DIRECT ENERGY USE AND CARBON FOOTPRINT OF SUGARCANE PRODUCTION

DN Boote

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The rising cost of energy coupled with an increasing awareness of Greenhouse Gas (GHG) emissions has led to a concerted effort to reduce fossil fuel Energy Use (EU) in all sectors. Sugarcane production in South Africa is dependent on fossil fuel to provide a source of energy for production. To remain commercially and environmentally sustainable, measures need to be taken to reduce EU and increase efficiencies of intense on-farm energy operations. The first step to realising this is the identification and quantification of energy inputs. Following on from this, total GHG emissions, otherwise known as carbon footprint, can be estimated. This review highlights energy intense processes and operations in sugarcane production. Techniques for measurement and estimation of energy used in production operations as well as the potential to reduce EU are identified. Studies in sugarcane production in Australia have shown that energy savings of 10-30 % for tractor powered operations, 10 % for harvesting, 36 % by improved farming practices and 50 % in irrigation operations are possible. Leading from this, a project is proposed to establish energy audit tools and protocols for on-farm assessments for sugarcane production in South Africa.
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1. INTRODUCTION

The productivity and efficiency of intensive cropping systems such as sugarcane is influenced by operational input costs. Baillie and Chen (2011a) estimate that within highly mechanised farming systems, direct Energy Use (EU) costs can represent 40 - 50 % of the total operational costs. Direct energy refers to the energy content of fuels, lubricants, and electrical power. Conversely, indirect energy accounts for the energy used in the production and transportation to and from the farm of all inputs used (Alluvione et al., 2011). It is also estimated that 20 % of global annual Greenhouse Gas (GHG) emissions result from land use and land cover change and agricultural practices (IPCC, 2001). The combination of governmental pressure to reduce GHG emissions and an increasing cost of energy is likely to result in a drive towards better energy efficiency in agriculture (Baillie et al., 2008). This leads to the debate of costs related to additional management and increased environmental awareness versus the potential of increased efficiency, reduced input costs and increased productivity.

Direct EU in crop farming can be considered a function of the number and intensity of mechanical operations and pumping requirements for irrigation (Baillie and Chen, 2011a). Rein (2010), from research into the carbon footprint of cane sugar production in the United States, apportions 19.7 % and 18.2 % of the total EU in sugar production to farm diesel usage and irrigation, respectively. Renouf and Wegener (2007) considered the entire life cycle of irrigated cane sugar production in Australia and estimated on-farm fuel use as 22 % of the total EU, while electricity for irrigation consumed 41 % of the total EU. In the South African agricultural sector, on-farm diesel and electricity use account for 54.7 % and 19.7 % of total energy inputs respectively (StatsSA, 2005).

Although alternative energy sources are available, agricultural production is largely dependent on energy sourced from non-renewable fossil reserves. Renouf et al. (2008) and Seabra et al. (2011) estimate GHG emissions from direct on-farm EU as 276 and 234 kg carbon dioxide equivalent (CO₂e) per kg monosaccharide, respectively. Typical GHG emissions in the agricultural phase of monosaccharide production from maize and sugar beet are 171 and 158 kg CO₂e per kg monosaccharide, respectively (Renouf et al., 2008).
Lal (2004) identified tillage and irrigation as being the most important primary sources of CO$_2$ emissions in agricultural production systems. GHG emissions from direct EU can be similar, if not greater, than that from soil–fertilizer–water interactions (Baillie and Chen, 2011a). Finding ways to improve direct Energy Use Efficiency (EUE), and thus reduce total energy consumed, could reduce these emissions. Results from Baillie and Chen (2009) indicate that a 55% saving in energy for pumped irrigation and a 30% saving in diesel for tractor operations are possible subject to design changes, regular maintenance and better management. Energy audits using instrumentation and simulation models are used as a platform from which these savings can be estimated.

The aim of this document is to review previous studies that focus on direct on-farm EU and the carbon footprint of intensive field crop agriculture. “On-farm” being defined by operations that take place within the farm gate. Seabra et al. (2011) refers to this as a “field-to-gate” study, clearly defining the system boundaries. The literature is reviewed so as to unpack the principals of EUE and carbon footprints. These principals can then be applied to practices which are unique to the sugarcane industry in South Africa. Specific objectives included:

(a) identify operations and practices which contribute to direct EU and carbon footprint of sugarcane production in South African,
(b) document methods to estimate and techniques for measurement and recording of direct EU,
(c) assess web-based energy calculators currently available for use in agricultural production, and
(d) review methods to estimate GHG emissions from direct EU.

Following this review, the possibility exists for the development of an on-farm energy audit tool for sugarcane production in South African. This could be used to evaluate total direct EU and EUE of alternate production systems, identify opportunities to reduce direct EU and increase EUE, and to estimate the GHG emissions related to total direct EU.

The review is structured such that Chapter 2 contains an overview of EU in worldwide sugarcane production. Further to this the characteristics that make sugarcane production in
South Africa unique in the worldwide market are reviewed. Energy-intense on-farm processes typical to sugarcane production in South Africa are identified and the processes explained. Chapter 3 contains a review of EU in mechanised operations. This chapter looks at methods to measure and estimate diesel fuel consumption in tractor powered operations as well as other mechanised processes typical to sugarcane production. Electrical pump station EU is reviewed in Chapter 4 together with the opportunities to reduce EU. Chapter 5 contains a review of energy assessments and web-based EU calculators that are currently available for the agricultural sector. Issues concerning the carbon footprint of direct EU in agriculture are covered in Chapter 6. Following the discussion and conclusions, a project is proposed for research into the direct EU in sugarcane production in South Africa. The aim, objectives and methodology are described and intended outcomes are listed.
2. AN OVERVIEW OF ENERGY USE IN SUGARCANE PRODUCTION

When assessing energy inputs for crop production it is necessary to consider mechanisation and agronomic inputs (Alluvione et al., 2011). Mechanisation inputs include machinery and tractor usage, as well as fuel consumption. Agronomic inputs account for fertilizer, chemicals and irrigation delivered to the field. The predominant sources of direct energy are diesel and electricity supplied from a network. Diesel is used to drive machinery and electricity typically used to power electric motors, and to provide energy for lighting as well as heating and cooling.

Energy requirements for the milling phase of cane sugar production are small when compared to the agricultural phase, with co-generation and steam from bagasse providing the necessary energy to run the mill (Seabra et al., 2011). The small portion of direct primary energy, usually coal, required in milling is used for starting the boilers. Indirectly energy is used in the manufacture of chemicals and embodied in the mill’s infrastructure and machinery.

Donovan (1978) uses costing data as a source to derive energy inputs in the production of sugarcane in South Africa. Results from this study show that in the rainfed mill areas 34% of the total energy input is accounted for by fertilizer use, 30% for fuel and lubricants and 5% for electricity usage. In the irrigated mill areas, the figures are 15, 24 and 28% respectively.

