BSES Sugarcane for the future

THE UNIVERSITY OF QUEENSLAND AUSTRALIA

Australian Government
Sugar Research and Development Corporation

CaneLCA Eco-Efficiency Calculator
for Australian sugarcane producers

Final Report – SRDC Project UQ045

Volume 1 (Main Report)

Development of a streamlined life cycle assessment (LCA) tool for assessing the environmental benefits of progressive sugarcane growing

by

Marguerite Renouf and Peter Allsopp

Contacts:

Dr. Marguerite Renouf
Senior Research Fellow
The University of Queensland
St. Lucia QLD 4072
(0478) 220551
m.renouf@uq.edu.au

Dr. Peter Allsopp
Manager, Cropping Systems and Technology
BSES Limited
(07) 3331-3316
pallsopp@bses.org.au

May, 2013

Project Team

BSES Limited
- Peter Allsopp
- Bernard Schroeder
- Brad Hussey
- Peter McGuire

University of Queensland
- Marguerite Renouf
- Nicole Price

Acknowledgements

Australian Government
Sugar Research and Development Corporation

The project team wish to acknowledge receipt of project funding from the Australian Government and the Australian Sugarcane Industry through the Sugar Research and Development Corporation.

The investigators also acknowledge the following people who provided valuable input to the development of the streamlined LCA tool – industry and scientific reviewers who guided its development (Bianca Cairns - SRDC, Bernard Milford and Jonathan Pavetto - CANEGROWERS, Sharon Denny - ASMC, Phil Moody - DSITIA and Phil Hobson - QUT), BSES officers and growers who tested early versions (Brad Hussey, Peter McGuire, Andrew Barfield, Ian and Di Dawes and Robert Quirk), researchers who provided technical input (Jeff Tullberg – CTF; Guangnan Chen – USQ/NCEA; Melanie Shaw – DSITIA; Joe Lane, UQ; Cam Whiteing - BSES), BSES communications staff who developed the user interface (Eve McDonald), and the industry personnel who evaluated the final version (Mark Poggio - DAFF, Michael Waring – Terrain, David Sudarmana – Sugar Australia, Guangnan Chen – USQ, and others who participated anonymously).

Citation

This document should be cited as follow:

Renouf, M.A., Allsopp, P. (2013). Development of a streamlined life cycle assessment (LCA) tool for assessing the environmental benefits of progressive sugarcane growing. Volume 1 (Main Report). SRDC Project UQ45. Brisbane: University of Queensland.

TABLE OF CONTENTS

EXECUTIVE SUMMARY

The Australian sugar industry faces continuing expectations to demonstrate environmentally sustainable sugarcane growing practices. This has been driven by moves to protect water quality (through the Australian Government's Reef Water Quality Protection Plan and the Queensland Government's Reef Protection Legislation), requirements to develop best-practice guidelines, and also by opportunities to participate in greenhouse gas abatement through the Australian Government's Carbon Farming Initiative.

In response, the University of Queensland and BSES Limited, with funding from the Sugar Research and Development Corporation (SRDC), have developed a tool that calculates the environmental footprint of sugarcane production using environmental life cycle assessment (LCA). The tool, referred to as the *CaneLCA Eco-efficiency Calculator*, can support the adoption of sustainable sugarcane practices by enabling the environmental evaluation and comparison of different sugarcane growing practices. The information it generates can inform practice change decisions and validate environmental improvement efforts.

The project brought together BSES's capabilities in identifying and promoting progressive cane-growing practices, and UQ's capabilities in modelling the environmental impacts of cane-growing systems. The project was also significantly informed of numerous industry stakeholders including industry associations, extension advisors, sugarcane farmers and researchers.

The two aims of the project were 1) to develop a user-friendly, streamlined LCA tool customised for sugarcane growing in Australia, and 2) to use the tool to test the environmental benefits of progressive cane growing practices against conventional practices.

The development of CaneLCA has made an otherwise complex LCA process more accessible to the sugar industry by making it available as an Excel-based application with user-friendly interfaces for entering data and interpreting results. It has been designed principally for use by extension advisors in conjunction with sugarcane farmers to understand the sources of environmental impacts over the life cycle of cane growing, rate the relative performance of a cane growing operation, and compare different combinations of practices. This is a novel development and one of the first attempts in Australia to tailor an LCA tool for use in an agricultural sector.

Evaluations demonstrated that CaneLCA can be used by intended users to produce a rapid, accurate and meaningful environmental assessment of cane growing operations, and be applied to test the environmental benefits of transitions towards progressive growing practices.

The tool was used to compare progressive practices against conventional practices for Wet Tropics, Central and Southern regions, using published descriptions of practice change. It was found that the progressive practices currently being promoted in the industry generally lead to improved environmental efficiency. However other types of practice changes can lead to mixed environmental outcomes, both positive and negative. The analysis demonstrated how CaneLCA can be used to understand the environmental benefits and trade-offs of different practices so that practice change can optimised to maximise the benefits and minimising trade-offs. This adds to the body of knowledge about how choice of agricultural practices influence environmental impacts, which has received little attention in the scientific literature to date.

Use of CaneLCA will lead to the more informed and strategic identification and adoption of innovative practices at a time when the industry needs to respond to external drivers for change (climate change mitigation and adaption, reef protection, environmental certification schemes). It will also give tangible demonstration to the community that the industry is interested and has the tools to improve its environmental performance. This will help maintains the industry’s social licence to operate.

1. BACKGROUND

There are continuing pressures and community expectations for the sugar industry to further to demonstrate environmentally sustainable sugarcane growing practices. This has been driven by moves to protect water quality through the Australian Government's Reef Water Quality Protection Plan (Reef Rescue), requirements to develop best-practice guidelines, and also by opportunities to participate in greenhouse gas mitigation through the Australian Government's Carbon Farming Initiative.

These developments flag a need for the sugar industry to have the tools and the capability to generate environmental impact information about cane growing, and to predict, develop and demonstrate eco-efficient cane growing strategies for the future, so that it can more effectively respond to the above-mentioned obligations.

A technique being applied across many sectors to generation information about the environmental impacts of production processes and inform environmental improvement initiatives is environmental life cycle assessment (LCA). LCA is a method for assessing the environmental impact of a product over its entire life cycle, accounting for all resources consumed, all wastes generated, and all emissions to the environment. The methodology is well developed (Pennington et al., 2004, Rebitzer et al., 2004), and governed by standards (ISO, 2006a). LCA has been applied to sugarcane systems since the early 2000s in many countries, including Australia, for purposes such as:

- identifying environmental hotspots (Ramjeawon, 2004, Ramjeawon, 2008, Renouf and Wegener, 2007);
- estimating the environmental benefits of sugarcane-derived bio-products (electricity, ethanol, plastics) (Beeharry, 2001, Botha and von Blottnitz, 2006, Groot and Boren, 2010, Kadam, 2002, Khatiwada and Silveira, 2011, Macedo et al., 2008, Renouf et al., 2011, Renouf et al., 2013)
- evaluating bioenergy and by-product utilisation opportunities (Contreras, 2009, Luo et al., 2009, Nguyen et al., 2010).

However it can play an important role in informing environmental improvements within production systems. Further information about LCA and it applications for sugarcane systems is provided in Attachment 1.

LCA has traditionally been a time-consuming and costly exercise requiring specialist software and skills. Hence, its use has generally been limited to the research sector, government agencies and larger manufacturers of consumer goods. Past LCA work on Australian sugarcane undertaken at the University of Queensland (Renouf, 2011) provided an opportunity to tailor a streamlined LCA tool for use within the Australian sugarcane industry. This is a novel development for LCA and for the environmental assessment of agricultural processes in Australia.

A number of carbon footprinting tools are available for agricultural activities (dairy, cotton, grain, vegetables, bananas, wine, livestock) (University of Melbourne, 2012), and one for sugarcane developed for the Bonsucro Standard (Rein, 2010). The tool developed by this project differs from these by assessing a range of environmental impact categories (not just carbon footprint), and giving flexibility for altering production details. Therefore, it is more suited to assessing a range of different cane-growing practices against multiple environmental objectives.

Past Australian LCA studies have found that an important route for reducing the environmental footprint of sugarcane products is to reduce the environmental impacts of cane growing (Renouf *et al*. 2013a), since this phase dominates life cycle impacts of sugarcane products (Renouf *et al*. 2011). The environmental hot-spots for sugarcane growing are well understood[1] (Renouf and Wegener, 2007), and environmental impacts are also known to vary considerably (Renouf et al., 2010) from one region to the next and within regions. While it is suspected that this variation is due to differences in practices, the influence of cane growing practices on environmental performance was not well understood. This was the gap in knowledge addressed by the project. In particular BSES recognised a need to better understand and validate the environmental implications of transitions toward the 'new' growing practices currently being promoted to growers.

A number of programs, such as BSES' SmartCane program and Reef Rescue promote improved cane-growing practices, such as controlled traffic with wider row width, reduced tillage, introduction of a legume fallow, reduced fertiliser and pesticide application rates, and use of non-residual pesticides. They collectively aim to improve profitability, sustain cane productivity and protect water quality, and we refer to them here as progressive practices.

The agronomic and economic implications of practice change have been studied through programs such as the Yield Decline Joint Venture (Troedson and Garside, 2005), and the application of the Farm Economic Assessment tool (FEAT) (Stewart and Cameron, 2006). For example, Schroeder *et al*. (2009) used FEAT to compare the profitability of 'new farming systems' against 'past practices' for a southern farming system, and found that there had been improved profitability from the transitions that had already occurred. Van Grieken *et al*. (2010b) predicted the economic impact of progressive practices under the Reef Rescue ABCD Framework by comparing the profitability across a range of regions using FEAT, and concluded that economic benefits can generally be expected with improvements from conventional to progressive practices.

---

[1] Known environmental hotspots for sugarcane growing are nitrous oxide emissions from the denitrification of applied nitrogen, loss of nutrients (nitrogen and phosphorous) and pesticide active ingredients to water, fertiliser production, energy use for irrigation, on-farm fuel use in tractors and harvesters, and cane burning emissions.

The environmental implications of practice change have also been considered in relation to meeting water quality objectives for the Great Barrier Reef under the Paddock to Reef Integrated Monitoring, Modelling and Reporting Program. However, the wider environmental implications over the life cycle of cane growing, such as energy intensity, carbon footprint, water use, as well as water quality, have not been considered. Intuitively, one might expect that the reduced inputs (fuel, machinery, fertilisers, pesticides etc.) commonly associated with progressive practices, and that drive the observed economic benefits, would also result in improved environmental performance. However, this has not been tested to date, and is the hypothesis tested in this research.

This research addresses the SRDC R&D strategy arena of "engaging with the community and regional bodies to improve the industry's environmental performance, and seek appropriate recognition for that improvement". It does this by providing the industry with a tool and the capability for assessing its impacts, so that it can strategically improve its performance, and also publically demonstrate its efforts.

The work also aligns with BSES's strategic objective of "improving the resilience of sugarcane cropping systems to changing climates" by providing a means of guiding its strategy development.

This project builds on prior R&D by UQ and BSES to develop and demonstrate a tool to meet the above mentioned need. It will be based on the life cycle assessment (LCA) methodology and will be used to gain a better understanding of the environmental benefits of progressive cane growing.

2. OBJECTIVES

The overall aim was to build upon a previous life cycle assessment (LCA) of Australian sugarcane to customise a tool that makes LCA more accessible to the sugar industry and researchers. The customised tool was used to evaluate the environmental impacts of different cane growing practices to aid extension efforts in the development and promotion of progressive cane growing practices.

The specific objectives of the project were:

1. To develop a user-friendly, streamlined LCA tool, for use by extension officers, researchers and growers they support, to quantify and rate the environmental impacts of sugarcane growing;
2. To use the tool to test the environmental benefits of progressive cane growing practices against conventional practices for use in industry extension activities by BSES and other providers.

3. METHODOLOGY

3.1. Development of the streamlined LCA tool

3.1.1. Establishment of an industry review panel

The development of the streamlined LCA tool was guided by an industry review panel made up of the project team and representatives from the Sugar Research and Development Corporation (SRDC), the Australian Sugar Milling Council (ASMC), Canegrowers, State Government Departments (DERM, now DSITIA), Reef Catchments and Sugar Research and Innovation at QUT.

The review panel met two times to inform the development of the tool on 08/08/2011 and 03/02/2012 (the minutes from which are provided in Attachment 2), and a third time to preview a final draft of the tool on 08/06/2013.

The review panel provided input to the tool's development in relation to defining the aim and desired features of the tool, intended users of and uses for the tool, access arrangements, linkages between this project and other SRDC-funded LCA projects, and compatibility with other data collection and reporting mechanisms.

3.1.2. Scoping and defining the tool

The following were defined by the industry review panel to be the fundamental aims of the tool:

– *To make LCA more accessible to the sugarcane industry, extension officers and researchers*

  The tool needed to be easy to use by the intended users, and contain all calculation factors and methods needed to generate LCA results. The targets users were define to be industry extension personnel, progressive growers, and researchers. However it was also identified that the tool could be used by policy personnel, natural resource manager and milling companies.

– *To enable the generation of environmental performance information about sugarcane growing in Australia*

  The tool was to be customised specifically for sugarcane growing activities in Australia (Qld, and northern NSW). The system boundary for the tool was defined to be up to the haulage of harvested cane to the transport siding (ie. at farm gate), and include upstream production of all farming inputs, and all on-farm activities commonly associated with cane growing and harvesting. Cane transport to mills was not to be included.

– *To generate environmental performance information that enables the assessment and comparison of different cane growing practices.*

The intent of the tool was to support extension activities promoting progressive cane growing practices. So the outputs from the tool should be meaningful to extension advisors and growers.

The desired features of the tool were defined as follows:

- *It should be a stand-alone MS Excel-based workbook that does not require the use of proprietary LCA software (for example, Simapro).*

  LCA software is commonly used to undertake LCA. However the use of this software by the industry is not practical, as it requires considerable skills and costs. The alternative was to have a simpler, excel-based tool that can be maintained internally by the industry, but that draws on emission factors generated by Simapro.

