Regional Resource Flow Model: Grain Sector Report

Disclaimer:

The life cycle assessments for wheat are still to be reviewed and thus the results are considered to be in draft form until externally verified

Examining the resource intensity of wheat and other grains in the Western Cape

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Contents page

List of acronyms

AFOLU	Agriculture, Forestry and Other Land Use
ALCAS	Australian Life Cycle Assessment Society
AN	Ammonium Nitrate
ANP	Ammonium Nitrate Phosphate
ARC	South African Agricultural Research Council
AusAgLCI	Australian Agricultural Life Cycle Inventories
CCC	Confronting Climate Change
Combuds	Western Cape Commercial Enterprise Budgets
CSIRO	Australian Commonwealth Scientific and Industrial Research Organisation
DAP	Diammonium Phosphate
DEA	South African Department of Environmental Affairs
DEADP	Western Cape Department of Environmental Affairs and Development Planning
DEDAT	Western Cape Department of Economic Development and Tourism
DOA	Western Cape Department of Agriculture
EDP	Environmental Product Declaration
EEIO	Environmentally Extended Input Output
EU	European Union
FAO	Food and Agricultural Organisation of the United Nations
GDP	Gross Domestic Product
GHG	Greenhouse Gases
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organisation for Standardisation
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
LULUCF	Land Use, Land Use Changes and Forestry
MAP	Monoammonium Phosphate
NSW	New South Wales
RIRDC	Rural Industries Research and Development Corporation
RRFM	Regional Resource Flow Model
SA	South Africa
SSP	Single Super Phosphate
TSP	Triple Super Phosphate
UAN	Urea Ammonium Nitrate
UN	United Nations
USDA	United States Department of Agriculture

List of figures

List of tables

1. Background and aims

Agriculture has come under scrutiny due to concerns related to climate change and water scarcity, both globally and within South Africa (IPCC, 2007; DEADP, 2012). As the Western Cape government seeks ensure the long-term productivity of its agriculture and agro-processing sectors, strategies need to carefully consider the resource intensity of products and sub-sectors and their relative economic opportunities and environmental impacts. This is particularly important to ensure access to global markets, where consumers are increasingly concerned with the sustainability of purchased goods. This is being addressed within the Regional Resource Flow Model (RRFM) project[1].

The goal of the RRFM project is to provide a strategic analysis of the provincial economy and identify possible resource constraints that may limit the competitiveness and resource productivity of key sectors. During the first phase of the project, the carbon and labour intensity of the provincial economy was examined and the importance of the food value chain was highlighted (2013/14). As a result, the second phase examined the agriculture sector in greater detail; specifically focusing on the fruit, grain and animal production sub-sectors (2014/15). The aim is to then focus on agro-processing in the third phase (2015/16) and assess possible trade-offs between environmental impacts and economic benefits.

The purpose of this report is to:

(a) Provide insight into the complexities of examining resource intensity within agriculture, particularly within the grain sector.

(b) Demonstrate the use of life cycle assessments (LCAs) and water footprints to examine the resource intensity (carbon and water) and the potential environmental impacts (global warming, eutrophication and acidification) of grain production in the Western Cape, using wheat as a case study.

(c) Determine the feasibility of this approach to investigate other key commodities and provide benchmarks for products and sectors of the Western Cape.

This report is one of several produced by the RRFM project and is linked to the primary goal for 2014/15: to examine the resource intensity of agricultural sub-sectors in the Western Cape. Other key sectors which were analysed include livestock, dairy, game, wine and other fruit (Pineo, 2015; Janse van Vuuren, 2015a; Janse van Vuuren, 2015b).

[1] For most recently released reports see RRFM webpage on GreenCape's website: http://green-cape.co.za/what-we-do/projects/regional-resource-flow-model/

2. Challenges in assessing resource intensity

Examining the resource intensity of agricultural production systems is highly complex; resource use and productivity are dependent upon the inter-relationship of several economic and agronomic factors which can differ both geographically and temporally. This is especially true for grain production. For example, grain yields vary across the Western Cape, even within homogenous farming areas. This is due in part to physical factors (e.g. soil), environmental factors (e.g. rainfall) and different production systems (e.g. conventional, minimum tillage, conservational, organic, dry land and irrigated).

Analysing the resource intensity is further complicated by the need to consider land use changes for which there is very little data available. Furthermore, grain production usually utilises a crop rotation system which may impact resource requirements and yields. For example, wheat grown after nitrogen-fixing legumes may require less nitrogen fertiliser than wheat grown after other crops or a fallow period. In light of this, the primary goal of the report was to develop potential approaches to understand the resource intensities of key commodities (e.g. wheat) and for the grain sub-sector as a whole.

3. Overview of the analytical approach

There is a great deal of research focused on agriculture by various government departments, academic institutions and NGOs. As a result, the RRFM project utilised the information and analyses from other studies where possible and focused efforts where additional analysis was necessary.

Two types of approaches were used in the RRFM project: a broad top-down approach and a more detailed bottom-up approach. Top-down and bottom-up approaches utilise different strategies to order and process information. Top-down approaches essentially disaggregate a system to gain insight into various sub-systems and base components. Although they provide a broad overview and understanding of a complex system, they often lack detail and require validation. In contrast, bottom-up approaches specify and detail base components and then piece them together to give rise to more complex sub-systems and systems. These strategies can be used to complement one another: for example, the top-down approach can focus efforts within a complex system while the bottom-up approach can be used to validate the top-down estimates and indicate areas of uncertainty in high-level economic analyses.

This report attempts to provide estimates of the carbon intensity the grain sector in the Western Cape using both analytical approaches. Details on the approaches and their results are discussed further in the report, with an outline of the approach shown below in Figure 1.

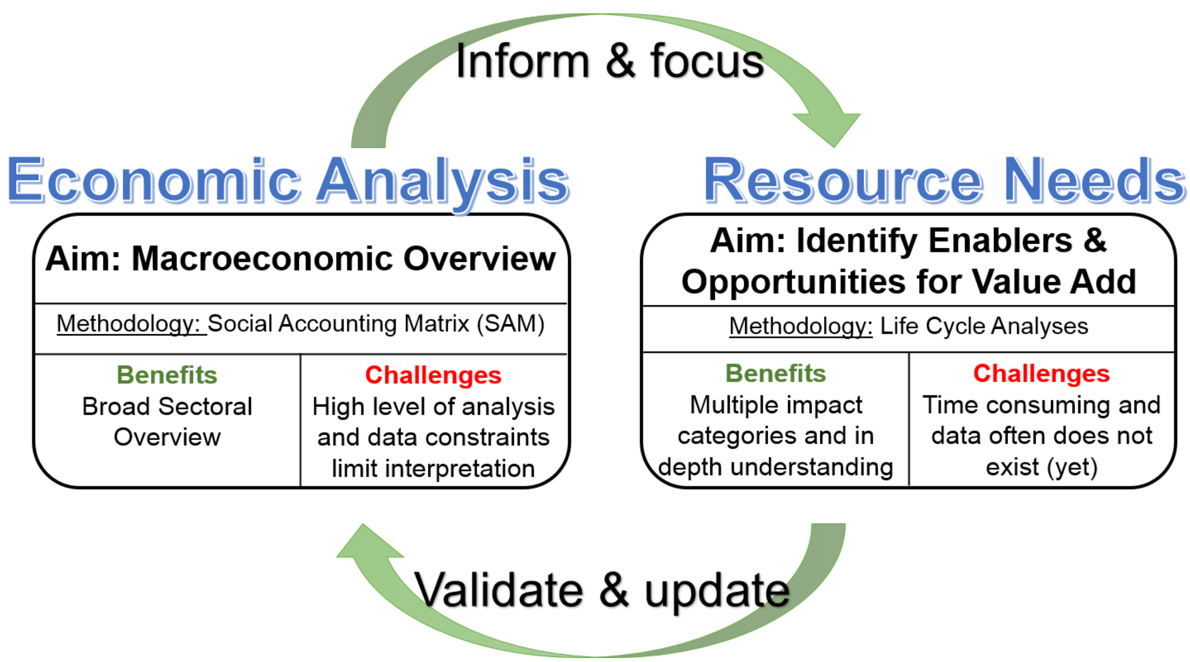

Figure 1: Project overview indicating the complimentary approaches used in the RRFM project.