For cane sugar production in the United States, Rein (2010) estimates 29% of total energy inputs are used in fertiliser and chemical production, 29% in mechanised operations and transport, 18.2% in irrigation, and the balance used in the milling process. Renouf and Wegener (2007) considered the entire life cycle of cane sugar production in Australia and apportioned the total Energy Use (EU) as follows: 26% for fertilizer production, 22% for on-farm fuel use of tractors and harvesters, 41% for electricity in irrigation, with capital goods, milling and transport accounting for the remainder. It must be noted that sugarcane production in both the United States and Australia is highly mechanised, with mechanical harvesting accounting for the majority of the farm diesel usage.
To compare total direct energy inputs of different sugarcane production systems, a number of factors should be taken into account. This includes whether or not the crop is irrigated, plant or ratoon crop, and the degree of mechanisation employed. Table 2.1 compares total direct energy inputs from studies conducted in major sugarcane producing countries.

Table 2.1 Direct energy inputs for sugarcane production

<table>
<thead>
<tr>
<th>Country</th>
<th>Ratoon/Plant</th>
<th>Irrigated/Rainfed</th>
<th>Mechanised/Manual Harvest</th>
<th>Direct energy input [GJ.ha(^{-1})]</th>
<th>Data source</th>
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<tr>
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<td>Plant</td>
<td>Irrigated</td>
<td>Manual</td>
<td>27.34</td>
<td>Donovan (1978)</td>
</tr>
<tr>
<td>Australia</td>
<td>Plant</td>
<td>Irrigated</td>
<td>Mechanised</td>
<td>20.03</td>
<td>Baillie and Chen (2011b)</td>
</tr>
<tr>
<td>Australia</td>
<td>Ratoon</td>
<td>Irrigated</td>
<td>Mechanised</td>
<td>10.52</td>
<td>Baillie and Chen (2009)</td>
</tr>
<tr>
<td>Brazil</td>
<td>Ratoon</td>
<td>Rainfed</td>
<td>20% Mechanised</td>
<td>5.16</td>
<td>Macedo (1998)</td>
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To compare sugarcane with other crop production, the on-farm Energy Use Efficiency (EUE) study by Alluvione et al. (2011) is relevant. A wheat – maize – soybean – maize rotation was studied under different cropping management systems. On average the crops required an input energy of 18.5 GJ.ha\(^{-1}\) of which fertilizers accounted for 47.1 %, mechanisation 31.8 %, irrigation 15.3 %, and 5.8 % for weed control and propagation.

Direct EU in sugarcane production in South Africa is dependent on factors such as geographical, climatic and socioeconomic characteristics. Annually an average of R 5.1 billion of direct income is generated from the sugarcane industry in South Africa (Anon, 2011). In the 2010/2011 season, 16 million tons of cane was crushed from 382,721 ha at an average yield of 66.74 t.ha\(^{-1}\) (Anon, 2011). This is a relatively poor season in comparison to previous years where total cane crushed has ranged between 18 and 23 million tons (Anon, 2011). Figure 2.1 indicates the geographical location of sugarcane mills in South Africa. The
majority (80%) of the crop area falls in the rainfed KwaZulu-Natal coast and midlands with the remaining 20%, accounting for 40% of the industry yield, in the irrigated northern regions of Pongola and Mpumalanga (Anon, 2011).

Due to the unfavourable topography for mechanical harvesting and the availability of relatively inexpensive labour, the majority of the sugarcane yield is harvested by hand (Meyer, 2005). In the 2010/2011 season less than 1% of the total crushed cane was harvested mechanically (Slabbert et al., 2012). For ease of cutting and efficiency in transport, 85 - 90% of the sugarcane is burnt before harvest between the months of April and December (Meyer, 2005). According to Smit et al. (2001), cutters expend 30% more energy when harvesting green cane. The burning of cane prior to harvesting is, however, slowly decreasing due to the increasing awareness of the benefits in retaining a good trash blanket for moisture retention, increased organic matter, weed prevention and erosion control (Meyer et al., 1996).

Mill regions under irrigation include, Umfolozi, Pongola, Komatipoort, Malelane and partial irrigation in Felixton (see Figure 2.1). Irrigation water is sourced from major rivers in these areas and delivered by dragline (67%), drip (18%), centre pivot (12%), flood (3%) and floppy (1%) irrigation systems (Olivier and Singels, 2004). The cost of irrigation is directly related to increases in electricity tariffs. Until recently the cost of electricity in South Africa has been among the cheapest in the world. It was proposed that from 1 April 2010 there will be a 25% annual tariff increase over three years, resulting in escalating electricity bills for irrigators (Jumman and Lecler, 2010). Although not as substantial as the 2010 increase, tariffs continue.
to rise with an 18.7 % increase in 2011 and 15 % proposed for 2012/2013 financial year (Eskom, 2012).

Tillage systems commonly used in sugarcane production in South Africa include conventional mechanical, reduced mechanical and minimum tillage systems (Tweddle, 2011a). The conventional system uses rippers, mouldboard and disc ploughs, tandem/offset disc harrows, and ridging equipment (Meyer, 2005). In a reduced tillage system rippers are avoided and ploughing only takes place at a shallow depth and the weight of the harrows is also reduced (Tweddle, 2011a). In a minimum tillage system and often in reduced tillage, herbicide application followed by rotary tiller operation is used for stool eradication (Meyer, 2005). An objective of minimum tillage is to retain a good plant residue or a trash blanket. For this reason tillage equipment that might incorporate plant residue into the soil is avoided.

Manual harvesting methods include cut and load, cut and windrow, as well as cut and stack methods (Meyer, 2005). The choice of method depends largely on the topographical characteristics of the land and the loading machinery available. Meyer and Fenwick (2003) conducted studies showing that the cut and windrow method is 61 % more effective in terms of labour productivity than the cut and stack alternative. Loading of stacked cane into infield haulage rigs is usually done by non-slewing grab loaders, or purpose designed self-loading trailers. Windrowed cane is, however, loaded by both non-slewing and slewing loaders.

Methods of transporting sugarcane from field to mill vary depending on the topography, cropping systems and lead distances. From the flat fields, harvested cane is often loaded infield and transported directly to the mill. In areas of steeper slope where direct transport is not possible, and often when fields are wet, smaller, self-loading tractor-trailers haul cane from the field to appropriate transloading zones. From these zones the cane is loaded into large haulage vehicles for delivery to the mill (Meyer, 2005).