- *It should report results for relevant and important environmental impact indicators.*

  As a minimum, the tool should generate results for the following indicators because the methodologies for their calculation are well established and results can be reported with confidence:

  - Non-renewable energy input - MJ/t cane;
  - Greenhouse gas emissions (carbon footprint) - kg $CO_{2\text{-eq}}$/t cane;
  - Water use (consumptive) – kL/t cane

  The following were also considered to be important indicators because they relate to water quality which has received significant emphasis in recent years.

  - Eutrophication - kg $PO_{4\text{-eq}}$/t cane
  - Eco-toxicity - various units

  In relation to water use indicators, it was recommended that the project consider adopting the water use impact methodology being developed by CSIRO (Brad Ridoutt).

- *It should generate results as relative indicators of environmental performance for extension purposes.*

  For extension purposes it would be appropriate for the tool's outputs to be presented as relative indicators of environmental performance. This way the emphasis is on showing how changes in practices influence environmental performance, rather than providing an absolute indication of environmental impact.

  The indicators reported should depict 'environmental performance' rather than 'environmental impact'. LCA traditionally reports results as environmental impacts (with negative connotations), where the lower the number the better. Users may respond more favourably to results reported as environmental performance (with positive connotations), where the higher the number the better. Therefore the conventional LCA results should be represented as eco-efficiency indicators, reported on a scale of performance with increments that allow changes in performance to be readily discernible. Reporting results as relative performance allow for uncertainty to be accommodated in the output of results.

– *Results should be calculated in accordance with nationally / internationally accepted methodologies*

  The tool should comply with Australian, international or sugar industry standards and guidelines for life cycle assessment (LC) and carbon footprinting.

– *Data entry should be as streamlined as possible*

  The design of data entry fields should minimising the amount of pre-calculation required by the user, be flexible enough to accommodate different modes of data input, and align with other data collection and record keeping requirements.

  Data entry requirements should consider the form of data most readily available to the user (eg. extension officers and growers). For examples, the information required for computing diesel fuel use should be based on machinery use (type of activity, type of machinery, number of runs/ha), depending on which is more easily sourced by the user.

  For other potential users of the tool (NRM bodies for instance) data may be available in other forms, for instance as outputs from spatial information systems. The ability to accommodate different modes of data input should be considered.

  Potential users of the tool already have obligations to keep records and report performance in relation to nutrient, pesticide, sediment, and runoff management. The input data to the LCA tool should try to align with these reporting regimes, wherever possible, to make data management easier.

– *The tool's outputs should include a contribution analysis to give transparency and allow for diagnosis of the results*

  As well as generating indicators of performance for each impact category, the tool should report a contributional breakdown showing how different aspects contribute to the result. This will allow the user to see how changes in practices influence the end result.

3.1.3. Defining the practices and environmental aspects captured by the tool

Since the aim of the streamlined LCA tool is to quantify the environmental impacts of different cane growing practices, a first step was to define the cane growing practices to be modelled in the tool, and the environmental impacts that they influence.

3.1.3.1. Cane growing practices

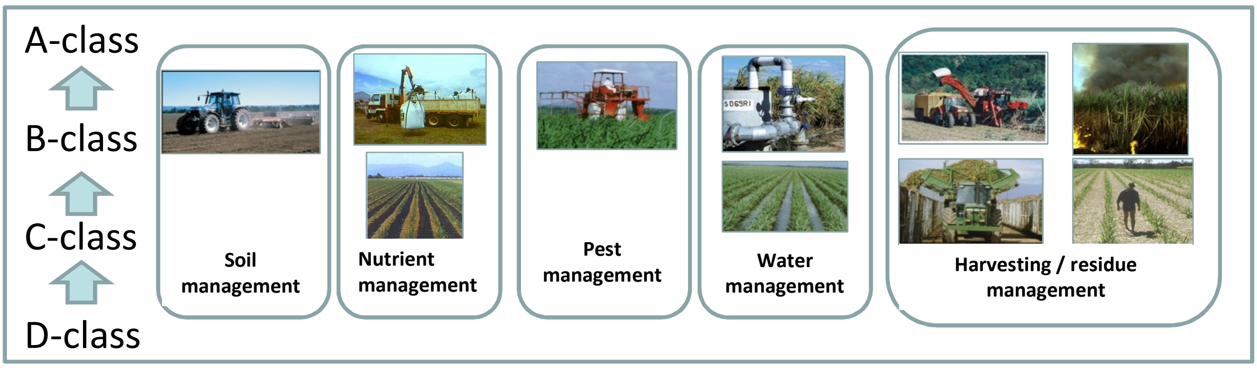
Cane growing practices in many Queensland regions have been categorised and defined under what is referred to as the ABCD Framework. The Framework's development has mostly been driven by the Paddock to Reef Integrated Monitoring, Modelling and Reporting Program, which classes management practices as 'Aspirational' (A), 'Best' (B), 'Common' (C) or 'Dated' (D), based on their potential to improve water quality in Great Barrier Reef catchments (See Table 1 and Figure 1). The Framework represents an alignment of a number of different regional approaches for classifying cane growing practices and provides consistency in the language used.

Table 1 Classes of cane growing practices from the ABCD Framework

(Evans, 2010, van Grieken et al., 2010, Vella, 2008, Vella et al., 2009)

Class		Description
A	Aspirational	Practice exceeds Best Management Practices, providing society with additional ecosystem services.
B	Best Practice	Practice meets agreed industry and community Best Management Practices.
C	Common / Compliant	Practice legislative requirements, codes of practice or locally agreed duty of care.
D	Dated	Practice unacceptable by industry and community standards.

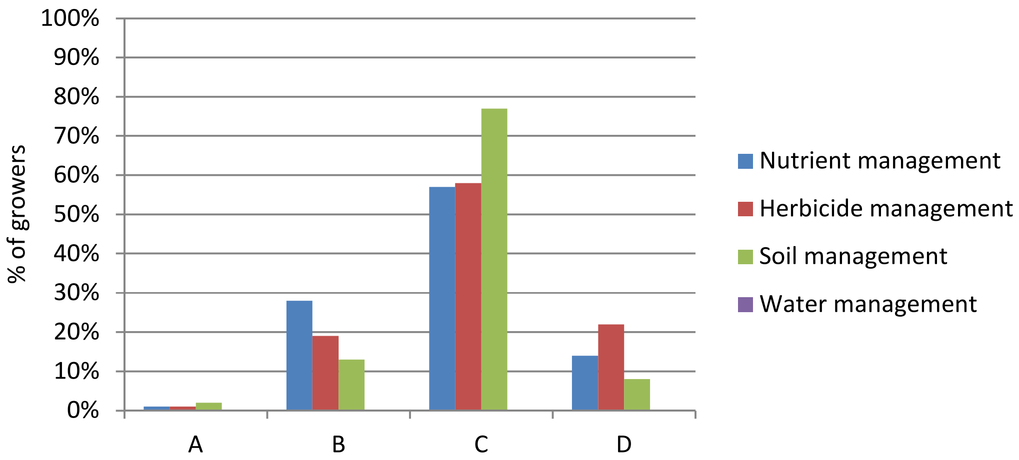
Figure 1 Categories of cane growing practices from the ABCD Framework



A Canegrowers-commissioned study in 2010 attempted to establish baseline information about the adoption of the different practice classes by Queensland sugarcane producers (GHD, 2010). It reports the numbers and percentages of cane growers (and associated hectares) undertaking A,B,C and D practices in four regions at the time. The process used data from a number of sources – a) a data aggregation process designed by a steering committee, b) industry expert opinion collected from workshops and past analyses, and c) Australian Bureau of Statistics (ABS) survey data. The authors noted that there were limitations for each of the data sources, resulting in different results from each source (Attachment 3).

While this early work did not provide a consistent quantification of the adoption of different practice classes, it does provide a general picture. Baseline information derived from industry expert opinion suggests the greatest number of growers (>50%) adopt C-practices, 10-20% adopt D-practices, 10-25% adopt B-class and less than 2% adopt A-practices (Figure 2). The focus of industry extension activities is to assist growers to transition to B-class practices.

Figure 2 Adoption of management practices by practice class



Under the ABCD Framework, practices that would meet the criteria for each class in respect to the management of soil, nutrients, pesticides, and water have been defined for a number of regions (Van Grieken *et al*. 2010a, NQ Dry Topics, 2009, Burnett Murray Regional Group, nd). These were compiled to understand the range of practices described by the Framework (see Attachment 4). Even though the Framework is driven by water quality protection, the described practices cover many aspects of cane growing and provide useful and authoritative descriptors for cane growing practices to inform the tool's development.

As the ABCD Framework mostly applies to the northern catchments adjacent to the Great Barrier Reef (Wet Tropics, Herbert, Central and Burdekin), it was necessary to supplement this with an understanding of practices occurring in southern Queensland and northern New South Wales. This was achieved through visits to cane farms in northern New South Wales as part of early testing of the tool, and drawing on the project team's knowledge of practices occurring in Southern regions (Bernard Schroeder's input).

The outcome of this process was the identification of the cane growing practices and variables that the LCA tool should be able to model, and descriptors and parameters used to define or quantify them (Table 2).

Table 2 Correlations between cane growing practices and environmental impacts

Note: While all the identified correlations between cane growing and environmental impacts are included here, those in italics could not be modelled by the streamlined LCA tool.

Category	**Cane growing variables**	**Descriptors**	**Environmental impacts influenced**	
			Off-farm (upstream supply chain)	**On-farm**
Production system	Cane production Crop rotations	- cane and sugar yields - number of ratoons in the crop rotation - inclusion of a fallow period in the crop rotation	Cane production (influenced by yield, fallow periods and number of ratoons) influences all impacts, as impacts are per unit of product. Hence the greater the production of sugarcane, the lower the impacts per unit of product, and vice versa.	
	Inclusion of nitrogen-fixing crops in crop rotation	- type of nitrogen-fixing crops in the crop rotation - fate of nitrogen-fixing crops (harvested, turned in)	Demand for synthetic nitrogen fertilisers, and hence the embodied impacts of producing fertilisers.	N losses from the farm to the environment.
Farm machinery infrastructure	Farm machinery in service Irrigation infrastructure	- number and size of machinery, vehicles and implements in service - amount of irrigation infrastructure in place - life span of farm machinery and infrastructure	Embodied impacts of producing machinery and infrastructure (steel, aluminium, rubber, plastics pipe, concrete, etc.).	-
Farm machinery operation	Tractor movements (controlled traffic) Tractor use efficiency Source of energy Tillage intensity	- tractor and implement selection - efficiency of tractor operations (load factors and speed) - number of operations - row width - type of fuel used (fossil fuels, renewable)	Amount of fuel combusted in farm machinery, and hence the embodied impacts of producing the fuel.	Emissions of fuel combustion gases to air. (*Tillage intensity influences soil compaction, and subsequently soil health, water infiltration, nitrous oxide emissions and yields*.)
Nutrient management	Type of nutrient products applied Type of ameliorants applied Application rates Transport distance for supplying fertilisers	- type of nutrient products (organic, synthetic) - type of ameliorants (lime, dolomite, gypsum) - amount of nutrient products applied - nutrient contents of applied products - delivery distance	Embodied impacts of producing and transporting fertilisers and ameliorants.	Nitrous oxide (N_2O) emissions to air N and P loss from the farm to aquatic environments.
	Application method (surface, sub-surface)	- proportion that is surface applied		Ammonia (NH_3) emissions to air from volatilisation of urea.
	(*Measures that prevent export of nutrients in runoff waters*)			*(Potential for N and P loss from the farm to aquatic environments.*)

Category	Cane growing variables	Descriptors	Environmental impacts influenced	
			Off-farm (upstream supply chain)	On-farm
Pest management	Type of pesticide products applied (residual, non-residual) Application rates (*Measures that prevent export of pesticides in runoff waters*)	- type of pesticide products applied (herbicide, insecticide and fungicide) - amount of pesticide products applied - active ingredients and their contents	Embodied impacts of producing and transporting pesticides.	Pesticide loss from the farm to aquatic environments.
Harvesting / residue management	Harvesting operation	- amount of fuel used	Amount of fuel combusted for harvesting, and hence the embodied impacts of producing the fuel	Emissions of fuel combustion gases to air.
	Pre-harvest burning Trash retention	- harvesting practice (green, burnt, whole) - % residues that are burnt, removed, retained	Trash retention influences N cycling and hence the demand for synthetic nitrogen fertilisers.	Cane burning emissions to air[2]. (*Trash retention influences soil carbon content and soil moisture retention, and hence nitrous oxide emissions*.)
	Harvesting efficiency	- fan type - fan speed		In-field sugar losses during harvesting, and hence for sugar losses to aquatic environments.
Water management	Volume of water used for irrigation	-volume of water applied -source of water	Influences the extraction of water from managed sources (*Source of water influences the stress on water resources*)	
	Energy used for pumping water Source of energy	- type of energy used (fuel, electricity) -head pressure - pumping efficiency	Amount of energy (fuel and electricity) consumed for pumping, and hence the embodied of producing the energy.	Emissions of fuel combustion gases to air.

[2] The carbon dioxide released from biomass combustion (referred to as a biogenic source) is not been accounted, in accordance accepted methods for estimating greenhouse gas emissions (IPCC 2000). This is because it is regarded as a short-term release, assumed to be taken up by subsequent crops.

Practices have been categorised to be consistent with the Framework, i.e., soil management, nutrient management, pest management, water management and harvesting.

The practice descriptors should be able to capture differences between practices across the continuum from out-dated (D) to aspirational (A). However the tool's development focused on modelling conventional (B) and progressive (C) practices, and so some D- and A- practice may not be able to be captured fully by the tool.

3.1.3.2. Environmental impacts influenced by practices

Environmental life cycle assessment (LCA) can consider a wide range of environmental impacts, including those related to the depletion of resources, global warming, protection of environmental qualities (acidification, eutrophication, eco-toxicity), human health (human toxicity, respiratory organics and inorganics), and biodiversity. However it is usually more meaningful and practical to focus on impacts most relevant and significant for the production system being assessed.