4. Top-down approach

The top-down approach examined the carbon intensity of the Western Cape economy by assessing greenhouse gas (GHG) emissions per sector. The carbon intensity is particularly important for some export markets where there is a demand for low carbon products (e.g. EU) and an understanding of GHG emissions is fundamental for the development of provincial mitigation strategies. Details of the macro-economic analysis is described in the relevant report (Janse van Vuuren, 2015c).

Current estimates, based on scaling national emissions to the province and then to agricultural sub-sectors using relative financial contributions, indicate that the Western Cape grain sub-sector emits 660 - 1320 Gigagrams (Gg) of carbon dioxide equivalents (CO_2e) per year[2] with the expectation that further work to scale GHG emissions to Western Cape land use will further improve the accuracy of this estimate (work in progress). Details on the approach and the results for the grain sub-sector are provided in Appendix 1.

Capacity and data constraints limit further analysis of the sub-sector as a whole. In theory, carbon footprints could be used to provide carbon intensity estimates for different grains and regions, which could then be weighted by production and aggregated to provide a bottom-up estimate for the grain sector. As Confronting Climate Change (CCC) is in the process of developing a grain-based carbon calculator, which could provide bottom-up estimates for grains in the future as done for the fruit and wine industry (CCC, 2015; Janse van Vuuren, 2015a; Janse van Vuuren, 2015b), the project focused on examining the feasibility of other bottom-up approaches; namely water footprinting and LCAs.

[2] Depending whether estimates for land use and land use changes are included. Land acts as a carbon sink and reduces the net GHG emissions (DEA, 2014).

5. Bottom-up approach

Wheat production was used as a case study for the bottom-up approach. Wheat is a key grain in the Western Cape and encompasses 42 – 47% of Western Cape field crop production and land use (Stats SA, 2011). Estimates of water intensity and total consumption were provided by water footprints, which were previously developed for several wheat production regions across the province (2013/14). The carbon intensity and potential impacts related to grain production were examined using streamlined LCAs. These LCAs were developed for four representative wheat farms in order to consider the potential impacts of wheat production. Details of the approaches are outlined below.

5.1. Water footprints

Water scarcity is a key concern in the Western Cape as water resources are limited and have become increasingly stressed (DEADP, 2012). A series of reports highlighted the large consumption of water in agriculture (Pegasys, 2012) and demonstrated the use of water footprinting to analyse water use within the Western Cape economy.

The water footprint is a comprehensive indicator of freshwater use and examines both the direct and indirect water use of a process, product, consumer, producer or geographic area (Hoekstra et al., 2011). In this study, water footprinting was used to estimate water consumption for irrigated wheat. The water footprint of wheat has been calculated previously in the RRFM project (2013/14) and was used to provide estimates of water intensity for Western Cape wheat and supplement the farming budgets used in the LCA analysis, which is described later in the report. The average water intensity for Western Cape wheat is 802 m^3 water per tonne of wheat when weighted by production, although there is a great deal of regional variation. Details on the methodology, results and limitations of these water footprints are available in Appendix 2.

5.2. Life cycle assessments

Over the last decade there has been a shift within companies, governments and global organisations to examine the environmental impact of products and services across the economy, particularly for primary industries such as agriculture which rely on vulnerable land and water resources. This has resulted in eco-labels, environmental product declarations (EPDs) and delivery agreements, whereby the supplier is required to demonstrate their environmental sustainability and implement on-going programmes to improve their performance. Although this has been driven primarily by global and regional organisations (e.g. UN, IPCC, EU)and developed countries (e.g. USA, Australia and New Zealand), less developed countries such as South Africa have, and will continue to be, impacted due to their role in global supply chains.

Life cycle assessment (LCA) is a technique to assess environmental impacts associated with a product or service through several stages of the product's life. Unlike other methods (e.g. environmental impact assessments), LCAs provide a holistic view of a system, thus identifying opportunities for improvement and ensuring that environmental burdens are not unintentionally transferred from one life cycle stage to another. LCAs typically examine environmental impacts over the complete cradle-to-grave life cycle (e.g. from raw material extraction to processing, manufacture, distribution, use, maintenance and disposal or recycling), although the scope can be reduced to consider smaller portions of the supply chain; for example cradle-to-farm gate, cradle-to-port or cradle-to-consumer.

In this project, agricultural (i.e. cradle-to-farm gate) LCAs were developed to examine the feasibility of the approach for region-based analyses, particularly in light of the importance of agriculture and agricultural products to the provincial economy.

5.2.1. Outline of methodology

The general procedures, requirements and terminology of LCA are defined in the international standards on LCA ISO 14040 and 14044 (ISO, 2006a-b). Good insights on the uses and limitations of LCA are described in many publications (for example: Curran, 2006; Curran, 2012). LCAs are composed of four phases as shown in Figure 2: goal and scope, inventory analysis, impact assessment and interpretation. A brief overview of these phases is provided below, with details provided in the LCA methodology report (pending external review).

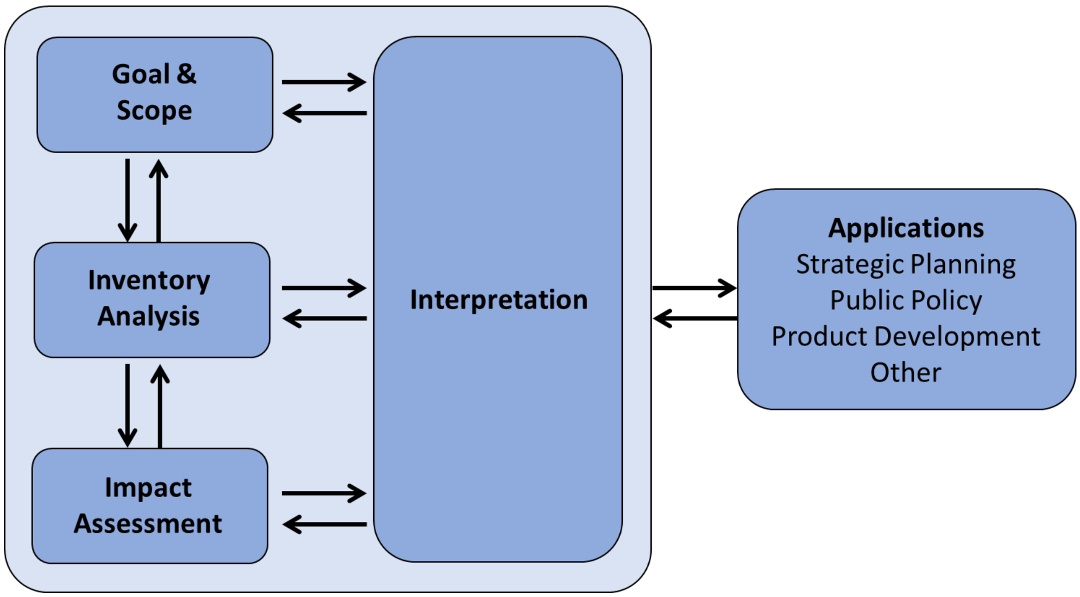

Figure 2: The four phases of life cycle assessment and their applications (ISO, 2006)

5.2.2. Goal and scope

The goal of the study was to develop cradle-to-farm gate LCAs for wheat in the Western Cape, using four representative farms in the West Coast district as case studies. This was done to determine: (a) the feasibility of using LCAs for regional analyses, e.g. the availability and quality of data; and (b) the application of LCAs to inform decisions, e.g. to understand the potential environmental impacts of wheat production and determine if different production systems and farming practises are associated with lower environmental impacts.

Two LCA stages were considered: (a) the “pre-farm” stage which examines indirect impacts, e.g. impacts related to production of fertilisers and transport of inputs to the farm; and (b) the “on-farm” stage which examined direct impacts, e.g. impacts related to emissions from fertiliser use and electricity consumption.

The functional unit is central to a LCA and is used to quantify the performance of a system relative to a reference unit. Wheat production is primarily measured on the basis of tonnage production so the functional unit for the study was one tonne of wheat. However, the potential impacts per hectare of planted wheat was also considered in this study, as a comparative LCA of Western Cape and Flemish pork production recommended that spatial factors be taken into account when assessing the competitiveness of Western Cape production chains (Devers et al., 2012), particularly for regional and local environmental impacts (e.g. eutrophication and acidification).