With the agricultural tractor being critical to various operations of differing power requirements, it is necessary to review the available methods of measurement and estimation of EU for this power source. Chapter 3 defines these methods for tractors as well as typical values for fuel consumption of other machinery common to sugarcane production in South Africa.
3. **DIRECT ENERGY USE IN MECHANISED OPERATIONS**

With very little mechanical harvesting taking place in the South African sugar industry, the bulk of direct energy consumed in mechanised operations lie in land preparation and planting, crop maintenance, loading and haulage. As this review covers only the “field to gate” Energy Use (EU), road transport will not be considered. In the United States, fuels and lubricants are estimated to account for at least 16 % to over 45 % of total machine cost (Siemens and Bowers, 1999; cited by Grisso *et al.*, 2004). Figure 3.1 contains an estimated breakdown of total costs in large scale grower sugarcane production in South Africa (Anon, 2010). These percentages have been compiled from surveys conducted by SA Canegrowers encompassing all mill regions. Care must be taken in interpreting the results due to the varying geographic and climatic factors that influence management and practices of each region. Figure 3.1 shows that mechanisation accounts for 26 % of total operational costs, and fuel and lubrication 7 %. Contractor costs (6 %) could also be considered a mechanical input due to the nature of the operations a contractor performs.

![Figure 3.1 Cost survey proportions of operating expenditure for the 2009/10 season (after Annon 2010)](image)

This chapter serves to review methods of measurement and estimation of tractor fuel consumption as well as typical values of fuel consumption for other mechanised operations in sugarcane production. Opportunities and techniques to reduce fuel consumption and increase energy use efficiencies are also discussed.
3.1 Methods to Quantify and Reduce Tractor Fuel Consumption

A number of methods exist for the measurement of tractor fuel consumption (Fathollahzadeh et al., 2011). The choice of system is dependent on the intended accuracy and the budget available to acquire instrumentation.

Bulk volumetric measurement is the most basic means of determining fuel consumption. This method requires a full fuel tank prior to commencing the field operation and a re-fill after completion. The volume of the re-fill is recorded and divided by the time spent in the field or the area worked. The accuracy of the measurement is limited, especially when the total fuel consumption in the test is low (Fathollahzadeh et al., 2011).

A more accurate means to determine fuel consumption is to monitor volumetric flow rate (Fathollahzadeh et al., 2011). Two flow meters are inserted into the fuel line so as to measure flow to the engine and return flow to the tank. The primary meter is located between the fuel filters and injector pump and a secondary meter on the return line between the injectors and tank. The difference between the two meters is the actual consumption. It must be noted however that this system of measurement cannot be used on most of the new common rail systems (Lyne, 2012).

The design of most modern tractor engines and makes it difficult to access fuel lines to strategically insert flow meters (Lyne, 2012). That said, most are sold with the option of preinstalled Tractor Performance Monitors (TPM) (Baillie et al., 2008). Examples of these are John Deere’s ® Greenstar™ and Massey Ferguson’s ® Dynamic Tractor Management™ systems. Systems like these estimate fuel consumption by calculations based on engine speed and loading. Some TPMs then have the ability to either suggest the most efficient operating range to the operator or automatically adjust the throttle and gearing to achieve this.

The American Society of Agricultural Engineers standards of 1998 (ASAE, 1998b) estimate Specific Volumetric Fuel Consumption (SVFC) [L.kW⁻¹.h⁻¹] for tractors working at loads greater than 20 % of rated power. The equations overestimate the consumption compared to results from the Nebraska Tractor Test Laboratory (NTTL) by 15 % to account for the loss of efficiency under field conditions (ASAE, 1998b). Fuel consumption for a specific operation
at full or partial load and maximum engine speed, or governed response curve, can be estimated using Equation 3.1 (ASAE, 1998a).

\[ Q_i = (2.64L + 3.91 - 0.203\sqrt{738L + 173}) \times (L \times P_{PTO}) \]  

(3.1)

where \( Q_i \) = estimated fuel consumption for a particular operation \([\text{L.h}^{-1}]\),  
\( P_{PTO} \) = maximum (rated) PTO power \([\text{kW}]\), and  
\( L \) = the ratio of tractor power (PTO equivalent) required for the particular operation to \( P_{PTO} \).

Grisso et al. (2004) highlighted the fact that Equation 3.1 is an estimate at maximum engine speed and that fuel consumption at reduced throttle settings have not been addressed. Using data from the NTTL for the time period of 1984-2004, Grisso et al. (2004) calibrated new equations to predict fuel consumptions for operations at reduced engine speeds as shown in Equation 3.2 (Grisso et al., 2004).

\[ Q = (0.22L + 0.096)[1-(-0.0045L N_{red} + 0.00877N_{red})]P_{PTO} \]  

(3.2)

where \( Q \) = diesel fuel consumption at partial load and reduced throttle \([\text{L.h}^{-1}]\), and  
\( N_{red} \) = ratio of operating engine speed to maximum engine speed expressed as a percentage [%].

Equation 3.2 will aid in predicting fuel consumption when adopting the Gear Up Throttle Down (GUTD) technique to reduce fuel consumption. The GUTD technique is discussed below together with other methods to reduce tractor fuel consumption.

The norm for the measurement of energy efficiency for tractor operations is by SVFC (Grisso et al., 2004). The SVFC can be used to compare the fuel consumption between tractors of different rated powers. Prior to establishing in-field techniques to reduce SVFC, it is necessary to consider management practices and decisions that affect the efficiency of tractor operations. Two vital management components are improved field efficiency and correct tractor-implement matching. These two factors have a direct influence on the efficiency at
which fuel is consumed due to their impact on field capacity [ha.day\(^{-1}\)] and subsequently running hours.

Field efficiency is a factor accounting for time spent on turning on the headlands, refuelling, refilling hoppers, maintenance stops and driver comfort breaks (Heyns and Pretorius, 1981) and can be calculated as the ratio of the actual working time to the total time spent in the field. Typical values for land preparation and chemical applications are 80 % and 55 % respectively.

Well matched tractor - implement combinations result in less power loss, increased operational efficiency, reduced operation cost and optimum utilisation of capital on fixed costs (Taylor et al., 1991). Two methods have been identified that can be used for tractor-implement matching in South Africa. Both methods are useful to determine the partial loading of a tractor engine and hence the fuel consumption for an operation.

Heyns and Pretorius (1981) developed a database of recommended tractor power requirements and travel speed for various field operations in differing soil types. Field operations are defined by implements, drawn or hitched, varying in width and purpose. Using this database, with a known tractor power capacity, a suitable size implement can be chosen together with its recommended travel speed. Alternatively, a suitably powered tractor can be chosen to match a given implement of known width. The ratio of the recommended power to the power of the tractor actually used yields a loading percentage which can be used in Equation 3.1 to estimate fuel consumption.