The environmental impacts that were the focus for the streamlined LCA tool were the use of non-renewable energy, greenhouse gas emissions leading to global warming, water use, and water quality impacts (eutrophication from nutrients and eco-toxicity from toxic substances). This sub-set were considered relevant and important for sugarcane production in Australia either because they have been identified in past LCA work (Renouf et al., 2010) to be significant, or they reflect community priorities for environmental protection. Other impacts were not considered to be as relevant or significant (acidification, respiratory organics and inorganics, human toxicity), or the methods for their calculation are not well established or well accepted (biodiversity).

The aspects of sugarcane growing that influence these environmental impacts were known from past LCA work (ibid) (see Figure 3 and Table 3). This was developed further by examining correlations between practices and environmental impacts, i.e. how cane growing practices influence environmental impacts (Table 2). These correlations formed the basis of the tool's developement, by defining the cane growing variables that needed to modelled by the tool, and the resulting environmental exchanges and impacts to be calculated.

Figure 3 Scope of environmental aspects for sugarcane production

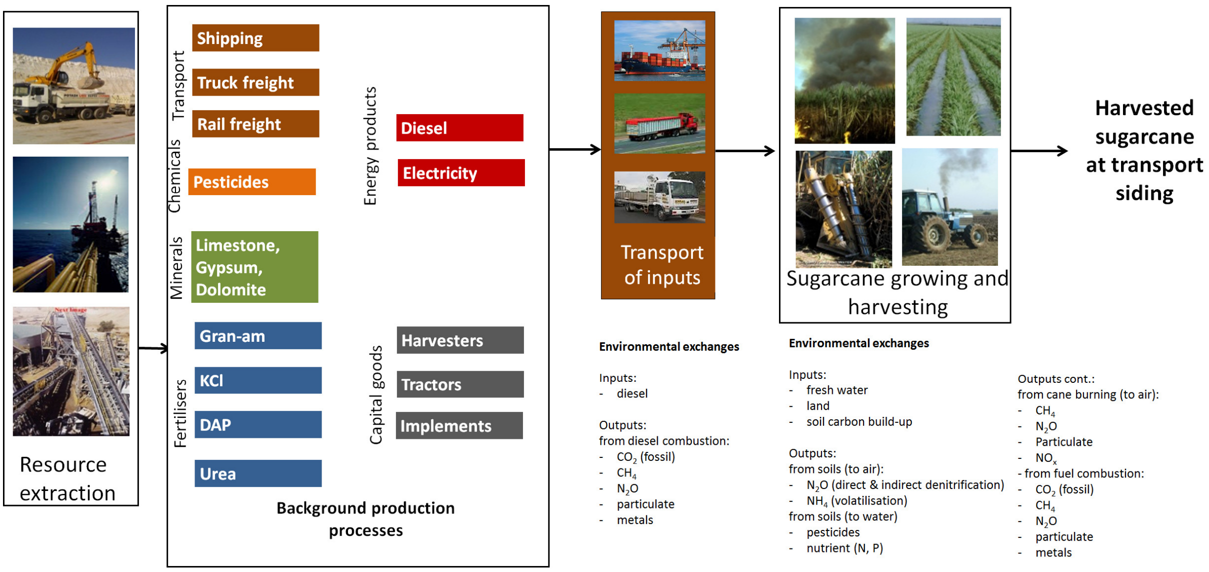


Table 3 Known environmental aspects of sugarcane production

Off-farm aspects (activities upstream of the farm)	**On-farm aspects**
Production of fuels	Emissions to air [1]:
Production of electricity	– Exhaust emissions from combustion of fuels in farm machinery
Production of agro-chemicals (fertilisers, lime, dolomite, gypsum)	– Nitrous oxide (N_2O) to air (from denitrification of applied nitrogen)
Production of pesticides (herbicides, insecticides, fungicides)	– Ammonia (NH_3) to air (from urea volatilisation)
Production of capital goods (tractors, harvesters, implements, irrigation infrastructure)	– Carbon dioxide (CO_2) from carbonation of lime and dolomite)
Transportation (of farm inputs from manufacturers to the farm)	– Cane and trash burning emissions (CH_4, N_2O, NOx)
Water supply (by irrigation schemes)	Emissions to water:
	– Nitrogen, phosphorous and pesticide lost to surface water runoff
	– Nitrate (NO_3) leaching to groundwater (from losses of applied nitrogen through the soil profile
	– Sugar losses (from harvesting) to surface water runoff

[1] Only the carbon dioxide releases from fossil fuel sources are accounted for, in accordance accepted methods for estimating greenhouse gas emissions (IPCC, 2000). Carbon dioxide emissions from organic sources (referred to as biogenic carbon) are not counted is because they are regarded as a short-term release, assumed to be taken up by biomass growth.

3.1.4. Design and development of the tool

3.1.4.1. Design concept

The design concept was to streamline the life cycle assessment (LCA) process by using MS Excel to generate a sugarcane growing model that captured the important processes and environmental aspects, and utilising accepted algorithms and factors for calculating environmental impacts.

A causal flow diagram was developed that mapped out the interactions between cane growing practices and environmental impacts (Attachment 5). The tool was then developed based on this to calculate environmental impacts through the following steps:

– Descriptors of cane growing practices for the assessed operation are entered by the user.

– Key cane growing parameters are calculated by the tool. These are the quantities of inputs to and outputs from the cane growing process for the defined operation.

– Environmental exchanges are calculated by the tool using in-built calculations, assumptions, and environmental emission factors. These are the quantities of natural resources consumed and emissions to the environment per unit of cane produced.

– Indicators of environmental impacts are calculated by the tool using in-built impacts characterisation factors for the resources and emissions.

The results generated from an LCA study are commonly referred to as environmental impact indicators. However to be more constructive for tool users they were instead referred to as eco-efficiency indicators. Eco-efficiency refers to the production of goods with lower environmental impacts per unit of product. The lower the environmental impacts the better the eco-efficiency. This approach was chosen to emphasise the positivity of environmental benefits rather than negativity of environmental impacts. Alternative terms for the environmental impacts that are meaningful for users were also devised based on feedback from the users (Table 4).

Table 4 Terms used to describe environmental impact indicators

Environmental impact terms commonly used in LCA	Eco-efficiency indicator terms used in CaneLCA	Units
Non-renewable energy use	Fossil energy use	MJ/t cane
Water use	Water use	L/t cane
Greenhouse gas emissions / Global warming potential	Carbon footprint	kg $CO_{2(eq)}$/t cane
Eutrophication potential	Water quality risk – from nutrients	kg $PO_{4(eq)}$/t cane
Eco-toxicity potential	Water quality risk – from toxic substances	kg 1,4-$DCB_{(eq)}$/t cane

The presentation of the results was designed so that users could visually see the contribution that different aspects of cane growing made to the eco-efficiency result, and thereby see the influence of different practices. Therefore eco-efficiency results were represented as a colour-coded stacked bar graph.

Presentation of results also aimed to show how the assessed operation compared with the rest of the industry. This was achieved by scaling the eco-efficiency results on the graph against the range expected across the industry (see Table 6), and using a 5-star rating system to rate the relative performance of the assessed operation (Table 5).

Table 5 Performance criteria for 5-star eco-efficiency rating scale

(% of expected maximum impacts for sugarcane growing in Australia)

½ star	1 star	1 ½ star	2 star	2 ½ star	3 star	3 ½ star	4 star	4 ½ star	5 star
95-100%	90-95%	80-90%	70-80%	60-70%	50-60%	40-50%	30-40%	20-30%	<20%

3.1.4.2. Methods employed in the tool

CaneLCA was designed to perform a partial LCA for sugarcane growing up to the production of harvested sugarcane at the transport siding. The methods employed comply with accepted standards for LCA and carbon footprinting (BSI, 2008, ISO, 2006a, ISO, 2006b), and the carbon accounting guidelines for sugarcane growing developed for the Bonsucro Sustainability Standard (Bonsucro, 2012). The important features that informed the tool's development are summarised here.

<u>Environmental emission factors</u>

Two types of environmental emission factors are employed in the tool; those for on-farm emissions and those related to the upstream production of farm inputs.

Emissions associated with up-stream production of material and energy inputs (such as fuels, machinery, fertilisers, agro-chemicals, transport etc.) were derived from the Australasian Life Cycle Inventory Library (Life Cycle Strategies, 2012).

On-farm emissions are direct emissions that come from the farm (nitrous oxide, ammonia, and cane burning emissions to air, and nitrogen, phosphorus, pesticides and sugar losses to water). The default emission factors used in the tool were derived from accepted or published values, which can be over-ridden by the user if site-specific emission factors are known. An attempt was made to adapt the outputs from other modelling tools, such as SafeGuage, HowLeaky and APSIM, so that site-specific emissions factors based on known risk factors could be estimated in the tool. However it was found to be too premature to include this capacity in the tool at this stage. It may be possible at a later stage once the above tools have been used more widely and are able to generate region-specific emissions factor under given sets of condition. Consequently the tool applies the default set of emission factors unless over-ridden by the user.

Impact characterisation factors

Impact characterisation refers to the process of converting the estimated emissions of a substance into an indicator of the environmental impact that the substances causes. The indicators express the degree of impact relative to the known impact of a reference substance. The environmental impact characterisation factors used in CaneLCA were derived from the following impacts assessment methods:

- non-renewable energy use (fossil fuel use) – Australian indicator set (V2.01) (Life Cycle Strategies, 2012), which quantifies energy flows based on lower heating values
- greenhouse gas emissions (carbon footprint) – Australian indicator set (V2.01) (Life Cycle Strategies, 2012) which applies global warming potentials from the IPCC 1996 SAR factors (IPCC, 1997)
- water use - Australian indicator set (V2.01) (Life Cycle Strategies, 2012), which simply quantifies consumptive water use
- eutrophication potential (water quality risk from nutrient) - Australian indicator set (V2.01) (Life Cycle Strategies, 2012), which applies factors based on the CML method (Heijungs et al., 1992)
- eco-toxicity potential (water quality risk- from toxic substances) – ReCiPe Midpoint (V1.1) (Goedkoop et al., 2009), which applied factors based on the USEtox model (Rosenbaum et al., 2008)

Considerable investigation went into the selection of eco-toxicity characterisation factors. Eco-toxicity has not commonly been assessed in Australia studies, and so there has been little prior research to inform this work. Early versions of the tool used characterisation factors based on an Australian method developed by Lundie et al. (2007). However results generated with this method were found to over-emphasise the impacts of metal emissions from the processes such as the production of machinery, and under-emphasise the impacts of pesticide losses from cane fields. Consultation with eco-toxicty researchers identified that the Recipe (I) method (Goedkoop et al., 2009) would be more appropriate.

Industry maximums for normalising the eco-efficiency ratings

The expected maximum environmental impacts for sugarcane growing in Australia were generated to normalise the environmental impact results and generate relative eco-efficiency ratings. This was done by using the tool to model cane growing practices and parameters expected to result in the lowest and highest environmental impacts (Table 6).

Table 6 Estimated maximum environmental impacts for sugarcane growing (per t cane)

	Environmental impact categories				
	Fossil Energy Use	Carbon footprint	Water use	Water quality risk	
				(eutrophication)	(eco-toxicity)
	(MJ)	(kg CO_{2eq})	(kL)	(kgPO_4eq)	(kg 1,4 DCBeq)
Maximum	1,080	120	160	0.7	1.42

3.1.4.3. Stakeholder participation

A range of stakeholders participated in the development of the streamlined LCA tool:

- Industry and scientific reviewers guided its development (Bianca Cairns - SRDC, Bernard Milford and Jonathan Pavetto - CANEGROWERS, Sharon Denny - ASMC, Phil Moody - DSITIA and Phil Hobson - QUT).
- BSES extension officers and growers tested early versions of the tool (Brad Hussey, Peter McGuire, Andrew Barfield, Ian and Di Dawes and Robert Quirk).
- Researchers provided technical input (Jeff Tullberg – CTF; Guangnan Chen – USQ/NCEA; Melanie Shaw – DSITIA; Joe Lane, UQ; Cam Whiteing - BSES).
- BSES communications staff developed the branding for the tool (Eve McDonald).
- Industry personnel evaluated the final version (Mark Poggio - DAFF, Michael Waring – Terrain, David Sudarmana – Sugar Australia, Guangnan Chen –USQ, and others who evaluated it anonymously).

3.1.4.4. Title and branding

A title for the tool evolved out of consultation with the industry review panel. Shortlisted names included CaneLCA, SugarCaneLCA, HowGreen (is your cane?), Cane Eco-Checker, and Sugarcane Eco-Checker. The title selected was “CaneLCA Eco-efficiency Calculator” or CaneLCA for short. The Eco-efficiency Calculator by-line was included in the title to give more information about the tool’s intended use.

The colour scheme and images (Figure 4) were developed by Eve McDonald (Marketing the Communications Specialist, BSES). This branding was applied to the tool, supporting documentation, and the webpage.

3.1.4.5. Supporting documentation

A user manual and a methodology document were also developed to support the use of the tool.