5.2.3. Inventory analysis

5.2.3.1. Motivation for region-specific inventories

Life cycle inventories (LCIs) specify the inputs, outputs and emissions associated with each stage of the life cycle and provide the underlying data for a LCA. Developing regional LCIs for agricultural products is essential when examining the environmental impacts related to food and fibre production, as differences in management systems, climate, soils and vegetation can significantly affect LCA results (Grant, 2014).

At present, South Africa largely relies on overseas LCI data when undertaking LCAs, thus generating results which may not be representative of local conditions, particularly within primary sectors such as agriculture. Region-specific agricultural LCIs have been developed by other countries (e.g. USA, Australia), primarily as a means to support their primary producers and examine supply chains (USDA LCA Commons, 2015; AusAgLCI, 2015).

For example, Australia has developed regional LCIs for cotton, grains, horticulture, livestock feeds and sugar through the Australian Agricultural LCI (AusAgLCI) project; a collaborative effort between the Australian LCA Society (ALCAS), the Rural Industries Research and Development Corporation (RIRDC), the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and other agricultural industry associations and corporations. These inventories will be updated and extended to give national coverage for all major agriculture products and they are publically available, locally relevant and standardised, providing important underlying data for environmental assessments (ALCAS, 2013; AusAgLCI, 2015).

This project was initiated in recognition that the development of regional LCIs has several strategic benefits (ALCAS, 2013; Grant, 2014). These benefits include:

Supporting agri-businesses and industries:

LCAs can identify and drive improvements in production by providing a better understanding of the inefficiencies and impacts related to farming systems.

Enabling local producers to gain access to international markets:

Inventories provide the environmental impact data required to access markets with strong environmental directives governing their operation (e.g. EU and Japan).

Ensuring that Australian primary producers can easily and objectively demonstrate that their products are being produced in a responsible manner:

Businesses are able to provide reliable carbon footprints and make sound environmental claims (e.g. carbon neutral) based on credible data that is Australian-specific, relevant and representative of Australian farming systems. Furthermore, having a centralised source of data can assist research organisations and industry bodies in terms of the time and money required to collect data and conduct LCAs.

Provides intensity and impact benchmarks for key commodities and sub-sectors:

Robust and scientific benchmarks can be used to implement mitigation drivers (e.g. carbon taxes) and evaluate the long-term effectiveness of mitigation strategies.

Thus, given the drive to develop the green economy, the economic importance of agriculture and the focus on promoting agro-processing, the development of regional LCIs may be of significant interest to provincial government and to agri-related industries.

5.2.3.2. Data collection

Commercial enterprise budgets (Combuds)

For the feasibility study, input data was primarily sourced from commercial enterprise budgets (Combuds) produced by the Western Cape Department of Agriculture (DOA). The Combuds are ideally suited for regional analyses as they are based on representative farms, are publically available and provide a partial mass balance for the production of crops. Furthermore, the Combuds are comparable to the Australian regional gross margin budgets (NSW Department of Primary Industries, 2015a), which was one of the primary sources used to develop the AusAgLCIs. Examples of a New South Wales (Australian) and Western Cape regional wheat budget are shown in Appendix 3 for comparative purposes.

It's important to note that although the Combuds were successfully used to develop LCIs, there are issues regarding data consistency, transparency and detail. This is discussed further in Appendix 3 and recommendations have been provided for the improvement of Combuds in terms of informing LCI development.

Wheat budgets

As the primary aim was to examine the feasibility of a LCA-based approach, the project selected a limited number of wheat budgets for the LCA study. Budgets developed for 2007 were used for the wheat analysis, as this was the baseline year used in the provincial economic analysis (Janse van Vuuren, 2015c).

In comparison to other agricultural products, wheat was well-represented in the available Combuds, primarily due to its importance within agriculture and the complexity of grain production systems. For example, there were thirty-four wheat budgets and only a single budget for various horticultural products (e.g. carrots). Furthermore, the wheat Combuds represented a number of regions within the Western Cape (e.g. Swartland, Overberg, South Coast and the Cape Winelands) and different production systems (e.g. dry land, irrigated, conventional, minimum tillage and organic). As the majority of Western Cape wheat is currently produced by dry land (rain-fed) production systems (93%; Stats SA, 2011), there was interest in examining differences between: (a) dry land wheat farms using different farming practices; and (b) dry land and irrigated wheat farms, with respect to carbon intensity and impacts.

Four wheat Combuds were used for the feasibility study, all located within the West Coast district. These comprised of three Swartland-based Combuds that utilized dry land production (with differing rotation systems and farming practices) and one North West-based Combud that utilized irrigated production. Taking this into consideration, the study covers an estimated 53 - 56% of wheat production in West Coast district and 27 - 35% of wheat production in the province, in terms of total planted area and tonnages produced (Stats SA, 2011; DOA, 2013). A summary of the analysed Combuds is shown in

Table 1, with details available in the LCA methodology report (to be reviewed).

Table 1: Summary of the wheat commercial enterprise budgets used for the LCA analysis

Wheat LCA	Dry_Conventional_1	Dry_Conventional_2	Dry_Min_Till	Irrigated
Combud no.	ADMIN873 1/1/1/1/373	ADMIN875 1/1/1/1/372	ADMIN876 1/1/1/1/416	ADMIN909 1/1/1/1/1374
Area	Middle Swartland (Moorreesburg)	Middle Swartland (Moorreesburg)	Middle Swartland (Moorreesburg)	North West (Clanwilliam)
Production	Dry land	Dry land	Dry land	Irrigated
Tillage	Conventional	Conventional	Minimum tillage	Conventional*
Rotation	Wheat after medic	Wheat after fallow	Wheat after canola	Unknown
Other information	-	Budget includes cost of fallow period	-	Centre pivot irrigation
Seed (kg/ha)	0.12	0.12	0.11	0.16
Fertiliser and lime (t/ha)	0.20	0.25	0.31	2.10
Nitrogen** (kg N/ha)	28	28	30	97
Fuel*** (L/ha)	71	98	31	63
Yield (t/ha)	2.5	2.2	3.0	4.0

*Advised to assume conventional production by Dr Johan Strass (DOA)
**Louis Coetzee (Agricultural Economist, Kaap Agri): Verified Combud estimates for nitrogen fertiliser inputs. Approximately 25 kg N fertiliser applied per ha on a Middle Swartland wheat farm (dry land).
***Assume majority of fuel is diesel. Estimated diesel consumption based on Combud fuel costs and the price of diesel in 2007. For the Dry_Min_Till budget: Total fuel use is approximately 31 L/ha. Combud fuel estimate was 28 L/ha but excluded fuel consumption from contracted lime spreading and aerospraying of crops. Included fuel estimates obtained from DOA (0.4 L/ha for fertilisation processes) and contractors (2.6 L/ha for aerospraying).

5.2.3.3. Structure of the inventory

The inventory step consists of identifying the flows into or out of a product system, including the flows to, or from, nature. These "inventory flows" have to be conducted for each stage of the life cycle and include inputs such as water, energy and raw materials, as well as emissions to air, soil, and water. A schematic overview of the inputs and emissions included in the wheat LCAs is shown in Figure 3.

The inputs included chemicals (synthetic fertilisers, pesticides and herbicides), energy (diesel and electricity) and water (for irrigated wheat) and the emissions specifically included those related to fertiliser use and fuel combustion. Additional details on the structure of the inventory is provided in Appendix 4.