Pretorius (1987) developed an empirical formula to eliminate unrealistic tractor - implement combinations (Equation 3.3).

\[
Y = K + 0.1 \frac{K^{5.4}}{P^{4.4}} \quad (3.3)
\]

where \( Y \) = the energy a tractor must deliver for a specific operation [kW.h.ha\(^{-1}\)],

\( K \) = the energy input required for a specific implement in a defined soil type at a known working depth [kW.h.ha\(^{-1}\)].
\[
\frac{P}{(\frac{ha}{\pi})}, \quad \text{and} \quad (3.4)
\]

\[
P = \text{the net rated engine power of the tractor [kW].}
\]

Values for \(K\) have been experimentally established and documented through trials conducted by Pretorius (1987). A tractor of net rated engine power \(P\) is considered capable of providing the necessary energy input for a specific operation if \(Y = K\). The speed of the operation will be at a theoretical maximum and calculated by Equation 3.5.

\[
s_T = \frac{P \times 10}{w \times Y} \times \frac{\eta}{100} \quad (3.5)
\]

where \(s_T\) = Theoretical max travel speed [km.h\(^{-1}\)]

\(w\) = effective width of implement [m], and

\(\eta\) = field efficiency [%]

For the same tractor, if the implement is changed or the working depth increased to result in a higher \(K\) value, Equation 3.3 will yield a \(Y\) value greater than the \(K\) value. There will thus be greater load on the engine and the operation will be carried out at a slower travel speed (Pretorius, 1987). A further increase in \(K\) will lead to scenario where the energy the tractor must deliver is unrealistically high and hence the operating speed unrealistically low to warrant that specific combination. The limiting factors are thus unnecessary overloading of a tractor and excessive time spent to complete an operation (Pretorius, 1987). In this case, a smaller implement, or alternatively a more powerful tractor could be selected.

Partial loading of a tractor can be determined by Pretorius’ (1987) method using Equation 3.6. Partial loading of a tractor occurs when the operator chooses a speed less than the theoretical maximum. This can be used in Equation 3.1 to estimate fuel consumption.

\[
L\% = \frac{s}{s_T} \times 100 \quad (3.6)
\]

where \(L\%\) = Loading percentage [%], and

\(s\) = Operator chosen speed [km.h\(^{-1}\)]
“Gear Up, Throttle Down” (GUTD) technique is a well-publicised in-field technique to reduce fuel consumption. Figure 3.2 is a typical torque, power and SVFC map of a diesel engine under test conditions (Fuls, 2005). The SVFC are mapped from a series of tests starting at different no-load speed settings. As shown in Figure 3.2, the same power can be obtained at two different engine speeds. Point A, at a higher engine speed, has a greater SVFC than that at point B. To attain a more efficient EU, point B can be achieved by the GUTD technique whereby a higher gear is selected and the engine speed reduced (Fuls, 2005). Grisso et al. (2011) recommends GUTD as a fuel saving practice for drawbar loads less than 75% of full power and where power-take-off (PTO) shaft speed can be reduced.

![Figure 3.2 Torque, power and SVFC map of a diesel engine (Fuls, 2005)](image)

### 3.2 Diesel Fuel Consumption of Loading and Haulage Machinery

This study is confined to activities that occur within the bounds of the farm gate. As such, loading, off-loading, extraction and haulage activities that take place beyond this are not considered. Due to a lack of published data the author has assumed the values used and published in SASRI mechanisation reports (2011b;2011a).

Infield loading of sugarcane in South Africa is commonly carried out using either a three-wheeled non-slewing grab loader, push-pile slewing type loader, or self-loading tractor-trailers (Tweddle, 2012). The popularity of the three wheeled grab-loader is based on its low costs, high productivity and versatility (de Beer, 1982). The push-pile slewing type is more commonly used on the larger flatter fields of the irrigated Northern regions (Meyer, 2005).
On steeper terrain a common harvesting method is the cut and stack followed by extraction to a transloading zone by self-loading tractor-trailer rigs.

No external independent measurements of fuel consumptions have been carried out for the commonly used Bell ® 120, 125 and 220 series loaders (Tweddle, 2012). A number of factors influence fuel consumption including travel distance between stacks and trailer, length of cane stalks, as well as ground conditions and topography. Typical values used in mechanisation costing range from 5 to 6 L.h\(^{-1}\) depending on engine size (Tweddle, 2011b). Work rates range between 20 and 30 t.h\(^{-1}\) for the non-slewing loaders and in excess of 60 t.h\(^{-1}\) for slewing loaders (Meyer, 2005). Fuel consumption per ton of sugarcane loaded is thus approximately 0.2 - 0.1 L.t\(^{-1}\).

Typical haulage tractors range in power from 55 kW two-wheeled-drives to 150 kW four-wheeled-drive tractors. From the SASRI vehicle and equipment cost analysis guides (Tweddle, 2011b), the respective fuel consumption is estimated as 6 – 17 L.h\(^{-1}\). Fuel consumption remains relatively constant depending on the size, number and payload of the trailers in tow.

Haulage trucks typically used in the South African sugarcane industry range from 8 t ridged trucks to 32 t, 300 kW assemblies. From the SASRI vehicle and equipment cost analysis guides, the associated fuel consumptions are 0.28 and 0.7 L.km\(^{-1}\) respectively (Tweddle, 2011b).
4. ENERGY USE AND EFFICIENCY IN ELECTRICAL IRRIGATION PUMP STATIONS

Worldwide, grid electricity is the main source of energy in irrigation (Moreno et al., 2007). West and Marland (2002) summarise data from the US Department of Commerce and the US Department of Agriculture showing that of the 14.48 million ha irrigated in the United States, electricity is the energy source for 8 million ha, distillate fuel 3.33 million ha and natural gas 2.46 million ha. In South Africa electrically driven pumps are more commonly used in commercial irrigated agriculture, unless electrical supply is unavailable (Mulder et al., 1997). Hence, this review will only cover Energy Use (EU) measurements and efficiency calculations of electrically driven pump stations.

Meyer et al. (2011) summarise typical values for electrical power consumption as shown in Table 4.1. Of the different irrigation systems used in sugarcane production in South Africa, sprinkler irrigation is the most energy intensive.