Figure 4 Branding for CaneLCA

3.1.5. Linkages with other LCA activities

CaneLCA was developed in consideration of two other LCA projects related to sugarcane (Figure 5):

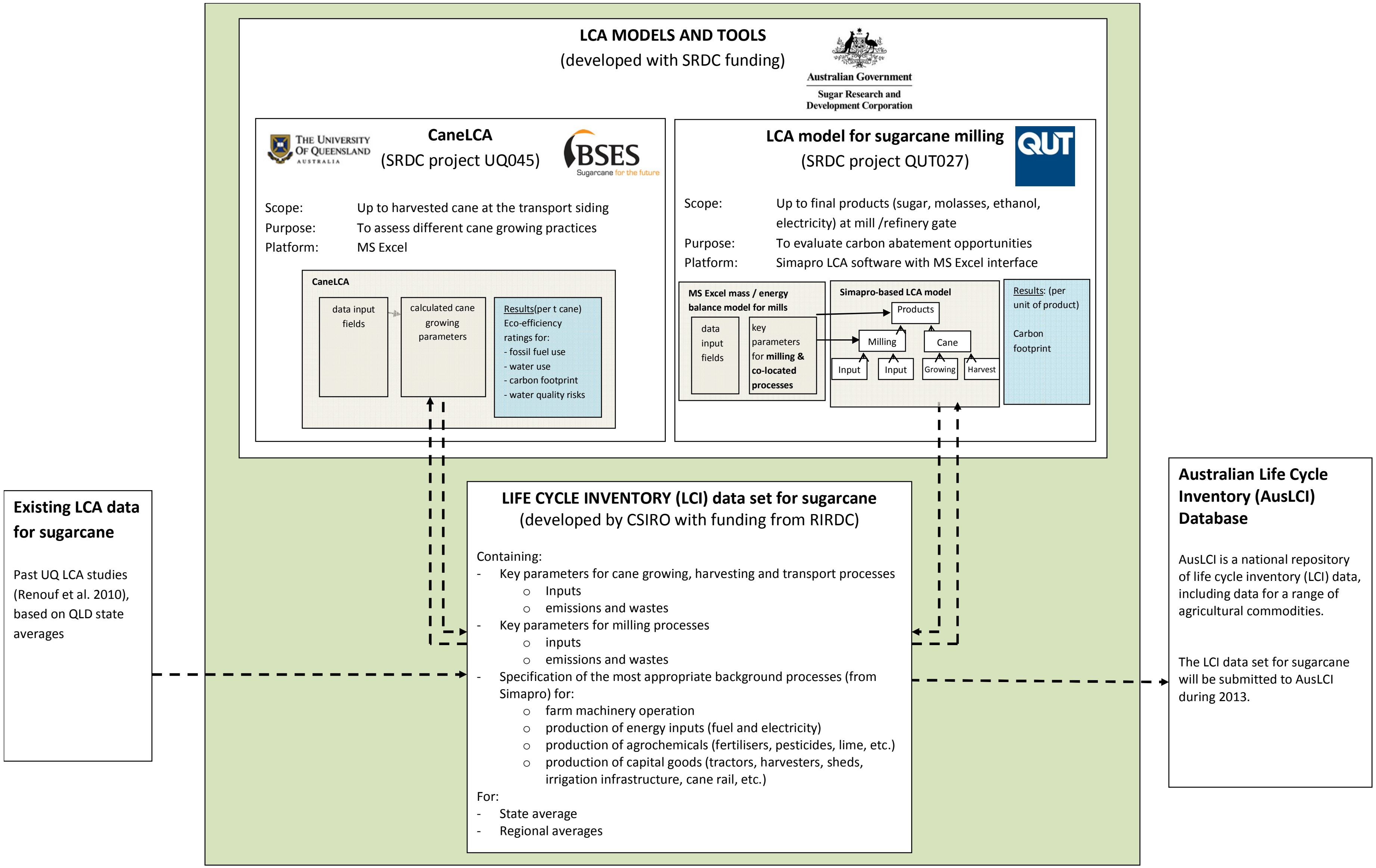
– Opportunities for the Australian sugar industry in greenhouse gas abatement and carbon trading – QUT project funded by SRDC (SRDC Project No. 027).

– Developing a LCI database for Australian agriculture- CSIRO project funded by RIRDC.

The first of these developed an LCA model for sugarcane milling using Simapro LCA software. CaneLCA was developed in close collaboration with the developers of this model, and some features incorporated into CaneLCA so that the two tools could be compatible and consistent. The cane growing parameters generated by CaneLCA can be imported into the Simapro LCA model for sugar milling. Secondly, both tools draw on a consistent set of background data.

The second project involved the development of a life cycle inventory (LCI) data set for sugarcane. The data set will help ensure that LCA can be applied consistently within the industry, and both CaneLCA and the LCA model for sugar milling draw on this data set. It can also be made available externally to ensure that Australian sugarcane products are accurately represented in environmental life cycle studies conducted outside the industry. For this purpose, the data set has been reviewed extensively by sugar industry personnel to ensure that it is representative, and will be submitted to the AusLCI database in 2013 after a process of industry engagement. AusLCI database is a central, on-line repository for Australian life cycle inventory (LCI) data for a wide range of production processes, including agriculture. It is managed by the Australian Life Cycle Assessment Society (ALCAS), and can be found at the AusLCI website.

Figure 5 Linkages between sugarcane LCA projects



3.2. Evaluation of the streamlined LCA tool

The success of the developed streamlined LCA tool (CaneLCA) was evaluated by:

- checking that the original desired features had been met;
- undertaking a user evaluation to test its effectiveness in providing a rapid and meaningful environmental assessment of growing practices for the intended users; and
- checking that the LCA results generated within the tool were accurate.

3.2.1. Achievement of original desired features

A check was made of whether the developed tool met the original design objectives defined by the industry review panel. The list of desired features were compiled from the minutes of the industry review panel meeting, and a judgement made as to whether they had been achieved.

3.2.2. User evaluation

The user evaluation aimed to test the effectiveness of CaneLCA in providing a rapid and meaningful environmental assessment of growing practices, but also to test for technical and interpretive problems. It was conducted between November, 2011 and February, 2012, after receiving ethical clearance from UQ (Attachment 6). The aim was to recruit up to ten industry personnel, representing the various categories of potential users from each of the main sugarcane growing regions.

Twenty-six (26) personnel were nominated to be invited based on expressions of interest received at LCA workshops and seminars and the recommendations of the BSES investigators. Invitations were sent by email along with participant information (Attachment 7), the test version of the tool and user manual, and a copy of the evaluation feedback form (Attachment 8). Participants were given the option for their involvement and feedback to be anonymous.

Participants were asked to undertake the following:

- Follow the instructions in the user manual to independently run an analysis using the tool.
- Input data for a sugarcane growing scenario of their choosing, into either a blank version of the tool or a version pre-filled with example data.
- Request assistance from the principal investigator, by email, telephone or in person if needed.
- Review and critique the results generated by the tool.
- Complete the feedback form which asked about any problems experienced, instructions that were difficult to follow, the time required to input data, and the presentation and usefulness of the results.
- Return the evaluation feedback form to the project team so that the feedback could be taken on board to improve the tool.

A sample of eight (8) users agreed to evaluate the tool, many of whom requested anonymity. Hence participant details are not recorded in this report. Five (5) undertook an actual assessment with the tool using real or typical data, and three (3) did not undertake a full assessment, but instead provided general feedback.

The sample represented a reasonable spread across the expected roles of potential uses (see Table 7). While not all of the key cane growing regions were represented in the participant sample, previous versions of the tool had been demonstrated to users from the other regions (Central and Northern NSW) in the early stages of the tool's development. This meant that representatives from most regions (except Far North QLD) had used the tool in some capacity and informed its development.

Table 7 Details of participants in the user evaluation

Total number of evaluators		**8**
Role (values in parentheses refer to the secondary role of some participants)		
	Sugarcane farmer	(3)
	Agricultural extension advisor	4
	Agronomist	(1)
	Policy personnel from sugar industry association	-
	Personnel from sugar milling and manufacturing company	2
	Personnel from natural resource management body	-
	Researcher	1
	Government officer	1
Region (values in brackets refer to other participants who took part in earlier testing)		
	Far North QLD	-
	Herbert	2
	Burdekin	3
	Central QLD (Proserpine to Sarina)	(1)
	Southern QLD (Bundaberg to Rocky Point)	1
	Northern NSW	(2)
	General - no particular region	2
Details of the assessment undertaken by the participant		
Scale	A single farming operation made up of different crop classes	5
	A region made up of different farming operations	-
Data source	Real data	2
	Typical data	2
	Hypothetical (estimated) data	1
Tool version	PRE-FILLED version	1
	BLANK version	4
Data not entered; only features of the tool reviewed		3

The evaluation form asked questions about the ease of data entry and overall use of the tool and the manual, and the usefulness of the outputs generated by the tool. Evaluators responded by selecting their level of agreement with given statements (see Attachment 8). This enabled a quantitative assessment of whether the tool was found to be easy to use, provided useful information, and met its design objectives. Evaluators were also requested to record any technical and interpretive problems experienced while using the tool. These qualitative responses gave the details needed to improve the tool. Feedback was received from evaluators either written (on the feedback form) or verbally over the phone, or both.

All eight (8) evaluators provided qualitative feedback, but only six (6) gave quantified responses to the targeted questions. Responses were compiled in a de-identified form, and an interpretation is presented in results (Section 4.2.2). The evaluation feedback forms were stored electronically on a secure server at UQ's School of Geography, Planning and Environmental Management. Significant refinements were made to the tool based on the users' feedback.

3.2.3. Results evaluation

The LCA results generated by the streamlined tool were evaluated for accuracy. This was done by comparing the results generated by CaneLCA with those generated by the Simapro LCA software using a life cycle inventory (LCI) data set for Australian sugarcane. This data set is comprehensive, has been reviewed by industry, and is considered the most accurate available. The aim was to check that the results generated in the streamlined LCA tool were consistent with those generated by LCI data set.

The CaneLCA results generated for the comparison were those generated for the scenario analysis (in Section 3.3), i.e., C-class practices in the Wet Tropics, Mackay and Southern regions, based on the descriptions of van Grieken, Webster et al. (2010) and Schroeder, Cameron et al. (2009).

Comparable LCA results were generated with Simapro (Pre Consulting, nd) using the regional LCI data sets for the Wet Tropics, Mackay and Southern regions (Renouf and Cruypenninck, 2012). The environmental impact characterisation methods applied for the Simapro analysis were consistent with those adopted in CaneLCA (See Section 3.1.4.2).

The two sets of results for each region were compared to check that the scale of the results and the contributional breakdown were consistent. An exact match was not expected as each set of data represent slightly different scenarios. The scenarios assessed with CaneLCA represent a single operation considered to be typical for the regional. Whereas the LCI data assessed with Simapro represent the average for the region.

Some refinements were subsequently made to improve the accuracy of the LCA results generated within CaneLCA. For instance, the impact characterisation factors for eco-toxicity (water quality risk from toxic substances) were revised, as discussed in Section 3.1.4.2. The methods for estimating on-farm fuel use were also refined so that fuel use estimates were more in line with those observed in the LCI dataset. The results comparison in Section 4.2.3 are those generated after these refinements had been made.

3.3. Analysis of cane growing practices using the streamlined LCA tool

CaneLCA was used to assess a number of cane growing scenarios, principally for the purpose of testing the environmental benefits of progressive cane growing practices compared to conventional practices. However it was also an opportunity to demonstrate and test the use of the tool for a purpose for which it was designed.

The analysis aimed to test the hypothesis that transition from conventional to progressive practices leads to better environmental performance. The following is a summary of the methodology, which is described further in a paper presented at the Conference of the Australian Society of Sugarcane Technologist (ASSCT) (Attachment 13).

Conveniently, it was possible to draw on the recent categorisation of practices under the ABCD framework (Section 3.1.3.1) to define conventional practices as C-class and progressive practices as B-class. Practice change scenarios were developed for three regions – Wet Tropics, Central and Southern regions (Table 8). The Wet Tropics and Central scenarios represent a change from a suite of C-practices to a suite of B-practices, and were based on regional practice models developed by van Grieken et al. (2010) supplemented with herbicide application models developed by Shaw and Silburn (in review). The Southern scenario was based on observations of past (1980-1990) and improved practices (2000-2008) by Schroeder *et al.*(2009), assumed to represent C and B practices in this region, respectively. These studies were selected because they provided enough detail to enable an environmental assessment.

The practices changes modelled mostly entail:

- Changed row spacing (from 1.5m to 1.8m) for controlled traffic
- Slightly reduced number of farm machinery due to consolidation of farm equipment;
- Reduced tillage, hence reduced tractor operations for soil work;
- Inclusion of a legume fallow in the crop rotation in place of no fallow or bare fallow;
- Reduced nutrient application rates;
- Green cane harvesting replacing burnt cane harvesting, and hence more retention of harvest residues; and
- Changed water use (for the Southern scenario only).

Details of the assumed practices and cane growing parameters for each regional scenario were entered into CaneLCA (details in the ASSCT paper - Attachment 13). The results were compared to determine the change in eco-efficiency - either improved eco-efficiency (i.e. lower environmental impacts), or reduced eco-efficiency (i.e. higher environmental impacts).

Table 8 Practice change scenarios

Region	Type of practice change	Source of information	General characteristics of practice change
Wet Tropics	From C to B practices	Van Grieken *et al.* (2010a), supplemented with other data from DERM (Shaw and Silburn in review) and industry audits (C4ES Pty Ltd, 2004) and assumptions.	No change to cane rotations and yields Grassy fallow to soybean fallow (green mulch) 1.5 m to 1.8 m row width Reduced number of tractors Reduced tillage Reduced N, P, K application rates No change to harvesting method Reduced herbicide application rates No irrigation
Central	From C to B practices	Van Grieken *et al.* (2010a), supplemented with other data from DERM (Shaw and Silburn, in review) and industry audits (C4ES Pty Ltd, 2004) and assumptions.	No change to cane rotations and yields Bare fallow to soybean fallow (harvested) 1.5 m to 1.8 m row width Reduced number of tractors Reduced tillage Reduced N, P, K application rates Burnt to green cane harvesting Reduced herbicide application rates No change to irrigation (HP travelling gun)
Southern	From 'past' to 'improved' practices	Schroeder *et al.* (2009) supplemented with assumptions.	3 ratoons to 4 ratoons No fallow to soybean fallow (harvested) Change to cane rotation resulting in reduced overall cane production 1.5 m to 1.8 m row width Reduced number of tractors Reduced tillage Reduced N, P, K application rates Increased herbicide application rates Increased insecticide application rates Flood to high-pressure travelling-gun irrigation, with higher water-application rates

A range of common practice changes were also assessed individually, relative to a reference case (C-class practices for the Southern scenario) to identify those with the greatest potential for eco-efficiency improvements.

3.4. Development of the process for accessing the tool

The proposed process for enabling access to the tool evolved through consultation with the industry review panel, with consideration to the following objectives:

- the need for the tool to be readily accessible to industry users ;
- industry sensitivities about who the tool was made available to; and
- the capabilities of project collaborators for servicing the distribution and maintenance of the tool.