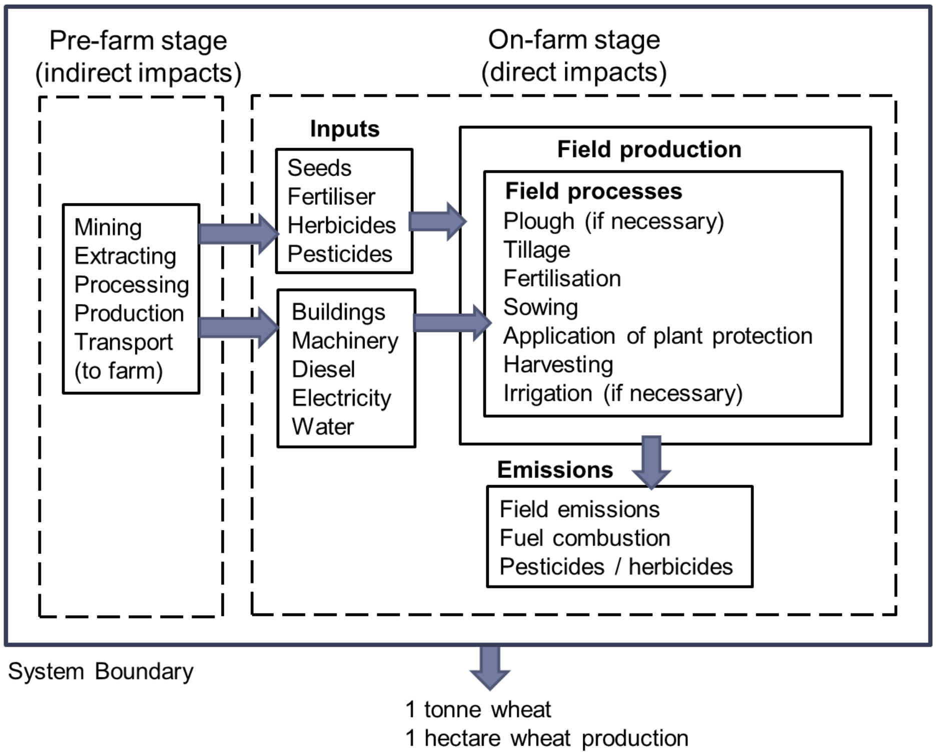

Figure 3: Schematic diagram of the stages, processes, materials, inputs and emissions included in the wheat LCA, as well as the functional units of the study (impacts expressed per tonne or per hectare of wheat)

5.2.4. Impact assessment

Although insights can be gained from simply examining the LCI data (e.g. in terms of total resource consumption), LCIA establishes links between the material inputs, processes and products and their potential environmental impacts, thus providing a more meaningful basis to make comparisons within and between life cycle stages. In simplistic terms, this is done by converting the materials and emissions into equivalent units using scientifically-based characterisation factors. For example, nitrous oxide, methane and carbon dioxide emissions associated with individual materials, processes and products are converted to carbon dioxide equivalent units (CO_2e) based on their global warming potential, which is a scale by which the potential to warm the atmosphere is expressed relative to carbon dioxide. This allows for comparison within and between life cycle stages with respect to their total carbon intensity and their impact on climate change.

LCIA consists of the following mandatory elements:

(a) Selection of impact categories, category indicators, and characterization models.

(b) The classification stage, where the inventory parameters are sorted and assigned to specific impact categories.

(c) Impact measurement, where the categorized LCI flows are characterized, using one of many possible LCIA methodologies (in this case ReCiPe was used), into common equivalence units that are then summed to provide an overall impact category total.

This was all done within the software Umberto NXT Universal (ifu Hamburg GmbH, 2015) with no normalization or weighting of different impact categories. Further details are provided in the LCA methodology report (pending review).

5.2.4.1. Impact categories

In this study, the important impact categories are climate change (which is measured in terms of CO_2e and thus is a measure of the total carbon intensity), terrestrial acidification, freshwater eutrophication and depletion of water resources. Where possible, inputs shown to be major contributors to these indicators were supplied using local data. A brief description of the impact categories is available in Appendix 5.

5.2.4.2. Results

The results are described below and have three focus areas: (a) comparing the total impacts between the four wheat LCAs; (b) examining the major contributing activities to climate change; and (c) benchmarking the carbon intensity of Western Cape wheat relative to other countries.

Comparative LCAs

Results for the selected impact categories are shown in Table 2 with impacts expressed per tonne or per hectare of wheat. For all impacts except eutrophication, dry land wheat produced using minimum tillage practises had the lowest impacts, followed by dry land wheat produced using conventional practises and the irrigated wheat.

Table 2: Potential impacts of Western Cape wheat production, expressed per tonne and per hectare. Impacts are provided in equivalent units to allow for direct comparisons across production systems.

Potential impact	Functional unit	Wheat LCA		
		Dry land Minimum tillage	Dry land Conventional*	Irrigated
Climate change (kg CO_2 equivalents)	Per tonne	330	420 – 550	2340
	Per hectare	990	1050 – 1210	9360
Terrestrial acidification (kg SO_2 equivalents)	Per tonne	2.0	2.4 - 3.1	19.3
	Per hectare	6.0	6.0 - 6.9	77
Freshwater eutrophication (kg P equivalents)	Per tonne	0.6	0.8 - 0.9	0.5
	Per hectare	1.9	2.0 - 2.1	2.1
Water depletion (m^3)	Per tonne	0.23	0.53 - 0.84	515**
	Per hectare	0.65	1.26 - 1.75	1953***

*Results for the two similar wheat LCAs were expressed as a range
** Sum of wheat irrigation consumption (510 m^3/t) + water depletion from pre-farm stage (4.63 m^3/t)
***Sum of wheat irrigation consumption (1940 m^3/t) + water depletion from pre-farm stage (13.15 m^3/t)

The difference between dry land practises was relatively small in comparison to the differences between dry land and irrigated wheat production. For dry land production, the impacts associated with conventional practises were 0 – 40% higher for climate change, acidification and eutrophication and 50 - 70% higher for water depletion (per tonne and per hectare of wheat) when compared to minimum tillage practises. However the impacts associated with irrigated wheat were 330 - 850% higher in terms of climate change, 520 – 1180% higher for acidification and >60,000% higher in terms of water depletion (per tonne and per hectare of wheat) when compared to dry land wheat production.

For eutrophication, impacts are similar across all production systems when measured per hectare (1.9 - 2.1 kg P equivalents), however irrigated wheat is associated with 20 – 40% lower eutrophication impacts when expressed per tonne wheat due to higher yields within this system. This demonstrates the importance of increasing productivity in order to improve resource efficiency and reduce the relative impact of production. The relative differences between the impacts associated with dry land and irrigated wheat production is shown in Appendix 6 where results for each impact category have been normalised by the irrigated wheat impacts.

Major contributing activities to the carbon intensity of wheat

The impact assessment also provides an indication of the major contributing activities for various impacts. Figure 4 shows the contributing activities for climate change and indicate which activities are indirect (pre-farm) and direct (on-farm). This can provide direction to primary producers and assist in the identification of potential interventions to reduce the carbon intensity of wheat. Similar results for terrestrial acidification and freshwater eutrophication are shown in Appendix 6.