Table 4.1 Comparison of power consumption between furrow, drip, pivot and sprinkler irrigation systems for a typical 50 ha block of irrigated sugarcane (after Meyer et al. 2011)

<table>
<thead>
<tr>
<th>Irrigation method</th>
<th>Crop water requirement per year [mm]</th>
<th>Application efficiency [%]</th>
<th>Operating head [m]</th>
<th>Static head [m]</th>
<th>Power consumption per year [kWh.ha⁻¹]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Furrow</td>
<td>900</td>
<td>70</td>
<td>1</td>
<td>20</td>
<td>1157</td>
</tr>
<tr>
<td>Drip</td>
<td>900</td>
<td>90</td>
<td>30</td>
<td>20</td>
<td>2044</td>
</tr>
<tr>
<td>Pivot</td>
<td>900</td>
<td>85</td>
<td>35</td>
<td>20</td>
<td>2424</td>
</tr>
<tr>
<td>Sprinkler</td>
<td>900</td>
<td>75</td>
<td>45</td>
<td>20</td>
<td>3238</td>
</tr>
</tbody>
</table>

Overall pumping efficiency is obtained by combining the hydraulic efficiency of the pump and electrical/mechanical efficiency of the motor (Moreno et al., 2007). To realise maximum energy savings, Moreno et al. (2007) suggests that pumping efficiency be assessed together with operating and management rules. Baillie et al. (2008) suggest the use of the following hardware instrumentation for measurement of various parameters necessary for efficiency calculations:
(a) Handheld electrical power meter to measure and store three phase power supply characteristics (phase-to-neutral voltage, current, frequency, active and apparent power, power factor, and quality parameters),
(b) handheld ultrasonic/electromagnetic flow meters to measure pump delivery which should have a measurement error less than 2.5 %,
(c) two pressure transducers for the suction and delivery sides with measurement error of less than 1 %, and
(d) a data logger to record data.

### 4.1 Estimating Total Pump Station Efficiency

In order to determine the overall efficiency of a pump station, the power delivered to the fluid by the motor needs to be calculated using Equation 4.1 (Kaya *et al.*, 2008).

\[
P_f = \rho \times g \times Q \times (H_2 - H_1)
\]  

(4.1)

where \( P_f \) = power delivered to the fluid [W],
\( \rho \) = density of fluid [kg.m\(^{-3}\)],
\( g \) = gravitational constant [m.s\(^{-2}\)],
\( Q \) = measured flow rate [m\(^3\).s\(^{-1}\)], and
\( H_1, H_2 \) = pressure head at suction side and delivery side respectively [m].

The overall efficiency is a measure of the energy lost through the combined inefficiencies of the network wiring, electric motor and pump. This can be calculated using Equation 4.2.

\[
\eta_t = \frac{P_f}{P_{input}} \times 100
\]  

(4.2)

where \( \eta_t \) = total pump station efficiency [%], and
\( P_{input} \) = power drawn from the electrical network by the motor [W].
4.2 Opportunities for Improved Energy Use Efficiency in Electrical Pump Stations

With the increasing cost of electricity it is necessary to explore opportunities for increased energy efficiency in irrigation pumping. In addition to the correct design and sizing of pumps, motors, pipes and electrical power cabling, as well as a proper maintenance schedule, there are other more recent management and technological advancements that can improve pumping Energy Use Efficiency (EUE).

The efficient application of irrigation through proper scheduling results in a reduction of unnecessary running time. Moreno et al. (2007) showed that a cost saving of 16% was possible by scheduling the operation of pumps according to irrigation needs. In this specific case study of a large scale multiple pump station it was shown that through the 16% reduction of energy cost it took only one season to recover the additional cost of installing permanent pump performance measuring devices. Effective scheduling is aided by software models that predict crop water requirements and it is essential that this software is used in conjunction with weather and soil moisture data to realise effective scheduling (Mottram, 2012).

In Moreno’s et al. (2007) study, savings, other than those from scheduling, were also achieved by the use of variable speed drives (VSDs). This approach was also recommended by Kaya et al. (2008). Variable speed drive controller units can be installed on existing fixed speed motors to regulate the speed according to the pressures monitored on the delivery side of the pump. Scheepers (2012) highlighted that most irrigation pumps are oversized and operate inefficiently, especially at reduced flow rates where the motor load can vary substantially. This implies that a pump could operate at low loads and therefore low energy efficiencies for long periods of time. With power consumption of a motor being proportional to the cube of engine speed (i.e. $P \propto n^3$), a small reduction in speed results in a large reduction in energy costs (Scheepers, 2012). Implementation of VSDs and effective scheduling requires capital investment, and better management practices. Coupled with this is the need for a willingness to adopt new technologies.
5. ENERGY ASSESSMENTS

Energy assessments are conducted in farming enterprises to determine total energy consumption and efficiency. This involves a systematic examination of the energy intense operations to highlight inefficiencies, potential cost saving opportunities, and the potential for improvement in quality and productivity (Baillie and Chen, 2011a).

Energy assessments form an integral part of the Life Cycle Assessment (LCA). LCAs have been extensively applied to industrial products and processes wherein the environmental impacts of resources consumed, wastes and emissions generated are assessed throughout their entire life cycle (Renouf and Wegener, 2007).

On a farm level energy intense processes can be identified by examining fuel and utility bills. To quantify total Energy Use (EU) per process, and at a higher aggregated level, per operation, may require specialised instrumentation, theoretical calculation and professional expertise. Coupled to this, and aiding in the estimation of EU is some form of programme or spreadsheet, which in this review are referred to as energy calculators. The rest of this chapter looks at energy calculators available in agriculture, the different types, how they are classified, as well as a review on reputable web-based calculators.

5.1 Introduction of Energy Calculators into the Agricultural Sector

Energy calculators are defined by Morris (2009) as tools enabling users to estimate energy consumption and identify energy-saving opportunities. The agricultural sector has been slow in adopting calculator tools for awareness towards wasteful EU. This trend is slowly changing with pressure from government departments, energy providers and consumers (Morris, 2009).

In a home or business energy assessment, an energy professional will visit the site, measure energy consumptions and write a report highlighting inefficiencies and opportunities to reduce costs. In the United States, Morris (2009) attributes the lack of adoption of energy assessments in agriculture to a number of factors, the most influential of which is cost.
The introduction of free web-based energy calculators makes it possible for farm managers to perform the assessment and obtain estimates for energy consumption. Depending on the complexity of the calculator, areas of high and inefficient EU can be identified and corrective measures can be implemented (Baillie and Chen, 2007). Farm managers will then be in a position to decide whether to further consult with energy professionals.

5.2 Classification of Calculators

Morris (2009) separates energy calculators by their degree of complexity and detail of user input. A low level, simple calculator will require the user to select or check multiple choice options given on a web-based form. Most of this input data will be of common knowledge to the user, such as approximate electricity tariffs, liquid fuel prices, size of land, and machinery in use. The final output will often be a monetary value that highlights areas of greatest cost to the producer. An example of such a type is the USDA Energy Estimator (USDA, 2006).

The next level of calculator will require further insight from the user. The form may automatically populate certain values depending on, for example, the geographical location of the farm. The user will be required to do some background research into details such as mechanical and electrical specifications, timing and intensity of operations, as well as specifics pertaining to management practices. Results are generally presented in a number of reports highlighting inefficiencies and where opportunities may exist to reduce EU. The carbon footprint, expressed usually as a unit mass of CO$_2$e, for defined operations, is also a common feature added to the final report. EnergyCalc (NCEA, 2011), developed by the National Centre for Engineering in Agriculture (NCEA) is a good example of calculator of this level.