The original intent was for the access, extension and monitoring of uptake to be managed by BSES Limited via its website, in a similar fashion to BSES' other extension tools (Nutricalc and QCaneSelect). However recent changes to BSES' role and priorities meant that access via the BSES website is no longer possible, and it is not clear how the ongoing extension of CaneLCA will occur. Alternative and interim measures for webbased access to the tool and monitoring of uptake have been progressed and are described in this report. However it has not been possible to explore alternative mechanism for extension of the tool within this project.

Uniquest (the consulting arm of UQ) have offered to assist with making CaneLCA available via its Uniquest Licencing Portal (uniquestportal.com/CaneLCA/). This provides a short-term measure for making CaneLCA accessible. However it cannot be guaranteed over the long term, as Uniquest have no vested interest in the project. A proposed process for distributing CaneLCA via the Uniquest Portal has been developed in line with the above objectives, and is described in Section 4.4. These arrangements are still being put in place by Uniquest, and other interim arrangements have been put in place.

A process for partially monitoring uptake of CaneLCA was set-up through the establishment of a user register, which lists users who have requested and been issued a copy of CaneLCA. The register's main purpose is for controlling the distribution of the tool, and for notifying users about updates to the tool, but it can also be used to help monitoring its uptake.

4. RESULTS

4.1. CaneLCA Eco-efficiency Calculator

The main output from the project was the streamlined LCA tool for sugarcane growing, named 'CaneLCA Eco-efficiency Calculator', which was released as Version 1.01 on 05/05/2013.

CaneLCA is a MS Excel workbook made up of 10 worksheets - eight for data entry and two for the output of results (Figure 6). The data input sheets align as far as possible with the ABCD classifications of cane-growing practices (van Grieken et al., 2010). There are also numerous hidden sheets containing the calculation fields and the factors used in calculations (Table 9). Screen shots of each sheet (populated with example data) are provided in Attachment 9.

The tool was described in a paper presented at the Conference of the Australian Society of Sugarcane Technologist (Attachment 12), and a summary is provided here.

To operate CaneLCA, users first enter the required data into the white cells of the data entry sheets (1-8):

- Sheet 1. Farm Details. Cropping areas and yields are entered so the tool can calculate overall farm production. Machinery and implements in service on the farm are then listed so they tool can generate a personalised machinery list for use in subsequent worksheets.
- Sheets 2-7. On each of these sheets, data about farm operations are entered - soil work, nutrient and pest management, harvesting, and water management etc.
- Sheet 8. Emission Factors. This sheet summarised the default environmental emission factors applied by the tool. The user only needs to use this sheet if the default emission factors are to be changed.

The tool uses in-built calculations, assumptions, and environmental emission factors to calculate (in the hidden calculation fields) the environmental exchanges between the cane-growing operation and the environment, and the final eco-efficiency indicators per tonne of sugarcane.

The user can then review the outputs generated by the tool on sheets 9 and 10:

- Sheet 9. Input Summary. Reviewing the inputs and checking for omissions and mistakes.
- Sheet 10. Results. Reviewing the generated environmental profile and eco-efficiency ratings.

The Input Summary (Sheet 9) reports the cane growing parameters generated by the tool, i.e., the inputs of resources to the farming operation (fuel, electricity, nutrient products, pesticides, water, transport) and the output to the environment from the farming operation (nitrogen, phosphorus, pesticides, cane burning emissions). The user can review these to check that data has been entered correctly, that it correctly represents the farm or scenario being assessed, and adjust entered values as necessary.

Figure 6 User map of CaneLCA

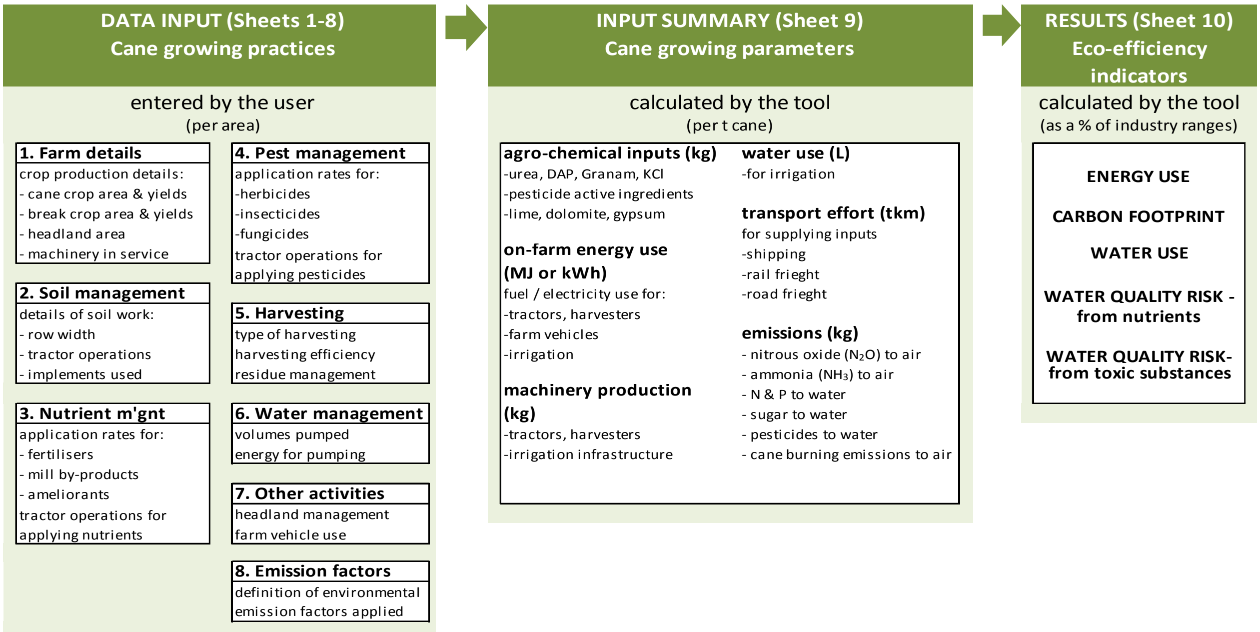


Table 9 Worksheets contained in CaneLCA

User interface worksheets (visible to the user)	Sheets containing calculation fields (hidden)	Sheets containing calculation factors (hidden)
Welcome page	Farm details – workings	Drop-down lists
1. Farm details	Soil management – workings	Crop attributes
2. Soil management	Nutrient management – workings	Fertilisers
3. Nutrient management	Pesticide management – workings	Machinery fuel use
4. Pest management	Harvesting – working	Transport distances
5. Harvesting	Irrigation management – working	Embodied impacts of inputs
6. Water management	Other activities – workings	Environmental emission factors
7. Other activities	Results - workings	Impact characterisation factors
8. Emission factors		Mass conversions
9. Input summary		
10. Results		

The Results (Sheet 10) are presented as a bar graph depicting the eco-efficiency profile of the assessed farm for the five key indicators (Figure 7). The total length of each bar represents the scale of the impact compared with expected industry maximums. For example, a 50% result for carbon footprint means the assessed farm is 50% less than the highest expected carbon footprint for the industry, per tonne of harvested cane. The colour coding on the bars shows the sources of environmental impacts. The user can click on the coloured sections to identify the corresponding activity from the legend below the graph.

The user can interpret the following from the environmental profile graph:

- the contributions that different activities make to each of the eco-efficiency indicators;
- the relative performance of the assessed farm, when compared with known ranges for sugarcane growing in Australia; and
- opportunities for improving the eco-efficiency of the assessed farm.

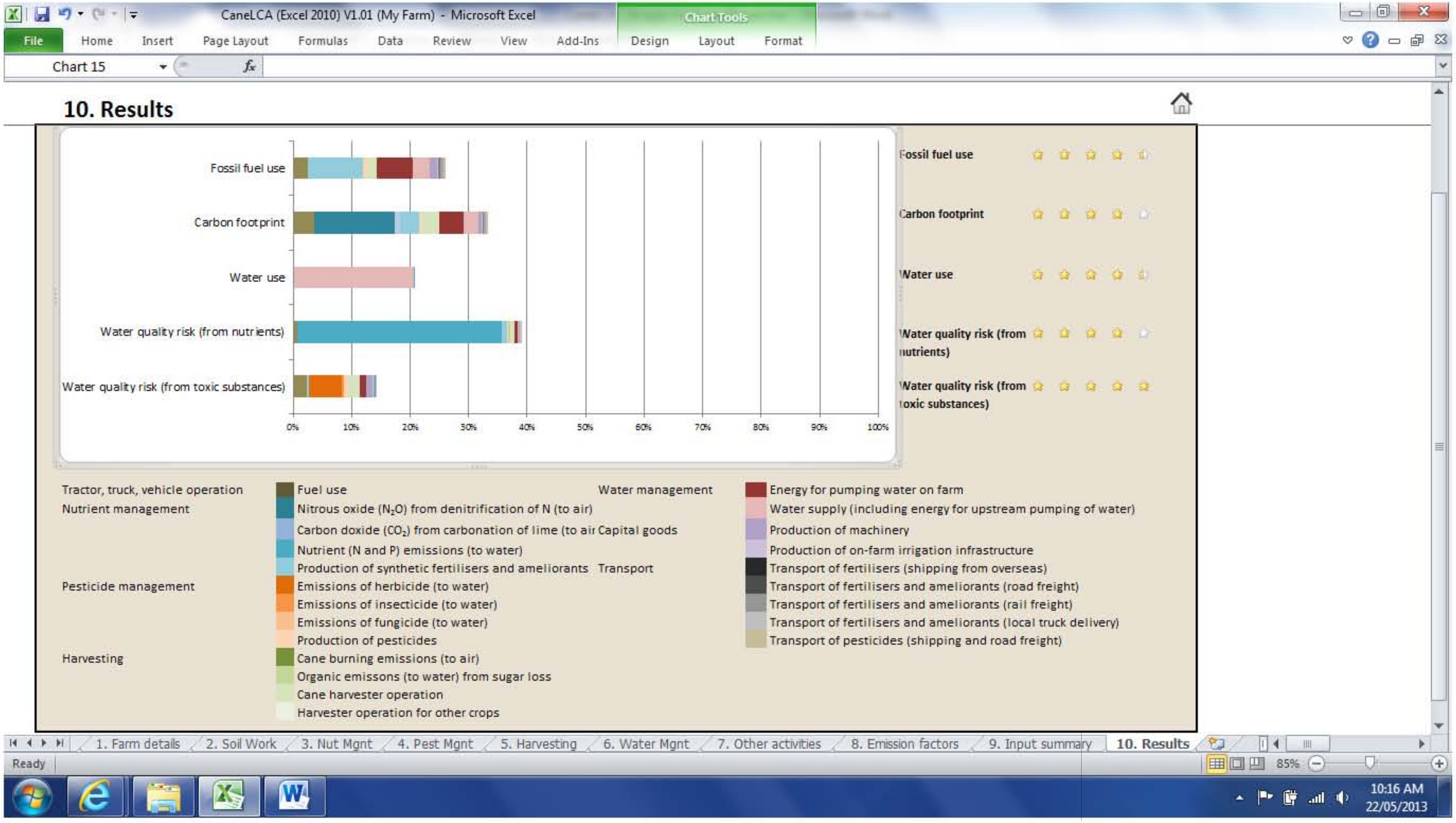
Different combinations of cane-growing practices can be assessed and compared to test if a proposed practice change will result in improved eco-efficiency. To enable this, the results graph can be exported to other documents (by copying and pasting) so that results from multiple assessments to be easily compared alongside each other.

Notable features of CaneLCA are:

- It is supported by a user manual and methods document (provided separately).
- Users can start with a blank version and enter data from scratch, or a pre-filled version for a particular region (which can be provided by the project team).
- Sheets 9 (Input Summary) and Sheet 10 (Results) can be easily printed as a record of the assessment.
- The parameters reported in Sheet 9 (Input Summary) can be exported to other LCA software tools, such as the LCA model for sugarcane milling (developed by QUT) and more general LCA software (Simapro, Gabi).
- The tool applies default environmental emission factors (for nitrous oxide, ammonia, and cane burning emissions to air, and nitrogen, phosphorus, pesticides and sugar losses to water) based on accepted or published values. However they user can be over-written by user’s own values.

The environmental profile generated by CaneLCA provides relative indicators of eco-efficiency. It does not report absolute environmental impacts results. Therefore, the outputs of CaneLCA cannot be used for external reporting. CaneLCA is designed for internal monitoring and comparison of cane growing practices. It is not appropriate to use CaneLCA for comparing between different farms or regions, as the normalisation process used to generate the eco-efficiency results is broad, and does not account for the different environmental conditions in different regions.

Figure 7 Examples results from CaneLCA



4.2. Evaluation

4.2.1. Evaluation against the original desired features

Most of the original desired features for the streamlined LCA tool, developed through consultation with the industry review panel, were achieved in the CaneLCA tool (Table 10). Those features not achieved are discussed in the notes following the table, and noted as opportunities in any future development of CaneLCA (in Section 8).