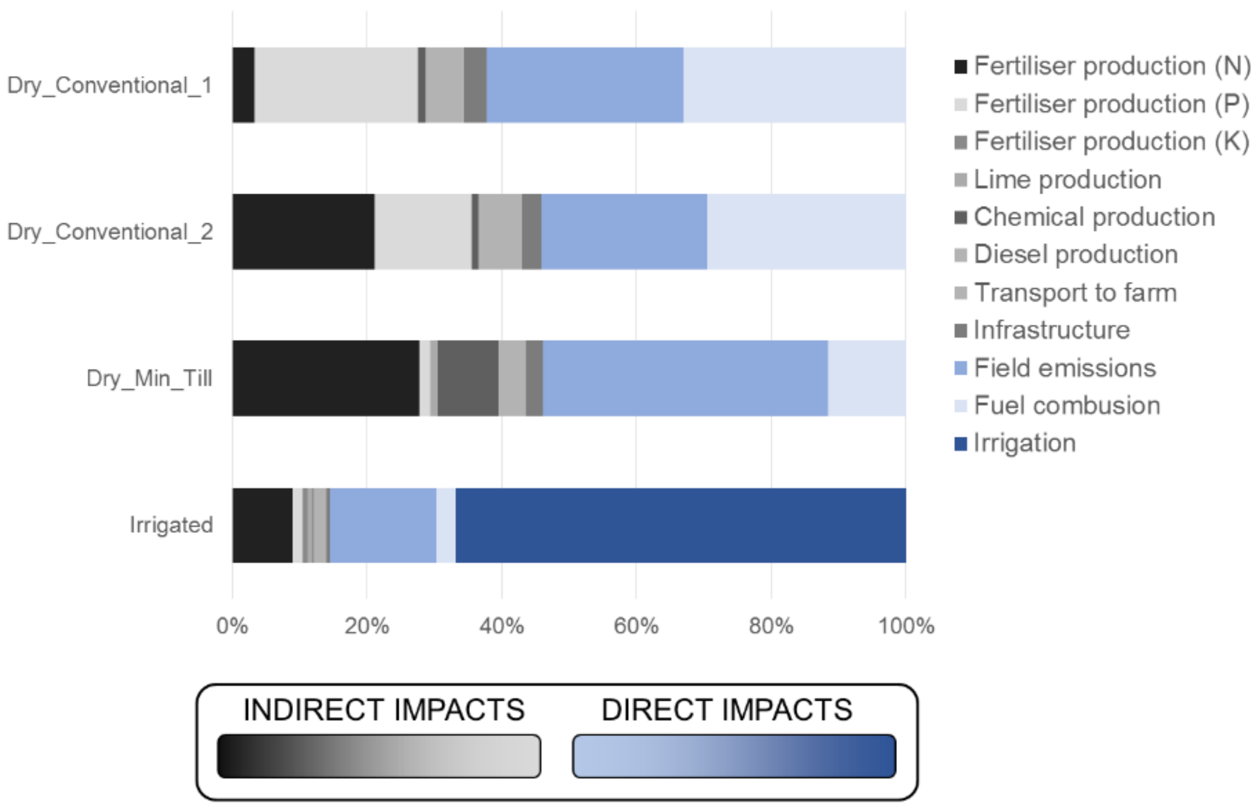

Figure 4: Activity contributions (%) to the total climate change impact associated with wheat production.

As shown in Figure 4, the carbon intensity of irrigated wheat is dominated by direct on-farm impacts (86%), with the major contributor being electricity use for irrigation (67%). For dry land wheat production, 54 – 62% of climate change is related to direct on-farm activities, with variation between conventional and minimum tillage systems indicated by a difference in proportional contributions from fuel combustion (e.g. from the use of tractors, etc. for on-farm activities such as sowing) and field emissions (i.e. GHG emissions from lime and fertiliser use). Specifically for minimum tillage systems, 42% of the total impact was from field emissions and only 12% from fuel combustion. For conventional wheat systems 25 - 29% were contributed from field emissions and 30 – 33% from fuel combustion. Within the indirect pre-farm impacts, the major contributor is fertiliser production, which is responsible for 27 - 35% of climate change impacts for dry land wheat and 11% of climate change impacts for irrigated wheat.

Benchmarking the carbon intensity of wheat

A goal of the LCA study was to provide an indication of the total carbon intensity of wheat produced in the Western Cape. The carbon intensity of dry land and irrigated wheat in the Western Cape (provided by the LCAs) has been benchmarked against intensities reported for wheat produced in other countries, however it should be noted that directly comparing carbon footprints and LCAs is challenging due to differences in scope and methodology. Details are shown in Table 4.

Based on the representative wheat LCAs from Middle Swartland and Clanwilliam, the carbon intensity is 330 – 550 kg CO_2e per tonne of dry land wheat and 2340 kg CO_2e per tonne of irrigated wheat. This falls within the range reported globally: 270 – 790 kg CO_2e per tonne of dry land wheat and 1070 - 4590 kg CO_2e per tonne of irrigated wheat. Furthermore the carbon intensities are comparable to countries with a similar climate (e.g. Western Australia; Biswas et al., 2008).

Table 3: Global benchmarks for the carbon intensity of wheat production

Wheat production	Practise	Area	Source	Yields (t/ha)	Climate change (kg CO_2e)	
					Per hectare	Per tonne
Dry land (rain-fed)	Conventional	Western Cape, South Africa	This study	2.2 - 2.5	1050 - 1210	420 - 550
		Chile	Huerta et al., 2012	4.5	-	790
		Denmark	Nielsen et al., 2003 (LCA food database)	-	-	700 - 710
		France	Laratte et al., 2014	-	-	<500
		USA	Meisterling et al., 2009	2.8	-	280
	Minimum tillage	Western Cape, South Africa	This study	3.0	990	330
		Western Australia	Biswas et al., 2008	2.7	730	270
	Conservational	Victoria, Australia	Biswas et al., 2010	6.2	1670*	270*
	Mixed	Ontario, Canada	Ho, 2011	3.5	1980	570
		New Zealand	Barber et al., 2011	8.8	2820	340
Irrigated	Conventional	Western Cape, South Africa	This study	4.0	9360	2340
		Esfahan, Iran**	Khoshnevisan et al., 2013	3.6***	3860 - 16520	1070 – 4590

*Excluding methane emissions from sheep.
**Range encompasses results for small, medium and large wheat farms (Khoshnevisan, 2013).
***Not stated in the LCA study (Khoshnevisan, 2013). Assume 3.6 t/ha irrigated wheat based on reported yields for the Esfahan province (Ghadiryanfar, 2009).

5.2.5. Interpretation

The interpretation step of an LCA includes: (a) assessing the limitations of the study by evaluating the LCI and LCIA in terms of its completeness, sensitivity and consistency; and (b) providing conclusions and recommendations based on a clear understanding of how the LCA was conducted and the results were developed.

5.2.5.1. Limitations of the study

The results of a LCA study can be affected by several sources of uncertainty, mainly due to the methodological choices, the initial assumptions[3] and the quality of the available data. As a result, a key part of the interpretation phase is to determine the level of confidence in the final results so that they can be communicated in a fair and accurate manner. This is assessed using a sensitivity analysis.

Sensitivity analysis

A sensitivity analysis is a systematic procedure to estimate the effect of the chosen data and assumptions on the outcome of a study. It can be used to identify crucial data which has a significant impact on the results (and thus must be accurately investigated) and to simplify data collection and analysis without compromising the robustness of a result.

As this was a feasibility study, the emphasis was on identifying the important underlying data and assessing whether the quality of the data available in the Combuds was sufficient. Thus, the sensitivity analysis was used to test the assumptions made in the absence of detailed or transparent data available in the Combuds (see Appendix 3) and to provide evidence of the accuracy required for key parameters.

Targeted parameters

Within the wheat LCAs, the largest contributors to climate change and the other impacts are the indirect emissions from the production of fertiliser and the direct emissions from fertiliser use and fuel combustion, as well as emissions from electricity for irrigated wheat (Figure 4). Due to data limitations in the Combuds, several assumptions were made regarding fertiliser sources and the irrigation efficiency. As a result, the impact of these assumptions on the accuracy of the results was assessed.

Fertiliser source

The fertiliser source is important for LCAs; it effects the indirect impacts associated with fertiliser production and effects the direct impacts associated with fertiliser use. For nitrogen fertiliser, it was assumed that ammonium nitrate (AN) was the primary source for providing nitrogen. For phosphate fertiliser, it was assumed super phosphate was the primary source for providing phosphate[4]. This was based on an analysis of fertiliser components and input from Sasol and Omnia, companies which provide fertiliser and encompass a significant share of the fertiliser market in South Africa (Grain SA, 2011).

The influence of the assumed sources for the nitrogen and phosphate fertilisers can be tested by varying the source and examining the magnitude difference in impacts. In the sensitivity analysis, various alternative scenarios included:

(a) Straightforward substitutions; i.e. substituting single super phosphate (SSP) for triple super phosphate (TSP) and substituting urea ammonium nitrate (UAN) for ammonium nitrate (AN).

[3] Assumptions relating to allocation rules, system boundaries and impact assessment methods

[4] As triple super phosphate is associated with greater potential environmental impacts than single super phosphate, it was selected for the baseline analysis to prevent underestimation of impacts.

(b) More complex substitutions using sources that provide both phosphate and nitrogen; i.e. substituting the phosphate input with ammonium nitrogen phosphate (ANP), monoammonium phosphate (MAP) and diammonium phosphate (DAP) and then supplementing their nitrogen inputs with AN.

Irrigation efficiency

Assumptions regarding the irrigation efficiency were also tested as electricity use for irrigation was also a key contributor to several impacts. Although the pump efficiency had been provided by the Combuds (70%), the motor efficiency was not stated and thus was estimated to be similar to that on Australian farms (65%; Grant, 2014). This may have been underestimated and the impact of an increased motor efficiency was analysed (95%).