On a higher level, spreadsheets are used so that input values together with a comprehensive database can be used to simulate different scenarios and assess the sensitivity of the total EU to changes in design, equipment, and management practices. It is common with such web-based calculators for the user to be able to create an account and store multiple simulations to revisit and add to them at a later stage. Such spreadsheets are often used by auditors to collate and analyse data recorded during a high level audit using specialised instrumentation.
Section 5.3 reviews selected web-based energy calculators. There is scope to expand the review to include offline programs and spreadsheet based calculators. However the quantity of these available, coupled with their varied range in complexity and functionality warrants a separate review document.

5.3 Web-based Energy Calculators

McHugh et al. (2010) conducted a literature search and industry interviews and identify two energy calculation software tools for possible use in developing a framework for energy audits. The USDA Energy Estimator (USDA, 2006) developed by the United States Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) consists of four separate calculators which estimate EU in tillage, nutrient application, animal housing and irrigation. The tools are intended to give an estimate of the magnitude and potential energy savings that could be realised under different management systems (USDA, 2011).

The second calculator, EnergyCalc (NCEA, 2011), was developed by the National Centre for Engineering in Agriculture (NCEA), Australia. Baillie and Khabbaz (2011) describe the software as a tool to assess on-farm EU, costs and greenhouse gas emissions, examine EU, and evaluate farming practices. Initially developed solely for use in cotton production, later versions make it possible to assess various products from the field crop, nursery, aquaculture and turf industries.

McHugh et al. (2010) reviewed the USDA Energy Estimator (USDA, 2006) and found that the calculator did not relate energy estimates to specific operations, basing calculations on basic low level user input. The calculator could only give a rough estimate for animal housing, irrigation, nitrogen and tillage from averages obtained from regions limited to the United States.

EnergyCalc (NCEA, 2011) calculations were initially based on generalised performance data. This database is continually being refined to better represent conditions unique to the Australian agricultural systems, thus further increasing the accuracy of the model (Baillie and Chen, 2007). The tool evaluates the EU of key processes in a field crop production system
including preparation, establishment, in-season operations, irrigation, harvest, post-harvest and general processes. Within one assessment it is possible to evaluate multiple crops, and operations to obtain a holistic view of the entire farming enterprise (Baillie and Khabbaz, 2011). Each analysis can be saved as a level 1, 2 or 3 assessment so as to differentiate between the accuracy of input data. The choice of level however does not change the required user inputs or method of calculation. The results are presented in reports that list energy inputs for different machinery used and categorises EU by the key processes mentioned above. User defined, site specific data can be added while populating the calculator, and this together with the output format of the reports enables benchmarking against peer farmers and best practices (Baillie and Chen, 2007).

The environmental impact of direct on-farm EU can be quantified by its carbon footprint. The following chapter reviews the carbon footprint from direct on-farm EU in agriculture as well as South Africa’s position in terms of carbon taxes and trading.
In light of a heightened awareness of climate change and subsequent promotion of biofuel production, Life Cycle Assessments (LCAs) have been conducted in the sugar industry to evaluate and validate the “cleanliness” of alternative energy. Recent studies by Renouf and Wegner (2007), Renouf et al. (2008), Rein (2010) and Seabra et al. (2011) highlight the carbon emission from intense operations and possible Greenhouse Gas (GHG) mitigation strategies. The GHG emissions are quantified per mass of extracted product in these studies. Table 6.1 contains typical CO$_2$e emissions (excluding carbon credits) for sugarcane, corn and sugar beet. This data is inclusive of all emission sources other than those associated with the energy embodied in equipment and infrastructure and land use change emissions. As a point of reference Table 6.1 also contains the potential tax cost to the grower using predicted carbon tax rates (see Section 6.2), national average yields (65 t.ha$^{-1}$) and average recoverable value (12 %) for South Africa.

Table 6.1 Total on-farm GHG emissions from the production of selected field crops and possible tax rate

<table>
<thead>
<tr>
<th>Crop</th>
<th>Country</th>
<th>Agricultural phase GHG emissions per kg sugar produced [kg CO$_2$e]</th>
<th>Carbon tax per hectare at R 75 per ton CO$_2$e [R.ha$^{-1}$]</th>
<th>Carbon tax per hectare at R 200 per ton CO$_2$e [R.ha$^{-1}$]</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sugarcane</td>
<td>Australia</td>
<td>0.276</td>
<td>161.46</td>
<td>430.56</td>
<td>Renouf et al. (2008)</td>
</tr>
<tr>
<td></td>
<td>Australia</td>
<td>0.226</td>
<td>132.21</td>
<td>352.56</td>
<td>Renouf and Wegener (2007)</td>
</tr>
<tr>
<td></td>
<td>Brazil</td>
<td>0.234</td>
<td>136.89</td>
<td>365.04</td>
<td>Seabra et al. (2011)</td>
</tr>
<tr>
<td></td>
<td>USA</td>
<td>0.275</td>
<td>160.88</td>
<td>429.00</td>
<td>Rein (2010)</td>
</tr>
<tr>
<td>Corn</td>
<td>Australia</td>
<td>0.171</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sugar beet</td>
<td>Australia</td>
<td>0.158</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

This chapter looks at carbon footprint estimation of direct energy usage, and its variability depending on source and method of production. The most recent government discussion
paper concerning GHG emission reductions is also reviewed to highlight the possible measures that might implemented in the near future.

6.1 Carbon Footprint Estimation

The term “carbon footprint” is used to quantify the GHG emissions of an isolated study, be that on an industrial, commercial, rural, process based and even residential scale. GHG’s, as defined in the Kyoto Protocol (1998) include CO₂, N₂O, CH₄, SF₆, hydrofluorocarbons (HFCs) and Perfluorocarbons (PFCs). To normalise the global warming potential of these gasses, coefficients have been formulated to equate them to a carbon dioxide emission equivalent (Rein, 2010). Different fossil energy sources emit unique quantities and combinations of these GHGs.

The source and production methods of diesel and electricity determine the magnitude of the carbon dioxide coefficient assigned to them (Letete et al., 2009). South African diesel is distilled in local refineries from imported crude oil (Letete et al., 2009). To account for transportation of the crude oil, the CO₂ coefficient for diesel available in South Africa is higher than in a country that has its own oil reserves. Similarly, grid electricity provided by Eskom is produced predominantly from coal power stations, the result of which is a higher CO₂ coefficient than that produced from a renewable resource. Table 6.2 contains the coefficients for South Africa and other sugarcane producing countries. The low CO₂ coefficients for Mauritian and the United States’ electricity production can be explained by their use of renewable energy sources. 60% of Mauritian energy is produced in sugar mills in cogeneration processes (Soobadar et al., 2010).