Table 10 Original desired features for CaneLCA

Required features	Achievement
Stand-alone MS Excel workbook tool that does not require the use of proprietary LCA software	Yes
Reports results for relevant and important environmental impact indicators	Yes
Generates results as relative indicators of environmental performance (for extension purposes)	Yes
Represents results using a graduated bar rather than a traffic light-style indicator	Yes
Represents results with a contribution analysis to allow for meaningful interpretation of the results	Yes
Generates results in accordance with nationally / internationally accepted methodologies	Yes
Include all processes in the life cycle up to the haulage of harvested cane to the siding	Yes
Data input should minimise the amount of pre-calculation required by the user	Yes
Data output should align with other LCA / carbon footprinting applications (QUT LCA model for sugarcane milling, Bonsucro certification, Australian national LCI database (AusLCI))	Yes
Versions of the tool available pre-filled with example data for different cane growing regions	Yes
Provide the capability to model environmental initiatives of interest to the industry, for eg. use of biofuels in farm machinery, eligible carbon abatement opportunities under CFI, best management practices for water quality protection.	Yes
Be informed by useful aspects of other tools (FEAT, NutriCalc, SAFEGUAGE, EnergyCalc)	Yes
Access to the tool is controlled	Yes
Generates results as absolute environmental impacts for reporting purposes where the methodologies and emission factors are well accepted	Partially [1]
Adopts the water footprint methods of Brad Ridoutt (CSIRO) for representing water use impacts	Partially [2]
Addresses issues that have made past tool awkward to use, such as:	
- data needing to be re-enter each time	Partially [3]
- data entered at the farm level – would be better entered at the block level	Partially [4]
- complicated user interface	Partially [5]
Data input should align with other record keeping requirements, and enable automatic data input of data from farm data collection systems	No[6]
Include vegetation management and changes in soil carbon	No [7]

1. The tool generates absolute values for the set of environmental impact indicators. However these are hidden from the user in the calculation sheets. Relative indicators of performance are reported instead. If a user has legitimate reasons for requiring absolute values, they can request to receive an unprotected version of the tool from BSES which will allow them to extract the absolute values.
2. The tool contains the algorithms required to generate a water footprint based on water stress indices, as per evolving water footprint methods. However water stress indices for the water sources are not clearly defined at this stage to allow water-stress weighted water use impacts to be calculated.
3. Using Microsoft Excel as the platform for the tool means that input data does need to be re-entered for each evaluation. However the ‘copy and paste’ function can be used to transfer similar data from one evaluation to another, to reduce the repetition of data entry.
4. An attempt was made to set the tool up so that evaluations could be undertaken at individual block level. However the tool became too complex. Using Microsoft Excel as the platform for the tool limits the ability to handle the large sets of data required for block by block assessment. More sophisticated data management software, such as that used by farm data collection and reporting systems (AgDat, HRIC), would need to be employed to achieve this.
5. The user interface sheets have been made as simple as possible. However the inherent complexity of LCA means makes this difficult.
6. The logistics of enabling automatic data feed into the tool from farm data management systems were investigated. The work involved in doing this is outside the scope of this current project. Also it may not be warranted at this stage, due to the relatively small proportion of growers that use farm data management system.
7. The capacity for assessing changes in soil carbon and vegetation management practices in the tool was considered. However scientific knowledge about the range of opportunities for carbon sequestration in soils and vegetation, and the method for quantifying it, are not developed enough to allow it at this stage.

4.2.2. User evaluation

Feedback received from the six (6) users who evaluated the tool and answered the targeted questions provide a quantitative gauge of the tool’s ease of use, the ease of data entry, the effective interpretation of results, and the tool’s overall usefulness for its intended purpose (Table 11).

The feedback suggested that the test version that was evaluated mostly met the required features for ease of use, but that improvements were needed in streamlining data entry and improving instructions. It also highlighted deficiencies in the way results were presented and the difficulty of some users in interpreting results. These were the focus of refinements subsequently made to the tool.

Table 11 Quantitative feedback from the user evaluation

Note: The figures indicate the number of evaluators who responded to each rating of agreement, out of six (6) who provided quantitative feedback.

Ease of using the tool	1.Strongly agree	2. Mostly agree	3. Neutral	4. Partly agree	5. Do not agree	Can't comment
Instructions on the 'Welcome' sheet gave me useful guidance to get started.		2	2	1		1
I preferred to use the sheet tabs at the bottom to move between sheets, rather than the navigation buttons at the top.	2	3				1
I was able to easily navigate around the individual sheets.	2	3				1
The tool doesn't seem too complex or overwhelming.		3	1		1	1
I didn't have to do too many side calculations to provide the required data.	1	2	1	1		1
The pre-filled version of the tool (if used) helped me enter the required data.		1	2	1		2
It took me less than 4 hours to complete an assessment of a scenario	2	2	1			1

Ease of the using the manual

I didn't need to refer to the manual too much, as the tool was self-explanatory.		2		1	2	1
I prefer to have instruction in the tool itself, rather than refer to the manual.	2	2			1	1
The INSTRUCTIONS section of the manual was structured so I could easily find the information I was looking for.		3	1		1	1
The instructions in the INSTRUCTIONS section of the manual were easy to follow.	1	3		1		1
I needed to refer to the METHODS section of the manual to interpret the results.		2			2	2
The METHODS section of the manual was easy to follow.		1	2		1	2

Ease of data entry

I could easily understand the data entry requirements from the instruction in the tool and the user manual.	1	4		1		
I was able to provide all of the required data without too much effort.	2	2		2		
I was able to choose the appropriate items from the drop-down lists.		2	1	2	1	
The values calculated by the tool seemed accurate.	1	1	1		1	2

Interpretation of results

I could understand the graph showing the eco-efficiency results.	1	2	2		1	1
The eco-efficiency categories reported on the graph (fossil fuel use, carbon footprint, water use, water quality) are relevant and meaningful.		2	2	2		
I was able to understand the origins of impacts from the graph.	1	2		2	1	
The breakdown of sources of impacts in the graph did not surprise me greatly.	1		2		1	2
I understand what the eco-efficiency rating means.		3	1		2	
The eco-efficiency rating for the scenario I assessed fell within the scale of the graph.		2	2	1		1
The eco-efficiency rating for the scenario I assessed did not surprise me greatly.			3			3

Usefulness for its intended purpose

understanding the sources of environmental impacts for the scenario assessed	1	4	1			
seeing where environmental impacts can be reduced	1	3	2			
communicating the eco-efficiency of a cane growing scenario		4	2			
comparing the eco-efficiency of different cane growing practices		4	2			
informing decisions about practice change		4	2			
verifying the environmental benefits of progressive / new cane growing practices	1	2	3			

Four (4) out of five (5) evaluators who responded to the question about the time taken to conduct an assessment agreed that it could be done within four (4) hours. It is expected that the final version, which is more streamlined than the test version, will require less time.

Users generally recognised the usefulness of the tool for identifying environmental impacts and opportunities for improvement, and for verifying the environmental performance of different practices. They were less sure about its role in comparing different practices and informing practice change. More guidance about how to use the tool for these purposes was subsequently provided in the instruction manual.

The qualitative feedback received from all eight (8) evaluators (compiled in Attachment 10) provided the details that informed the improvements made to the tool, and the project team were very grateful for this valuable industry input. A summary of the modification that were subsequently made to the tool are summarised on the last page of Attachment 10.

4.2.3. Results evaluation

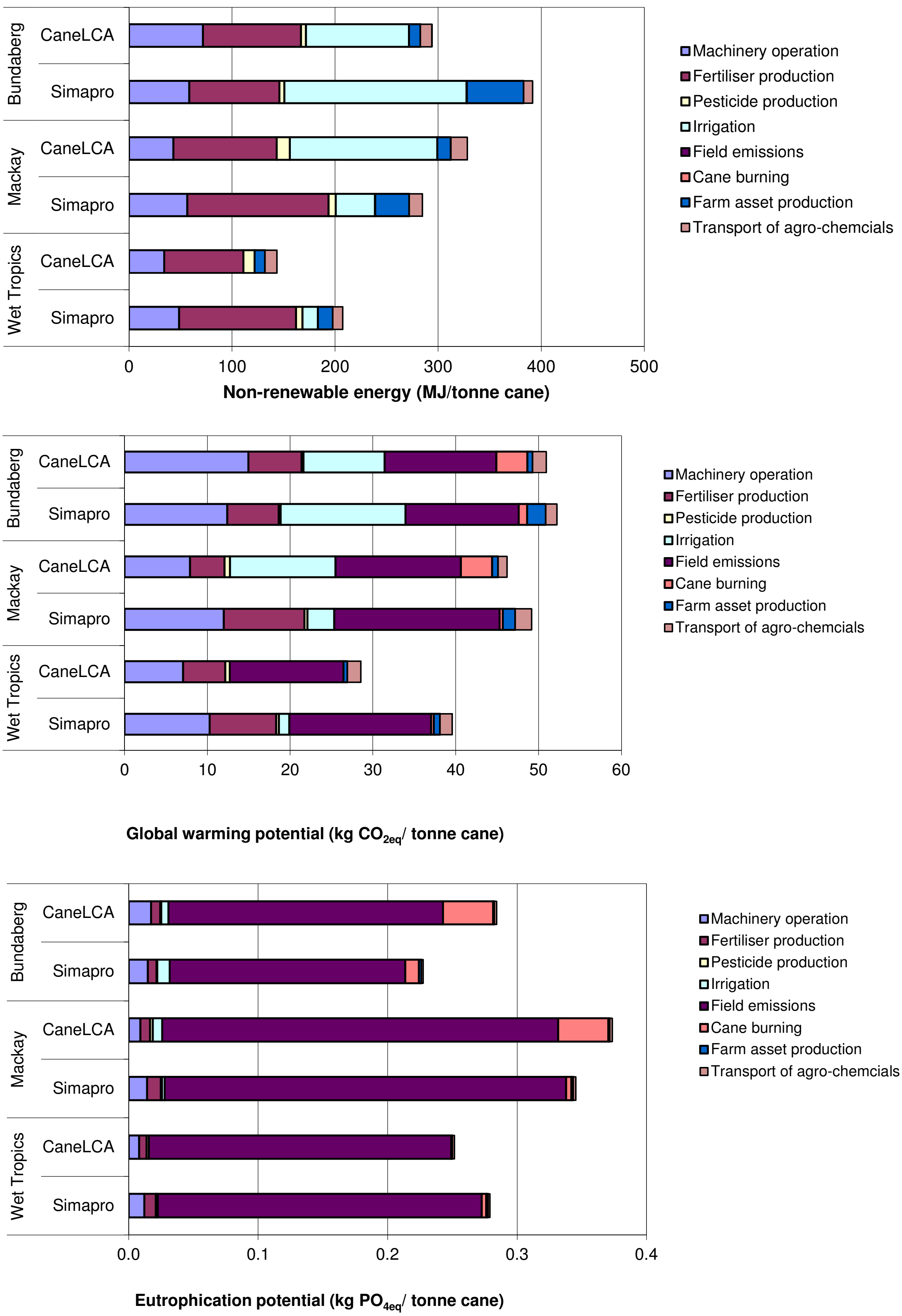
LCA results generated within CaneLCA demonstrate acceptable consistency with those generated by the Simapro LCA software using a life cycle inventory (LCI) data set for Australian sugarcane (**Error! Not a valid bookmark self-reference.**). The total impacts and contributional breakdowns reported by each of the methods are relatively similar, in light of the differences in what is represented.

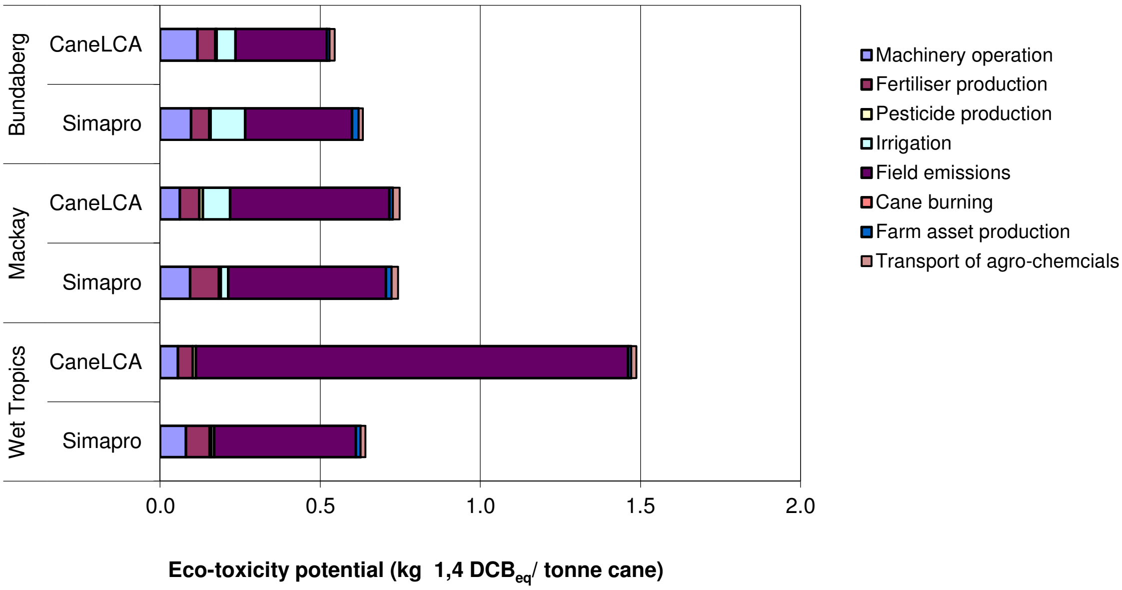
The CaneLCA results represent a single example operation for the regional, whereas the Simapro results represent the average of practices for the region. For example, in the Mackay and Southern cases, cane burning is assumed in the scenario represented in the CaneLCA results, but is represented in the Simapro results for only a fraction of cane on average. Similarly, impacts for irrigation vary considerably depending on how much irrigation is assumed to occur.

This evaluation confirms that:

- the scope of aspects captured by CaneLCA is as comprehensive as that included in a Simapro analysis using the LCI data;
- the breakdown of impacts by source in consistent with that generated by a Simapro analysis using the LCI data;
- the LCA results will be consistent with those generated by a Simapro analysis, as long as the same impact characterisation methods and factors are applied in a Simapro analysis.

Figure 8 Comparing LCA results generated by CaneLCA and Simapro





4.3. Analysis of cane growing practices

CaneLCA was successfully applied to compare the eco-efficiency of progressive and conventional cane growing practices in three regions (Wet Tropics, Central and Southern). The following is a summary of the results, which are described further in the ASSCT paper reporting the work (Attachment 13). The observed changes in eco-efficiency from each regional practice-change scenario are summarised in Table 12.

Both the Wet Tropics and Central scenarios show improved eco-efficiency across all indicators for a transition from C to B practices. The sources of environmental improvements were:

– reduced consumption of fossil fuels associated with lower tractor operation, due to controlled traffic and reduced tillage;

– reduced consumption of fossil fuels and reduced greenhouse-gas emissions for fertilisers and pesticide production, due to lower application rates;

– reduced greenhouse gas emissions due to cessation of pre-harvest burning;

– reduced denitrification of nitrous oxide (N_2O) from lower N application rates; and

– improved water quality from reduced potential for nutrient and pesticide losses due to lower application rates.

