areas such as irrigation, heavy tillage operations and harvesting. Low-cost abatement methods (eg adopting more efficient machinery and switching to different mix of fuel) must be actively identified and encouraged. It is also important to further reduce the indirect embodied energy and post-harvest energy uses. Previous research shows that fertilizer and chemicals account for large amounts of energy and efficiency in these is to be improved [23]. While minimum or no till systems can work and reduce in-field energy use, they on the other hand increase chemical use. Further research is required to determine the balance of this trade-off.

Examples of specific applications of renewable energy in agriculture include solar crop drying, solar space and water heating, solar irrigation and using biomass for heating purposes and electricity generation. Other applications include off-grid electric fences, lighting, irrigation, livestock water supply, wastewater treatment pond aeration, communication and remote equipment operation and others [24].

At present, the main barrier to the adoption of renewable energy is often economics, since up-front investment costs for renewable technologies are often higher when compared with conventional technologies. The viability of renewable energy may also be subject to uncertainty in government policies. Further research is thus still required to identify suitable pathways and policy frameworks to encourage future market uptake [5].

5. CONCLUSION

All primary industries use energy and other resources throughout their production and supply chains. Currently, the global agri-food supply chain is heavily dependent on fossil fuel inputs - both direct and indirect. Energy in agriculture is also becoming an increasingly important issue for both economic and environmental reasons. Energy use is one of the key measurements of agricultural sustainability.

This paper has assessed the practices and opportunities in terms of energy efficiency in agricultural production. It has been shown that energy uses vary significantly between different farms and different practices. These range from 2.5 GJ/ha for grain crop to up to 100 GJ/ha for sugar cane for direct on-farm energy inputs. Considerable opportunities also exist for the improvement of energy efficiency.

To achieve best outcomes, it has been suggested that energy audits would need to be customer-focused and encourage implementation. The future of energy management may lie in offering a full service that makes recommendations much easier for clients. Developing alternative energy sources, such as anaerobic digestion, solar and wind, to directly substitute for purchased fossil energy supplies and reduce carbon and greenhouse gas emissions should be explored.

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