<table>
<thead>
<tr>
<th>Country</th>
<th>Electricity coefficient [kg CO₂e.kW⁻¹.h⁻¹]</th>
<th>Reference</th>
<th>Diesel coefficient [kg CO₂e.L⁻¹]</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>1.051</td>
<td>Baillie and Chen (2007)</td>
<td>2.890</td>
<td>Baillie and Chen (2007)</td>
</tr>
<tr>
<td>Mauritius</td>
<td>0.550</td>
<td>Panray Beeharry (2001)</td>
<td>2.110</td>
<td>Panray Beeharry (2001)</td>
</tr>
<tr>
<td>South Africa</td>
<td>1.015</td>
<td>Letete et al. (2009)</td>
<td>2.681</td>
<td>EIA (2011)</td>
</tr>
<tr>
<td>United States</td>
<td>0.676</td>
<td>EIA (2007)</td>
<td>2.681</td>
<td>EIA (2011)</td>
</tr>
</tbody>
</table>
6.2 Government Legislation

The most recent government release regarding GHG and carbon footprint is contained in the white paper discussion paper “Reducing Greenhouse Gas Emissions: The Carbon Tax Option” (Hemraj, 2010). The focus of the paper is on the economic policy instruments that will enable South Africa to reach its emission reduction targets as voluntarily set in the 2009 Copenhagen climate change negotiations. The set target is a 34% reduction by 2020 and 42% reduction by 2025, subject to the availability of technical, financial and other support (Hemraj, 2010). The instruments that have been identified as pivotal to realising these goals are carbon taxation and emissions trading schemes. Carbon taxes will serve to reduce emissions by the direct mechanism of pricing, whereas trading schemes allow targets to be reached by sharing emission burdens between different sectors (Hemraj, 2010).

The discussion paper suggests that carbon tax schemes may be easier to implement and manage than emissions trading, insofar as the management structures are already in place to take on this responsibility and to the simple structure required compared to the trading alternative, and will minimise the potential for lobbying. Uncertainties identified by Hemraj (2010) and under discussion include:

(a) the rate at which carbon is taxed,
(b) issues surrounding international competitive trade,
(c) accurate measurement of carbon emissions, and
(d) the initial/maintenance cost to the payer of establishing structures and administration to monitor carbon emissions.

The price placed on carbon emissions should match the marginal cost of damage incurred on the environment for each unit of CO₂e. An initial price estimate of R 75 to R 200 per ton CO₂e at 2005 prices is mentioned in the discussion (Hemraj, 2010). In terms of where total emissions are measured or estimated is also up for debate. Although measured and verified quantification of carbon emissions would be preferred, Hemraj (2010) suggests that it would not be practical or feasible on every level for all energy users. A proxy tax can, however, be implemented on the carbon content of fossil fuels used and the bulk consumption of fuels and electricity can be used as a basis for estimating GHG emissions (Hemraj, 2010).
7. DISCUSSION AND CONCLUSIONS

Research has shown that a large portion of energy inputs into sugarcane production are accounted for by direct diesel and electricity usage. The energy used in manufacturing chemicals, fertiliser and other indirect inputs cannot be managed on a farm level. Management practices can however influence direct diesel and electricity Energy Use (EU) and the consumption of indirect and agronomic resources. Although many sugarcane production operations in South Africa are carried out manually, mechanised operations still require constant review to limit the rapidly increasing costs of energy. There is therefore a potential for energy assessments to aid in the identification of energy intense operations. High level energy assessments from Life Cycle Assessments (LCAs) of raw sugar production are common in agriculture, but there remains scope for dedicated energy assessments for more in-depth analysis and understanding.

By and large, mechanised infield operations in South African agriculture are carried out by agricultural tractors. The core mechanised cropping operations, crop eradication and seedbed preparation, planting, in-crop management, harvesting and infield haulage all require full or at least partial use of agricultural tractors. Management decisions and operator knowledge have been identified in the literature as key to reducing EU and increasing EU efficiency. In addition to this, tractor-implement matching together with effective planning and a reduced number of operations will aid in increased field efficiencies and subsequent reduction in total EU.

The measurement of diesel use in tractor operations as well as other infield machinery can be conducted in numerous ways depending on budget and intended accuracy. The most cost effective and least intrusive means of measuring fuel use would be by direct bulk volumetric measurement. Although very effective, it does not allow for real time instantaneous evaluation, which may be necessary to further understand the sensitivity of EU to key variables. For this, flow meters and loggers or integrated performance monitors are required.

Pressurised sprinkler systems are the most common irrigation system used in the South African sugarcane industry. This system has a considerably higher energy demand than the alternative drip, furrow and pivot systems. Of increasing awareness to farm managers is the
need to schedule irrigation dependant on crop water requirements to reduce EU, keeping in mind the energy provider’s tariff structures.

Inefficiencies in irrigation EU are often identified by analysing recorded pumping data. Pump station evaluations typically require instrumentation such as pressure sensors, flow meters, electrical analysers and data loggers. The use of these instruments and pump evaluation protocols makes it possible to assess the loading of motors and the operating point of the pumps. Corrective measures can then be implemented. Key to improving pumping efficiencies and reducing operating costs is the synthesis of good management practices, regular maintenance and the adoption of proven and appropriate energy saving hardware.

With the possibility of carbon taxes being implemented as a proxy tax on carbon content of liquid fuels and electricity as opposed to the carbon trading alternative, leads to a debate as to whether sugarcane growers might be unfairly taxed for their assumed negative net carbon balance. This might become even more of a concern looking to future where cogeneration of electricity to supplement the national grid is likely to be introduced. Cogeneration of electricity in itself will raise the question as to whom possible carbon credits will go, the mill or the grower?

The adoption of energy calculators as tools to estimate and evaluate the efficiency of EU in agriculture has been slow in comparison to other industries. However, with pressure from government and the rising cost of energy this trend is changing. There are a numerous web-based calculators freely available for public use which range in accuracy and comprehensiveness. Reviews emphasise that the choice of calculator and interpretation of results needs careful consideration depending on the type and complexity of the farming enterprise and the accuracy required. It must also be considered that the operations and management practices of certain processes as well as their associated energy intensities vary between countries and regions. For this reason the database and input variables from which the calculator tool draws from needs to be continually updated to suit varying production practices, socio-economic, geographic and climatic conditions. It can thus be said that the possibility exists to adopt and adapt an existing calculator to suit the uniqueness of the South African sugarcane industry.
The project will analyse direct on-farm Energy Use (EU) in the South African sugarcane industry. Total EU and the efficiency of energy consumption in various processes and operations will be examined. It is expected that this study together with the associated Greenhouse Gas (GHG) emissions from direct EU will form part of a broader life cycle assessment of cane sugar production in South Africa.