Results

The results from the sensitivity analysis are shown in Table 4 and clearly indicate that the source of nitrogen and phosphate in fertilisers is a key parameter for measuring potential impacts, particularly for climate change and acidification. In particular, impacts related to the use of UAN are significantly higher for acidification and climate change, suggesting that nitrogen supplied by urea-based sources should be clearly distinguished in the LCIs. Furthermore, parameters relating to electricity consumption are important and have a significant effect on all the evaluated impacts. Thus the sensitivity analysis emphasises the need for additional detail and transparency within the Combuds if they are to be utilised for regional assessments of environmental impact.

Table 4: Results for the wheat LCA sensitivity analysis

Wheat LCA	Input	Description*	Sensitivity analysis**		
			Climate change (carbon intensity)	Terrestrial acidification	Freshwater eutrophication
Dry land Conventional	Phosphate fertiliser	Baseline: TSP Scenario: SSP	- 6%	- 14%	- 4%
Dry land Minimum tillage	Phosphate and nitrogen fertiliser	Baseline: TSP + AN Scenario: TSP + UAN Scenario: ANP + AN Scenario: MAP + AN Scenario: DAP + AN	UAN: - 9% Other: - 6 to -8%	UAN: + 90% ANP: - 13% MAP: - 5% DAP: + 2%	< - 1%
Irrigated Conventional	Irrigation motor efficiency	Baseline: 65% Scenario: 95%	- 20%	- 27%	- 8%

*TSP: Triple super phosphate, SSP: Single super phosphate, AN: Ammonium nitrate, UAN: Urea ammonium nitrate, ANP: Ammonium nitrogen phosphate, MAP: Monoammonium phosphate, DAP: Diammonium phosphate
**Impact on water depletion was not included (minimal)

Despite the sensitivity of the results with respect to fertiliser source and irrigation efficiencies, the assumptions made in consultation with DOA and industry experts were believed to be accurate for the wheat LCAs. As a result, the sensitivity analysis was used to demonstrate the importance of the parameters and is not indicative of inaccuracies in the LCAs.

5.2.5.2. Conclusions and recommendations

The study has several conclusions and recommendations with respect to the goal and scope of the LCAs. They are specifically focused on: (a) the feasibility of this approach for regional analyses; (b) providing an indication of the potential impacts of wheat production and whether they differ according to different production systems and farming practises; and (c) to provide areas for potential intervention.

Feasibility of using Combuds for LCAs

The feasibility study suggests it is possible to use Combuds to develop representative LCIs and inform LCA-based regional analyses. However, due to the lack of detail and transparency of the Combud information, significant time and several assumptions are required to create LCIs, some of which have a potentially large impact on the accuracy of the LCIA results (as shown in Table 4). As a result, this project has provided several recommendations for Combud development with respect to assisting with environmental impact-based analyses. These are described in detail in Appendix 3.

Potential impacts of wheat production

High level comparison of production systems and farming practises

When comparing different farming practises and production systems, there are three key observations: (a) there is generally a significant difference between irrigated and dry land wheat production, with dry land systems associated with a lower environmental impact than irrigated systems, particularly when utilising minimum tillage practises; (b) the reduced impact of dry land production is primarily due to the water and electricity required for irrigation; and (c) eutrophication is similar across systems per hectare of planted wheat, however irrigated wheat has a lower eutrophication impact when expressed per tonne of wheat.

This indicates that the water and energy intensity (and the potential impacts) differ across different production systems and farming practises. Also, as shown by eutrophication, the productivity of the farm (i.e. wheat yield) has a large impact on the relative impact of wheat production suggesting that efforts to improve productivity may also reduce the environmental burden. Given the significant potential impact of irrigated production, efforts to improve the yields of dry land wheat production may be more beneficial than simply increasing the amount of wheat produced under irrigation.

Detailed analysis of the major contributing processes

Across all the production systems and farming practises assessed in the feasibility study, fertiliser and fuel use were highlighted as significant contributors to the impact of wheat production. Given these results, there are several possible areas for intervention.

Increase fertiliser efficiency and examine alternative fertiliser sources

Farmers have limited control on indirect pre-farm impacts (e.g. GHG emissions associated with fertiliser production). As a result, interventions are limited to increasing fertiliser efficiency (and thus reducing consumption) or changing the fertiliser source; e.g. using ammonium-based fertilisers rather than urea. This would also have a significant effect on on-farm impacts of wheat production, as the quantity of applied fertiliser and the nutrient source are primarily responsible for field GHG emissions.

Increase fuel efficiency

In terms of the GHG emissions from fuel combustion, improvements in fuel efficiency may reduce the carbon intensity of wheat and possibly reduce production costs. Furthermore, changes in farming practises from conventional to minimum tillage (or even no tillage or conservational) may reduce fuel usage, and thus GHG emissions, due to the exclusion of additional farming activities (i.e. ploughing and tilling), in addition to other benefits such as improved soil structure, nutrient availability, etc.

Increase water efficiency

Increasing water efficiency in agriculture is clearly a priority given concerns regarding water scarcity in the Western Cape. Although irrigated production clearly uses significantly more water than dry land production, an important issue to address is whether the areas producing wheat under irrigation are experiencing water stress. This is discussed in greater detail below.

Assessing water consumption relative to water scarcity

As traditional LCAs do not consider water consumption in significant detail and measure the impacts in limited ways, the project recommends that additional methodologies are used for regional analyses. The water footprint methodology supplied by the Water Footprinting Network (Hoekstra et al., 2011) provides a better picture of the water intensity of crop production, indicating both the total water intensity and providing an indication of regional variation (described in detail in Appendix 2).

Further work which may add value to regional water analyses

Although water footprints can provide an appropriate indication of regional variation, it is recommended that the analyses is improved by: (a) providing average water footprints per region over a significant period of time rather than a snapshot view for a single year; and (b) adding a measure of water scarcity to the regional analysis (e.g. weighting results based on a water scarcity index for different water catchment areas), thus indicating possible “hotspots” where water scarcity may become an issue for wheat production. Furthermore, the crop water requirements for fruits are assessed through Fruitlook (a DOA initiative). Although the coverage of the Western Cape is still low, with increased coverage the software could possibly be used to provide an understanding of water demand for irrigation and the water intensity of different fruits. It is envisioned that the project examines this in the future in collaboration with DOA.

6. Consolidation of the analytical approaches

The top-down approach utilised by Janse van Vuuren (2015) in the economic analysis provided crude carbon intensity benchmarks for sectors of the economy. These benchmarks need to be verified and thus a bottom-up approach was designed to provide more accurate estimates of resource intensity for key commodities and sub-sectors.

The LCAs provided carbon intensity estimates for dry land and irrigated wheat[5]. Assuming the carbon intensity is similar for wheat produced across the province and is similar to the carbon intensity of other field crops, the 2007 bottom-up benchmark is 270 - 380 Gg CO_2e for wheat and 820 - 1180 Gg CO_2e for field crops. This compares well with the top-down 2010 benchmark estimate of 1050 - 1320 Gg CO_2e for the grain sub-sector[6]. Details are provided in Appendix 7.

In the future, incorporating LCAs or carbon footprints done for other wheat production regions in the Western Cape and for other grain crops will improve the accuracy of the estimate and is recommended for updating the benchmarks.

[5] Carbon intensity estimates exclude GHG emissions associated with land use changes
[6] Carbon intensity benchmarks excluding GHG emissions associated with land use, land use changes and forestry.

7. Conclusions and recommendations

Information on the relative resource intensity of key agricultural commodities will be important to strategic decision makers, given the current focus by provincial government on supporting agriculture and developing agro-processing while simultaneously striving to develop a greener, low carbon economy. The goal of this report was to demonstrate the complexity and variability within grain production and examine the feasibility and application of life-cycle based approaches for regional resource analyses. The analyses provided insight into the complexities of examining resource intensity, demonstrating variation in resource intensity and impacts across production systems and even farming practises in the wheat feasibility study.

Given the variation across the Western Cape, regional agricultural analyses require a significant amount of information collected using defined and robust methods. The Combuds provide a platform for large-scale regional analyses, which can highlight possible resource constraints and long-term environmental impacts. With some modifications, the collected information may be of significant use to the wider community, particular those involved in research, innovation and marketing within agriculture and agri-businesses. This is described in detail within the report and in Appendix 3.