Therefore, the results suggest that a transition from C to B practices in these regions, as currently defined by the Reef Rescue ABCD Framework, give environmental benefits with no environmental down-sides. The scale of benefits is higher for the Central scenario than for the Wet Tropics scenario, because the Central scenario involves a higher degree of change than the Wet Tropics scenario, for aspects that significantly influence the results.

Table 12 Changes in eco-efficiency from regional practice change scenarios

			Change in eco-efficiency				
			Fossil energy use	Carbon footprint	Water use	Water quality	
						Eutrophication potential	Eco-toxicity potential
Wet Tropics scenario	Soil work	Tractor operation for soil work					
	Nutrient management	Nitrous oxide N_2O emissions (to air)		↑ -2%			
		Carbon doxide (CO_2) from lime (to air)					
		Nutrient (N&P) emissions (to water)				↑ -3%	
		Production of fertilisers and minerals	↑ -2%				
		Tractor operation for applying nutrients, minerals					
	Pesticide management	Emissions (to water) from pesticide application					↑ -2%
		Production of pesticides					
		Tractor operation for applying pesticides					
	Harvesting	Cane burning emissions (to air)					
		Cane harvester operation					
		Harvester operation for fallow crops					
	Irrigation (and dewatering)	Electricity use for pumping					
		Extraction of water					
	ALL OPERATIONS		↑ **-3%**	↑ **-4%**	0%	↑ **-4%**	↑ **-2%**
Central scenario	Soil work	Tractor operation for soil work	↑ -1%				
	Nutrient management	Nitrous oxide N_2O emissions (to air)		↑ -5%			
		Carbon doxide (CO_2) from lime (to air)					
		Nutrient (N&P) emissions (to water)				↑ -11%	
		Production of fertilisers and minerals	↑ -6%	↑ -3%			
		Tractor / truck operation for applying nutrients					
	Pesticide management	Emissions (to water) from pesticide application					↑ -2%
		Production of pesticides					
		Tractor operation for applying pesticides					
	Harvesting	Cane burning emissions (to air)		↑ -5%			
		Cane harvester operation					
		Harvester operation for fallow crops					
	Irrigation (and dewatering)	Electricity use for pumping					
		Extraction of water					
	ALL OPERATIONS		↑ **-8%**	↑ **-14%**	0%	↑ **-12%**	↑ **-2%**
Southern scenario	Soil work	Tractor operation for soil work	↑ -2%	↑ -1%			
	Nutrient management	Nitrous oxide N_2O emissions (to air)		↓ 3%			
		Carbon doxide (CO_2) from lime (to air)					
		Nutrient (N&P) emissions (to water)					
		Production of fertilisers and minerals	↑ -1%				
		Tractor operation for applying nutrients, minerals	↑ -1%				
	Pesticide management	Emissions (to water) from pesticide application					↓ 22%
		Production of pesticides					
		Tractor operation for applying pesticides	↑ -2%	↑ -1%			
	Harvesting	Cane burning emissions (to air)		↑ -7%			
		Cane harvester operation					
		Harvester operation for fallow crops					
	Irrigation (and dewatering)	Electricity use for pumping	↓ 17%	↓ 18%			
		Extraction of water			↓ 9%		
	ALL OPERATIONS		↓ **12%**	↓ **11%**	↓ **9%**	0%	↓ **22%**

Notes: Only changes greater than 1% are shown to simplify interpretation of the results. So contributing values will not necessarily add up to the total for all operations.

A green 'up' arrow indicates an improved eco-efficiency rating, i.e. reduced environmental impact.

A red 'down' arrow indicates a reduced eco-efficiency rating, i.e. increased environmental impact.

Values are the % change in relative environmental impact. A negative value is a reduced environmental impact.

Only changes greater than 1% are included. Therefore 'all operations' values will not necessarily tally with the total of individual values.

For the Southern scenario, most of the above-mentioned eco-efficiency improvements are also observed. However there is reduced eco-efficiency for the following aspects:

– higher impacts associated with electricity use for irrigation pumping (fossil energy use and greenhouse gas emissions) due to a change from low-pressure flood irrigation to high-pressure overhead irrigation

– higher potential for eco-toxicity from increased herbicide use to compensate for reduced mechanical weed control due to reduced tillage, and greater use of insecticides

– higher emissions of N_2O despite reduced N application rates. This is because the area under cane production in the 'improved' scenario is lower than the 'past' scenario (and hence cane production over the entire farm is lower), and the N_2O emissions are not reduced far enough to result in an overall reduction per tonne of cane produced.

The Southern scenario demonstrates that practice change may result in both environmental benefits and trade-offs. One example is the trade-off between lower fuel use for reduced tillage and higher water quality risk from increase herbicide use required to compensate for less mechanical weed control. Another is the improved water use efficiency of high-pressure overhead irrigation versus the higher electricity impacts that result. The last point also highlights that the eco-efficiency (when measured per tonne of cane) is influenced by cane yields. If progressive cane growing practices result in reduced cane production, say from reductions in the area under cane due to introductions of legume fallow, then the system may become less eco-efficient for some cane-growing aspects.

A range of individual practice changes were also assessed in isolation to identify those with the greatest potential for eco-efficiency improvements (Table 13). The following appear to offer good potential, either because they offer substantial impact reductions for one impact category, or because they offer reasonable impact reductions across a range of categories:

- Reducing nitrogen fertiliser application rates, as long as it is not at the expense of cane yields;
- Reducing nitrous oxide (N_2O) emissions through measures such as denitrification inhibitors and managing soil moisture;
- Increasing the energy efficiency of water pumping for high-pressure irrigation systems;
- Increasing yields without increases inputs;
- Cessation of burnt cane harvesting (where appropriate);
- Use of bio-diesel. However it may come at the expense of water quality, due to the agricultural production required to produce oil seed crops. So the source of biodiesel would need to be checked.

Reducing fuel use through wider row spacing and reduced tillage each appear to offer only modest reductions in energy use and GHG emissions, but when combined could be significant. However the assessment did not considered the possible yield increases from the improved soil health that controlled traffic and reduced tillage offers. In relation to the previously observed trade-off between mechanical and herbicide weed control, a slightly higher energy / carbon footprint may be justifiable given the potentially more significant eco-toxicity risk of herbicide use.

Table 13 Changes in eco-efficiency from individual practice changes

Notes: Values are the % change in relative environmental impact. A negative value is a reduced environmental impact.

	Fossil energy input	Carbon footprint	Water use	Water quality - eutrophication	Water quality – eco-toxicity
Changing row spacing from 1.5 to 1.8m	-1.3%	-2.6%	0.0%	0.0%	0.0%
Reduced tillage	-1.9%	-2.3%	-0.1%	0.0%	-1.8%
Reducing N fertiliser application by 10%, from 1.8kgN/t to 1.6kgN/t	-4.6%	-5.2%	-0.1%	-7.1%	-1.8%
Reducing N_2O emissions from 0.0125 to 0.0025 kgN_2O-N /kg applied N	0.0%	-16.7%	-0.1%	0.0%	0.0%
Green cane harvesting	0.0%	-4.0%	-0.1%	-10.7%	0.0%
Improving energy efficiency of irrigation by 20%	-7.4%	-4.2%	-0.1%	0.0%	0.0%
Use of biodiesel in tractors and harvesters	-9.3%	-22.2%	0.1%	14.3%	-18.2%
Increasing cane yield by 10% with the same inputs	-9.2%	-8.4%	-9.6%	-7.1%	-9.1%

This preliminary analysis has demonstrated how CaneLCA can be used to understand and prioritise environmental improvement opportunities. It has shown that there is definitely potential for environmental benefits from most of the progressive cane growing practices currently being promoted. However, some practice change may have downsides, which need to be considered.

It provides a foundation for future examination of a wider range of practice change scenarios to verify and optimise the eco-efficiency of proposed practice changes. A small number of practice change options and scenarios were considered, but there is considerable scope for evaluating a wider range of options across a wide range of regions. It is recommended that any future investigations should be done in conjunction with farm profitability modelling so the environmental implications can be considered alongside economic considerations.

4.4. Process for accessing the tool

Arrangements for the ongoing distribution of CaneLCA to users are still in development. What follows is a description of the proposed process. In the interim, users can request to receive a copy of the tool by making direct contact Marguerite Renouf (UQ) or Peter Allsopp (BSES).

Access to CaneLCA will be via a licence to use CaneLCA, which is provided free to persons working in a capacity that supports the Australian sugar industry. As the University of Queensland (UQ) owns the IP for CaneLCA, copyright is held by UQ. Hence licences to use CaneLCA will be issued by Uniquest, the consulting and commercialisation arm of UQ.

The distribution of CaneLCA to eligible users will be via a webpage on the Uniquest Licencing Portal (http://uniquestportal.com/CaneLCA/). This portal makes research innovations developed at a range of research institutions available for others to access and evaluate. A draft of the content for this webpage has been developed (Attachment 11).

Interested parties will be able to obtain information about CaneLCA at this webpage, and request to receive a licenced copy of CaneLCA by following the links to a request form. The request form will collect the user's details, confirmation they are working in a capacity that supports the Australian sugar industry, and details about the intended use of CaneLCA. The request form will be submitted to the UQ email account of a project team member (Marguerite Renouf) who will check eligibility in consultation with BSES (Peter Allsopp) if necessary.

If eligible, applicants will receive by email a copy of the CaneLCA Excel workbook and user manual and the terms and conditions of the licence. Applicants' details will be recorded in a user register, which will be used to inform users of updates, and monitor the uses to which the tool is being put. Registered users can request support in the use of CaneLCA and provide feedback to the developers about technical difficulties and the tool's usefulness by contacting Marguerite Renouf (m.renouf@uq.edu.au).

Extension of CaneLCA to the industry, ongoing maintenance, and monitoring of uptake are outside the scope of this project, and hence are not discussed in this report. However the aspects that will need to be reviewed and updated from time to time were identified. Recommendations for aspects that will need to be considered to achieve benefits from this work are provided (in Section 9).

5. DISCUSSION AND CONCLUSIONS

The streamlined LCA tool (CaneLCA) developed by this research fills an identified need for better understanding the environmental impacts of different cane growing practices. The research has demonstrated that CaneLCA can be used by intended users to produce a rapid, accurate and meaningful environmental assessment of cane growing operations, and be applied to test the environmental benefits of transitions towards progressive growing practices.

The features CaneLCA that make it different from over other carbon footprinting tools are that it is specifically customised for sugarcane growing, the data inputs are presented in terms that sugarcane producers understand, it allows the user to easily assess different cane growing scenarios by modifying a wide range of cane growing inputs and outputs.

Preliminary analysis of a general suite of progressive cane growing practices currently being promoted in the industry found that transitions for C- to B-class practices under the ABCD Framework will lead to reduced environmental impacts across all impact categories. Although other practice change scenarios, outside the ABCD Framework, can have environmental side-effects which need to be considered. The research identified a number of priority categories of practice change which can result in significant environmental improvements. However there is considerable scope for more detailed analysis of practice change options, alongside economic analysis so that profitability considerations can also be taken into account.

6. OUTPUTS

A primary output from this project was a software product to support extension activities for promoting sustainable cane growing. However, commensurate with its development, there has also been knowledge and skill development.

Product outputs

> The CaneLCA Eco-efficiency Calculator is a MS Excel-based workbook for calculating life cycle based environmental performance indicators for sugarcane growing in Australia, supported by a user manual.

Knowledge outputs

> The methodologies employed in the tool and their scientific rationales have been documented. As well as helping users interpret the results generated by CaneLCA, it is also a knowledge resource for the broader application of the LCA technique to sugarcane growing.
>
> An analysis undertaken using CaneLCA identified the scale of environmental improvements that could be expected from practice change scenarios currently being promoted in the industry, and

those the offer the greatest potential for reducing impacts. This will help with the development of best environmental management practice by the industry.

Identification of correlations between cane growing practices and environmental impacts is a novel outcome from this research. The tool's ability to model different practices made it possible to examine how different practices influence environmental impacts. This is something that has not been studied to date in agriculture LCA research in Australia or overseas.

Skill outputs

Approximately nine industry extension advisors and researchers became familiar with the life cycle assessment (LCA) technique through their participation in the development or evaluation of the CaneLCA tool. This is a significant increase in the industry's knowledge base related to modern environmental assessment techniques.

Intellectual Property

The project IP generated by this project are all components of the CaneLCA Eco-efficiency Calculator and supporting documentation (user manual and methodology documents). This IP is owned by the University of Queensland (UQ) and is protected by copyright.

Licences to use CaneLCA will be issued by Uniquest, the consulting and commercialisation arm of UQ. Licence terms and conditions are currently being drawn up.

Confidentiality

No information in this report needs to be treated as confidential. Feedback received from industry personnel who evaluated the tool has been reported in a de-identified form in this report, as some participants requested their involvement and feedback to be anonymous. Therefore the names of evaluators who requested to be anonymous are to be treated as confidential indefinitely.

Environmental and Social Impacts

Activities undertaken for this project involved desk-top computer modelling and consultation with industry personnel and stakeholders. There have been no on-farm activities. Consequently, there have been no direct environmental impacts.

There are expected to be indirect environmental benefits from the project outputs. The CaneLCA tool will support future decision making about sustainable cane growing. It may influence a transition towards cane growing practices with lower environmental impacts.

7. OUTCOMES

The development of a streamlined and customised LCA tool for an agricultural sector is a novel initiative and puts the Australian sugar industry on the front foot in relation to understanding the environmental impacts of its operations and for devising improvement strategies.

The tool developed by this project is a rapid, easy to use and low-cost means of generating environmental information about sugarcane growing so the industry can:

- enhance its collaborative understanding of the impacts of sugarcane growing;
- assist the promotion of eco-efficient growing methods to growers; and
- guide the selection of eco-efficient cane growing strategies that improve the resilience of sugarcane cropping systems to a changing climate (an objective of BSES's strategic plan).