8.1 Research Question

The combination of governmental pressure to reduce GHG emissions and an increasing cost of energy is likely to result in a drive for better energy efficiency in agriculture (Baillie et al., 2008). This has been a topic of research in commercial agriculture in many of the world’s leading agricultural producing countries. Studies conducted in Australia have shown that irrigation and harvesting in the cotton and sugar industries may use up to 80% of the operational energy. These studies have shown that fuel savings of 10-30% for tractor powered operations, 10% for harvesting, 36% by improved farming practices and 50% in irrigation operations are possible. Significant variation in EU and energy efficiency between the different production systems used for the same crop were also noted in these studies. In the South African sugarcane industry little research has been done in quantifying EU and establishing where inefficiencies may lie. This presents an opportunity for research in this field and leads to the following two research questions:

i) How much direct energy is being consumed by sugarcane production and what possibilities exist to save on direct energy use?

ii) What contributions to GHG emissions does the use of direct energy in sugarcane production in SA make?

8.2 Rationale

Farming practices in the South African sugarcane industry differ to those in highly mechanised countries such as the United States and Australia largely due to climate, geographic factors and the availability of manual labour. Harvesting and land preparation
have been identified as processes where practices differ considerably. It could be considered inaccurate to base total EU for key processes on values obtained from other countries.

To estimate direct on-farm EU, documented coefficients and operating norms for irrigation and mechanised processes are required. EU can also be estimated by calculation from first principles. High level energy calculators require documented norms and coefficients to be used in conjunction with first principal calculations for a comprehensive analysis of EU. The accuracy of results is thus largely dependent on whether norms and coefficients are updated and representative of the region and practices involved. There is therefore scope to develop or adopt or adapt an EU calculator to estimate EU in South African sugarcane industry and in doing so verify documented coefficients and norms as well as and equations from agricultural standards.

8.3 Aims and Objectives

The aim of this study is to develop an on-farm energy audit tool for the sugar industry in South Africa. Specific objectives include:

i) Verification and validation of the calculator using selected case studies, and

ii) Development of a protocol to undertake on-farm energy audits

8.4 Methodological Approach

The research plan will entail the following actions:

i) A comprehensive literature review.
   A comprehensive review and synthesis of the literature on techniques for on-farm energy measurement, energy calculators, energy efficiency, and estimating GHG will be conducted to inform the development of a detailed project plan.

ii) Adoption and adaptation or development of a desktop energy calculator with operations specific for sugarcane production in South Africa.

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The energy calculators reviewed will be assessed in terms of their suitability to meet the requirements of this project and if they are adaptable for local conditions. Depending on this assessment, an existing energy calculator (for example, that developed by the Australian National Centre for Engineering in Agriculture (http://kmsi.nceaprd.usq.edu.au) will be adopted and adapted to meet the objectives of this project.

iii) Purchase equipment or source previously acquired data to verify the energy calculator.

In order to verify the energy calculator and to measure on-farm energy consumption, instrumentation will be required to measure electrical energy, hydraulic characteristics and liquid fuel consumption. Alternatively, previously acquired field data from pump station evaluations conducted by Eskom and mechanisation testing conducted at SASRI or the Agricultural Research Counsel (ARC) can be used.

iv) Case studies will be undertaken in order to verify the energy calculator.

If data from previously conducted energy assessments are available, this will be used in a desktop study to verify the energy calculator’s accuracy in predicting energy use for specific farming operations. If data is not available, verification will be conducted in selected case studies that encompass operations typical to sugarcane production practices in South Africa.

v) Development of a protocol to undertake on-farm energy audits.

A standardised methodology or protocol will need to be developed to perform the on-farm energy audits. This will require the design on a standardised information collection sheet and method which will be used to collate the required on-farm data.

A Gantt chart highlighting timeframes and milestones is shown in Figure 8.1.

8.5 Resources Required

The funding for the project is secured within a research contract with the South African Sugar Research Institute (SASRI) and funding from UKZN.
8.5.1 Human resources

Other than the project supervisor and co-supervisors, it is likely that expertise will be sought from researches of the University of Southern Queensland.

8.5.2 Experimental instrumentation

The opportunity exists to loan or hire the instrumentation listed in Table 8.1. It is envisaged that measurement of fuel consumption will be done by the bulk volumetric method to negate the need for costly fuel flow meters.

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Quantity</th>
<th>Means of acquisition</th>
<th>Approx. purchase price [ZAR]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wattnode electrical meter and three current clamps</td>
<td>1</td>
<td>Purchase</td>
<td>5000</td>
</tr>
<tr>
<td>Pressure Transducer</td>
<td>2</td>
<td>Purchase</td>
<td>1000</td>
</tr>
<tr>
<td>Clamp-on ultrasonic flow meter</td>
<td>1</td>
<td>Purchase/hire</td>
<td>15000</td>
</tr>
<tr>
<td>Cambell Scientific Logger</td>
<td>1</td>
<td>Loan (SASRI)</td>
<td>2000</td>
</tr>
</tbody>
</table>

8.5.3 Software

All necessary software is already installed on the desktop computer provided by SASRI. The possibility exists to adapt an existing calculator together with the intellectual property holders. In this case additional software may need to be acquired.

8.6 Health and Safety Considerations

Consideration towards health and safety will need to be adhered to when conducting case studies. In both mechanical and electrical analyses that may be conducted there is potential for injury, and the necessary precautionary measures and protective barriers should be in place.
<table>
<thead>
<tr>
<th>Task Name</th>
<th>Duration</th>
<th>Start</th>
<th>Finish</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comprehensive literature review</td>
<td>81 days?</td>
<td>'12 Jan 09</td>
<td>'12 Apr 30</td>
</tr>
<tr>
<td>Review and assess currently available calculators</td>
<td>15 days?</td>
<td>'12 Apr 16</td>
<td>'12 May 04</td>
</tr>
<tr>
<td>Development or adoption of energy calculator</td>
<td>41 days?</td>
<td>'12 May 04</td>
<td>'12 Jun 20</td>
</tr>
<tr>
<td>Development of protocol</td>
<td>23 days?</td>
<td>'12 Jun 25</td>
<td>'12 Jul 31</td>
</tr>
<tr>
<td>Purchasing of equipment</td>
<td>40 days</td>
<td>'12 Jun 25</td>
<td>'12 Aug 31</td>
</tr>
<tr>
<td>Validating literature and calculator on case studies</td>
<td>140 days?</td>
<td>'12 Apr 23</td>
<td>'12 Nov 02</td>
</tr>
<tr>
<td>Complete energy audit on selected case study</td>
<td>31 days</td>
<td>'12 Nov 08</td>
<td>'12 Dec 20 6</td>
</tr>
<tr>
<td>Report write up</td>
<td>50 days</td>
<td>'12 Dec 21</td>
<td>'13 Apr 25 7</td>
</tr>
</tbody>
</table>

Figure 8.1 Gantt chart of the project
9. REFERENCES


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