The feasibility study successfully demonstrated the use of LCAs and water footprints to examine the resource intensity (carbon and water) and the potential environmental impacts (global warming, eutrophication and acidification) of wheat production in the Western Cape. The results, conclusions and recommendations are described in detail within the report. Furthermore, the carbon intensity of wheat was used to provide a bottom-up benchmark for the grain sub-sector and validate top-down estimates provided by the economic analysis.

Although the application of this approach for a detailed sub-sector analysis is currently constrained by data limitations, the development of the grain carbon calculator by the CCC suggest that the carbon and energy intensity benchmarks for the grain sector could be improved and updated over time. Furthermore, possible developments of regional LCIs and water footprints may allow the Western Cape to develop water and impact benchmarks for key products and sub-sectors. This may be particularly beneficial in regions experiencing issues with water scarcity and quality (e.g. Berg River Catchment).

8. Moving forward

Further analysis of the resource intensity of Western Cape food and other animal-related will be vital to examine competitiveness, provide baselines for benchmarking and support mitigation strategies and economic development at a regional level. Thus the third phase of the RRFM will focus on the agro-processing sectors and key agricultural value chains should funding for this continuation be secured (2015/16).

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10. Appendices

10.1. Appendix 1: Top-down approach

10.1.1. Overview of approach

The top-down approach examined the carbon intensity of the Western Cape agricultural sector and sub-sectors. The agricultural sector has a significant effect on climate change, primarily through the production and release of GHGs which absorb and re-emit heat in the atmosphere and through land transformation which releases carbon stored in biomass and soils (IPCC, 2007). Thus the carbon intensity of agricultural sub-sectors is of particular interest when developing focused mitigation strategies.

There are two top-down estimates provided for the Western Cape grain sub-sector, obtained by scaling the total national GHG emissions from agriculture. These totals were provided by: (a) the Eora multi-regional input output (MRIO) estimates for South Africa (Lenzen et al., 2012; Lenzen et al., 2013), which was used to develop the environmentally extended input output (EEIO) model for the economic analysis (Janse van Vuuren, 2015c); or (b) the national GHG inventory, which was recently updated and published in November 2014 (DEA, 2014).

10.1.2. Outline of methodology

Both top-down estimates were obtained using a similar scaling method. In brief, national GHG emissions from the agriculture sector were scaled to a provincial level based on the sector's GDP contribution. The provincial agriculture GHG emissions were then scaled to 10 sub-sectors (Figure 5) based on output ratios provided by the Western Cape Social Accounting Matrix (DBSA, 2006). Although aggregated data was used in this analysis, the top-down estimates provided focus for the bottom up component of work. For detailed methodology, data sources and assumptions refer to the RRFM economic analysis report (Janse van Vuuren, 2015c).

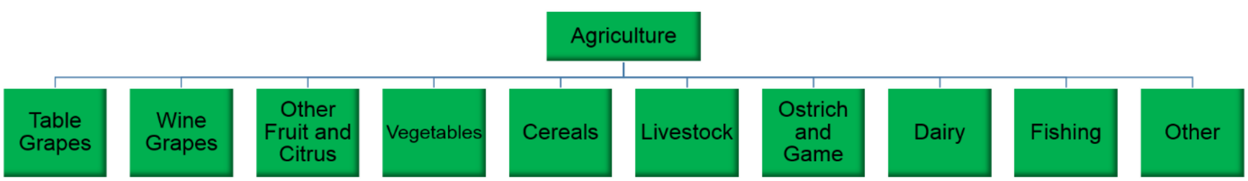


Figure 5: Agriculture sub-sectors in the Western Cape Social Accounting Matrix (DBSA, 2006)

The methodology and results for the agriculture, forestry and land use (AFOLU) sector is available in the national GHG inventory (DEA, 2014). It should be noted that the national GHG inventory contained several emission categories within the AFOLU sector: livestock, land, aggregate sources and non-CO_2 emissions on land, as well as harvested wood products. However, these categories were not scaled separately and allocated to various sub-sectors due to time constraints; i.e. only the total agriculture GHG emissions were considered for comparative purposes. Further analysis of the national GHG inventory is planned for 2015/16, including scaling national GHG emissions using Western Cape data (e.g. land use data from the provincial DOA).

10.1.3. Results of analysis

Table 5 summarises the GHG emissions for the agriculture sector as a whole and provides the estimates for the Western Cape grain sub-sector (Janse van Vuuren, 2015c).

Table 5: GHG emission estimates for the grain sub-sector using top-down approaches

Top-down approach	Source (estimates from 2010)	GHG emissions ($Gg\ CO_2e$ per year)		
		National	Western Cape	
		Total Agriculture	Total Agriculture	Grain sub-sector
Total (including LULUCF)*	EEIO economic analysis**	110 730	26 210	2830
	National GHG inventory***	25 710	6090	660
Sub-total (excluding LULUCF)	EEIO economic analysis	40 880	9680	1050
	National GHG inventory	51 790	12 260	1320

*Land use, land use changes and forestry (LULUCF).
**Economic analysis: total GHG emission estimates obtained using a Western Cape EEIO model, scaled using input output data for SA (2010).
***National GHG inventory: excludes direct GHG emissions from game and there are uncertainties within the soil and land use categories. Nationally, the total agriculture, forestry and other land use (AFOLU) GHG emissions in 2010 are 25,714 Gg CO_2e (including land and harvested wood products) and 51,789 Gg CO_2e (excluding land and harvested wood products) (See Table 5.1; DEA, 2014). The LULUCF GHG emissions are referred to as FOLU in the national GHG inventory documentation.

There are large differences between the top-down estimates, with the totals from the economic analysis 77% higher than the estimates from the national GHG inventory. The differences appear to lie within the GHG emissions from land use (LU), land use changes (LUC) and forestry (F), as the top-down estimates are similar when LULUCF are excluded (1050 vs. 1320 Gg CO2e per year).

The national GHG inventory contains details on carbon sinks, which decreases the agriculture estimate, and is believed to be more accurate than the economic analysis (details provided in Pineo, 2015). As a result, the annual GHG emissions are estimated to be 660 Gg CO2e for the grain sub-sector (including LULUCF), with the expectation that further work to scale estimates to Western Cape land use will further improve its accuracy.

10.2. Appendix 2: Water footprint assessments

10.2.1. Overview of water footprinting

The water footprint is a comprehensive indicator of freshwater use and examines both the direct and indirect water use of a process, product, consumer, producer or geographic area, in contrast to the traditional and restricted measure of water withdrawal. Water footprint assessments can also quantify the water use associated with consumption and trade, thus linking human activities or specific products with water availability.

A water footprint has three components: blue, green and grey water. The blue water footprint refers to consumption of surface and groundwater, the green component refers to consumption of rainwater (insofar as it does not become run-off), and the grey component refers to water pollution. The distinction between blue and green water footprint is important due to different hydrological, environmental and social impacts, as well as economic opportunity costs (Falkenmark & Rockström, 2004; Hoekstra & Chapagain, 2008). Although, blue water resources are usually scarcer and are associated with higher opportunity costs than green water, green water resources are also limited and are historically undervalued. Furthermore, the green water footprint is particularly relevant for agricultural and forestry products (Hoekstra et al., 2011).

10.2.2. Outline of methodology

Given that water scarcity is a key concern in the province and little is known regarding water intensities of agricultural products, on-farm blue and green water footprints were developed to examine the water intensity of wheat production in the Western Cape (expressed as m^3 of water per tonne of wheat). The Water Footprint Network (WFN) provides global standards for assessments and their manual gives a detailed overview of the methodology (Hoekstra et al., 2011). Details of the data sources, climate models, crop factors and crop water models are described below.

10.2.2.1. Productivity data

Regional water footprints were calculated using 2007 production data from Stats SA Census of Commercial Agriculture; the census gives detailed production, area and gross farming income statistics for the Western Cape at a magisterial district level (Stats SA, 2011).

10.2.2.2. Climate model

As agricultural production potential and stability varies greatly across the province primarily as a result of geographic and climatic differences, a geo-spatial approach was used. The New LocClim model (New LocClim version 1.10, 2005) was used to obtain climate data for the 42 different magisterial districts in the Western Cape.