Use of the tool will lead to the more informed and strategic identification and adoption of innovative practices at a time when the industry needs to respond to external drivers for change (climate change mitigation and adaption, reef protection, environmental certification schemes). It will also give tangible demonstration to the community that the industry is interested and has the tools to improve its environmental performance. This will help maintains the industry's social licence to operate.

Whether these outcomes are achieved will depend on the extension of the tool into industry.

There may also be cost savings for the industry if and when organisations within the industry are required to generate LCA-based information or data. Examples are participation in the Australian Government's Carbon Farming Initiative (CFI), certification to sustainability standards, customer requests for carbon footprints for sugarcane products, etc. Having LCA capabilities internally avoids the need to engage external consultants often at significant cost.

This project has also built a new collaboration between the industry's extension organisations and UQ's environmental research programs, and amongst researchers within the industry whose work relates to the environmental sustainability of sugarcane growing.

8. FUTURE RESEARCH AND DEVELOPMENT NEEDS

The following aspects were identified during the project as opportunities for enhancing the function of CaneLCA, but which could not be progressed in the project.

- Compatibility with the Farm Economic Assessment Tool (FEAT) so that profitability could be considered alongside environmental consideration to better inform practice change decisions.

- Automatic data feed from farm data management systems (if used) to avoid duplication of data collection and entry.
- Addition of modules to calculate carbon sequestration from increasing soil carbon content, bio-char application, farm forestry, to allow the assessment of these carbon abatement opportunities;
- Addition of functions to enable the reporting of CFI-compliant outputs to enable participation in the Carbon Farming Initiative (CFI);
- Adoption of new water footprinting methods (developed by CSIRO) to provide water stress indicator rather than just consumptive water use indicators.

9. RECOMMENDATIONS

Future work that should be considered to ensure that the anticipated benefits are achieved are:

- An industry extension program for promoting uptake of CaneLCA. Activities within this could include:
  - Demonstration workshops with progressive growers (those participating in Project Catalyst for instance) to kick start a process of engagement.
  - Modelling the environmental profile of a wide range of practice scenarios across all regions to inform the development of best environmental practice.
  - Modelling the life cycle environmental implications of different nitrogen management strategies.
- Monitoring the uptake and applications of CaneLCA to evaluate its effectiveness in informing practice change and bringing about reduced environmental impacts.

10. LIST OF PUBLICATIONS AND COMMUNICATION ACTIVITIES

Peer reviewed papers published in the conference proceedings of the Australian Society of Sugarcane Technologists (ASSCT) (papers provided in Attachment 12 and Attachment 13):

1. Renouf, M.A., Allsopp, P.G., Price, N., Schroeder, B.L. (2013). CaneLCA - a life cycle assessment (LCA) based eco-efficiency calculator for Australian sugarcane growing. Proceedings of the Australian Society of Sugarcane Technologists, 35.
2. Renouf, M.A., Schroeder, B.L. , Price, N., Allsopp, P.G. (2013). Assessing the environmental benefits of practice change using the CaneLCA Eco-efficiency Calculator. Proceedings of the Australian Society of Sugarcane Technologists, 35.

Conference and seminar presentations:

3. Renouf, M.A., Price, N., Allsopp, P.G., Schroeder, B., Hobson, P., Cairns, B. (2012). Making LCA more accessible to the Australian sugarcane industry. 2nd Conference of the New Zealand Life Cycle Assessment Society, 28-29 April, 2012. Auckland.
4. Renouf, M.A. (2012). Life Cycle Assessment (LCA) tool for assessing the environmental benefits of progressive cane growing. SRDC Roadshows, Mackay and Proserpine.
5. Renouf, M.A. (2012). Life cycle assessment and carbon footprinting in the Australian sugar industry. SRDC Seminar, 27 August, 2012. QUT Gardens Point Campus.
6. Renouf, M.A., Price, N., Allsopp, P.G., Schroeder, B. (2012). LCA-based eco-efficiency tool for carbon abatement decision support in sugarcane. Climate Change Research Strategy for Primary Industries (CCRSPI) Conference, 27-29 November, 2012. Melbourne.
7. Renouf, M.A. (2013). Life Cycle Assessment (LCA) tool for assessing the environmental benefits of progressive cane growing. SRDC Roadshows, Ayr and Ingham.
8. Renouf, M.A., Allsopp, P.G., Price, N. (2013). CaneLCA tool to support practice change decision making in sugarcane growing. 8th Conference of the Australian Life Cycle Assessment Society: Pathways to Greening Global Markets, 15-18 July, 2013. Sydney.

Magazine articles:

9. Renouf, M.A., Price, N., Schroeder, B.L. (2012). Industry invests in life cycle assessment. BSES Bulletin. Indooroopilly: BSES Limited. Issue 33, March, 2012, p. 22-24.
10. Anon. (2013). Life cycle assessment on going green. Sugar Researcher. Brisbane: Sugar Research and Development Corporation (SRDC). Edition 2, June, 2013, p. 22 -23.

REFERENCES

BEEHARRY, R. P. 2001. Carbon balance of sugarcane bioenergy systems. *Biomass and Bioenergy,* 20**,** 361-370.

BONSUCRO. 2012. Bonsucro Production Standard. Available: http://www.bonsucro.com/standard/index.html [Accessed 7/12/2012].

BOTHA, T. & VON BLOTTNITZ, H. 2006. A comparison of the environmental benefits of bagasse-derived electricity and fuel ethanol on a life-cycle basis. *Energy Policy,* 34**,** 2654-2661.

BSI 2008. PAS 2050:2008 Specification for the assessment of the life cycle greenhouse gas emissions of goods and services. BSI Standards, UK.

CONTRERAS, A. M. 2009. Comparative Life Cycle Assessment of four alternatives for using by-products of cane sugar production. *Journal of Cleaner Production,* 17**,** 772-779.

EVANS, J. 2010. Reef Rescue Sugar Industry - Broad ABCD for Water Quality Land Management Practice Framework. Internal Canegrowers document.

GHD 2010. Report for Sugar Cane Land Management Practices Baseline Study. A GBR-wide Report August ed. Brisbane: Canegrowers.

GOEDKOOP, M., HEIJUNGS, R., HUIJBREGTS, M. A. J., DE SCHRYVER, A., STRUIJS, J. & VAN ZELM, R. 2009. Recipe 2008. First edition. Report 1: Characterisation. The Netherlands: Dutch Ministry of Housing, Spatial Planning and the Environment.

GROOT, W. J. & BOREN, T. 2010. Life cycle assessment of the manufacture of lactide and PLA biopolymers from sugarcane in Thailand. *International Journal of Life Cycle Assessment,* 15**,** 970-984.

HEIJUNGS, R., GUINEE, J. B., HUPPES, G., LANKREIFER, R. M., UDO DE HAES, H. A., WEGENER SLEESWIFJK, A., ANSEMS, A. M. M., EGGELS, P. G., VAN DUIN, R. & DE GOEDE, H. P. 1992. *Environmental life cycle assessment of products. Vol I: Guide and Vol. II: Backgrounds,* Leiden, Centre for Environmental Studies (CML), Leiden University.

IPCC 1997. Second Assessment Report (SAR). Climate Change 1996. International Panel on Climate Change.

IPCC 2000. Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories. Japan: Intergovernmental Panel on Climate Change/OECD.

ISO 2006a. Environmental management - Life cycle assessment - Principles and framework. ISO 14040:2006.: International Organization for Standardization. Geneva. Switzerland.

ISO 2006b. Greenhouse gas management and related activities. ISO 14064:2006.: International Organization for Standardization. Geneva. Switzerland.

KADAM, K. L. 2002. Environmental benefits on a life cycle basis of using bagasse-derived ethanol as a gasoline oxygenate in India. *Energy Policy,* 30**,** 371-384.

KHATIWADA, D. & SILVEIRA, S. 2011. Greenhouse gas balances of molasses based ethanol in Nepal. *Journal of Cleaner Production,* 19**,** 1471-1485.

LIFE CYCLE STRATEGIES 2012. Australasian Unit Process LCI Library and Methods. 20 July 2012 ed.

LUNDIE, S., HUIJBREGTS, M. A. J., ROWLEY, H. V., MOHR, N. J. & FEITZ, A. 2007. Australian characterisation factors and normalisation figures for human toxicity and ecotoxicity. *Journal of Cleaner Production,* 15**,** 819-832.

LUO, L., VAN DER VOET, E. & HUPPES, G. 2009. Life cycle assessment and life cycle costing of bioethanol from sugarcane in Brazil. *Renewable & Sustainable Energy Reviews,* 13**,** 1613-1619.

MACEDO, I. C., SEABRA, J. E. A. & SILVA, J. E. A. R. 2008. Greenhouse gases emissions in the production and use of ethanol from sugarcane in Brazil: the 2005/2006 averages and a prediction for 2020. *Biomass and Bioenergy,* 32**,** 582-595.

NGUYEN, T. L. T., GHEEWALA, S. H. & SAGISAKA, M. 2010. Greenhouse gas savings potential of sugar cane bio-energy systems. *Journal of Cleaner Production,* 18**,** 412-418.

PENNINGTON, D. W., POTTING, J., FINNVEDEN, G., LINDEIJER, E. W., JOLLIET, O., RYDBERG, T. & REBITZER, G. 2004. Life cycle assessment Part 2: Current impact assessment practice. *Environment International,* 30**,** 721-739.

PRE CONSULTING. nd. About Simapro. Available: http://www.pre-sustainability.com/simapro-lca-software [Accessed 7/12/2012].

RAMJEAWON, T. 2004. Life Cycle Assessment of Cane-sugar on the Island of Mauritius. *International Journal of Life Cycle Assessment,* 9**,** 254-260.
RAMJEAWON, T. 2008. Life cycle assessment of electricity generation from bagasse in Mauritius. *Journal of Cleaner Production,* 16**,** 1727-1734.
REBITZER, G., EKVALL, T., FRISCHKNECHT, R., HUNKELER, D., NORRIS, G., RYDBERG, T., SCHMIDT, W.-P., SUH, S., WEIDEMA, B. P. & PENNINGTON, D. W. 2004. Life cycle assessment. Part 1: Framework, goal and scope definition, inventory analysis and application. *Environment International,* 30**,** 701-720.
REIN, P. W. 2010. The carbon footprint of sugar. *Zucker Industrie / Sugar Industry,* 135**,** 427-434. Available at: http://www.bonsucro.com/thought_leadership/article2.html.
RENOUF, M. A. 2011. *Environmental evaluation of product diversification in sugarcane systems using life cycle assessment: An Australian case study.* Doctor of Philosophy, The University of Queensland.
RENOUF, M. A. & CRUYPENNINCK, H. 2012. Life cycle inventory (LCI) data set for Australian sugarcane (unpublished). Prepared for the Rural Industries Research and Development Corporation (RIRDC) project - "Developing a LCI database for Australian agriculture". *In:* CSIRO, L. C. S. A. (ed.). Australian Life Cycle Inventory (AusLCI) database: Australian Society of Life Cycle Assessment (ALCAS).
RENOUF, M. A., PAGAN, R. J. & WEGENER, M. K. 2011. Life cycle assessment of Australian sugarcane products with a focus on cane processing. *International Journal of Life Cycle Assessment.,* 16**,** 125-137.
RENOUF, M. A., PAGAN, R. J. & WEGENER, M. K. 2013. Bio-production from Australian sugarcane: an environmental investigation of product diversification in an agro-industry. *Journal of Cleaner Production,* 39**,** 87-96.
RENOUF, M. A. & WEGENER, M. K. 2007. Environmental life cycle assessment (LCA) of sugarcane production and processing in Australia. *Proceedings of the Australian Society of Sugar Cane Technologists,* 29**,** 385-400.
RENOUF, M. A., WEGENER, M. K. & PAGAN, R. J. 2010. Life cycle assessment of Australian sugarcane production with a focus on sugarcane growing. *International Journal of Life Cycle Assessment,* 15**,** 927-937.
ROSENBAUM, R. K., BACHMANN, T. M., SWIRSKY GOLD, L., HUIJBREGTS, M. A. J., JOLLIET, O., JURASKE, R., KOEHLER, A., LARSEN, H. F., MACLEOD, M., MARGNI, M., MCKONE, T. E., PAYET, J., SCHUHMACHER, M., VAN DE MEENT, D. & HAUSCHILD, M. Z. 2008. USEtox—the UNEP-SETAC toxicity model: recommended characterisation factors for human toxicity and freshwater ecotoxicity in life cycle impact assessment. *International Journal of Life Cycle Assessment,* DOI 10.1007/s11367-008-0038-4.
SCHROEDER, B. L., CAMERON, T., LINEDALE, A. I. & ALLSOPP, P. G. 2009. Realised value of RD&E in the Australian sugar industry: economic benefits of the changing farming system. *Proceedings of the Australian Society of Sugarcane Technologists,* 31**,** 221-229.
SHAW, M. & SILBURN, D. M. in review. Paddock to Reef Integrated Monitoring, Modelling and Reporting Program, Paddock Scale Modelling Technical Report (unpublished). Brisbane: Queensland Department of Natural Resources and Mines.
UNIVERSITY OF MELBOURNE. 2012. *Greenhouse in agriculture* [Online]. Available: http://www.greenhouse.unimelb.edu.au/Tools.htm [Accessed 7/12/2012.
VAN GRIEKEN, M., E., WEBSTER, A. J., COGGAN, A., THORBURN, P. & BIGGS, J. 2010. Agricultural Management Practices for Water Quality Improvements in the Great Barrier Reef Catchments. A report to the Marine and Tropical Science Research Facility. CSIRO: Water for a Healthy Country National Research Flagship.
VELLA, K. 2008. State-Wide ABCD Framework for Sugar Cane Environmental Management Systems. Alignment of Regional ABCD approaches for practice classifications. . Draft October, 2008 ed.
VELLA, K., SING, N., BASS, D. & REGHENZANI, J. 2009. Wet Tropic Reef Rescue Impact Report 2009. Innisfail.

LIST OF ATTACHMENTS (CONTAINED IN VOLUME 2)