10.2.2.3. Crop factors

To model the crop water requirement and evapotranspiration, several inputs were required: (a) local climate data, (b) specific crop factors; including crop coefficient (Kc), growth stage length, rooting depth, critical depletion fraction (p), yield response factor (Ky), and (c) information on the typical planting period.

Table 6 indicates the crop factors used in this analysis and their sources.

Table 6: Wheat crop factors used for water footprinting

Factor	Details	Wheat	Source
Crop co-efficient (Kc)	Kc1	0.15	Agricultural Research Council report (Durand, 2006)
	Kc2	0.15	
	Kc3	0.15	
Growing stage (days)	Stage 1	30	
	Stage 2	50	
	Stage 3	45	
	Stage 4	10	
	Total	135	
Rooting depth (m)	Depth 1	0.3	CROPWAT values (CROPWAT version 8.0, n.d.)
	Depth 2	1.2	
Critical depletion fraction (p)	p1	0.55	
	p2	0.55	
	p3	0.8	
Yield response factor (Ky)	Ky1	0.4	
	Ky2	0.6	
	Ky3	0.8	
	Ky4	0.4	
	Total	1.15	
Crop height (m)		1.0	SAPWAT values (SAPWAT3, n.d.)
Planting period		May	Farm budgets from DOA wheat production trials (Dr Johann Strauss, DOA)

10.2.2.4. Crop water model

Although other models such as SAPWAT (SAPWAT3, n.d.) were considered, CROPWAT was ultimately chosen as it is relatively simple, user-friendly and less data intense than other dynamic models. Furthermore, a SA-based study indicated that CROPWAT could be used as a tool to calculate crop water use using local crop parameters from the SAPWAT database as inputs to the model (Durand, 2006).

The CROPWAT model (CROPWAT version 8.0, n.d.) was developed by the Land and Water Development Division of FAO and is based on the method outlined in FAO Irrigation and Drainage Report 56: "Crop Evapotranspiration – Guidelines for Computing Crop Water Requirements" (Allen et al., 1998). CROPWAT functions as a decision support tool; calculating crop water requirements (CWR) and irrigation requirements based on soil, climate and crop data. In addition, the model can be used to develop irrigation schedules for different management conditions, calculate scheme water supply for varying crop patterns, evaluate irrigation practices, and estimate crop performance under both rain-fed and irrigated conditions (FAO, n.d.).

The CROPWAT model was used to calculate the crop water requirements and evapotranspiration, based on the inputted crop factors, soil type and climate data, and using the simplified 'crop water requirement option' which assumes optimal conditions. The soil type was kept constant, using the default 'medium' soil input provided by CROPWAT.

10.2.3. Limitations

There are several limitations of this study which should be taken into consideration. These are: (a) the exclusion of water evaporated during storage (surface reservoirs) and transport (irrigation canals), which should ideally be included in the water footprint of the harvested crop; (b) the lack of consideration regarding differences in soil type and irrigation practices when estimating the crop water footprints, due to the broad scope of the project and lack of data; (c) the limited temporal scope of the study: water footprints provide a snapshot view of 2007 and may not be broadly representative as annual fluctuations in productivity and rainfall would have a direct impacts on the water footprint; and finally (d) the assumption that all production occurred within the chosen planting and harvesting periods, when in reality the crop planting dates (and thus water requirements) would vary from this estimate.

10.2.4. Results of analysis

Figure 6 indicates the regional variation within the Western Cape with respect to the total water footprint and the composition of green and blue water. The water footprint is expressed as the quantity of water consumed per tonne of wheat. These footprints provided information for the second component of the bottom-up analysis; specifically, the blue water footprint for Clanwilliam supplemented the 2007 irrigated wheat Combud and provided estimates of on-farm water use for irrigation.

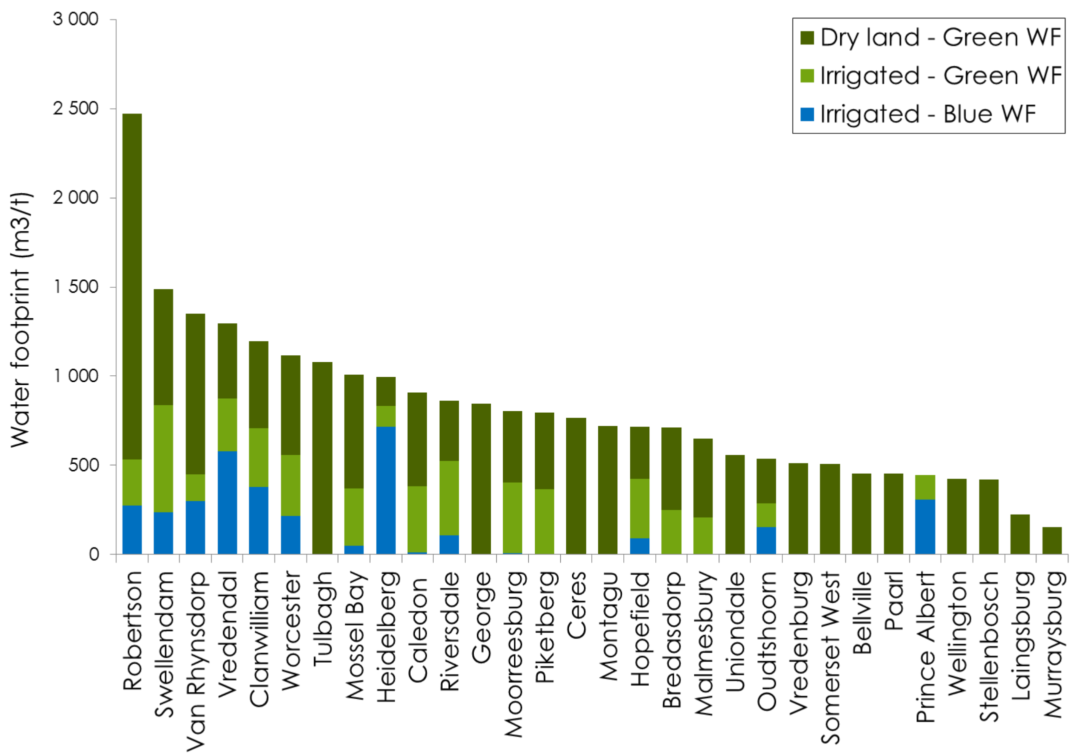


Figure 6: The blue and green water footprint of wheat (irrigated and dry land) per Western Cape magisterial district. The annual water footprints are expressed as water required per tonne of wheat production for 2007.

Although the water footprints are useful for determining total water consumption, it's important to note that the water scarcity has not been considered. Thus, given possible water constraints in the future, further work to express water footprinting values relative to a water scarcity index could be beneficial in terms of assessing impacts and identifying environmental hotspots.

10.2.4.1. Benchmarking water footprints

Table 7 below compares the Western Cape water footprints (calculated using 2007 production data) to published estimates from a global study (Mekonnen & Hoekstra, 2010), which were based on data from 1995 - 2005.

Table 7: Average blue and green water footprints for wheat (m^3/t)

Water type	Western Cape (m^3/t) Wheat			South Africa** (m^3/t)	Global** (m^3/t)
	RRFM project*		Estimate from an international study**		
	Weighted average	Average			
Green	733	848	952	1219	1277
Blue	69	201	226	178	342
Total	**802**	**1049**	**1178**	**1397**	**1619**

*Estimates provided by the RRFM project. Calculations were based on production figures from the Stats SA Census of Commercial Agriculture 2007 (Stats SA, 2011)
**Average regional (Cape Province), country and global estimates (Mekonnen & Hoekstra, 2010)

As shown in Table 7 the RRFM project provides two water footprint estimates for the province, a weighted average calculated according to production contributions from each region and the average across the province. The weighted average indicates a lower water footprint for the province and is the most accurate estimate, taking into account the variation in productivity within the province. For validation purposes, the unweighted average water footprint was included in the table and is shown to be similar to the “Cape Province” estimate provided by a global water footprinting study (Mekonnen & Hoekstra, 2010).

10.3. Appendix 3: Data sources

The commercial enterprise budgets (Combuds) were the primary source for the development of wheat life cycle inventories (LCIs) used in this study and have significant potential for use in the wider research community (i.e. beyond the obvious agricultural stakeholders such as farmers, agricultural suppliers, industry associations, Agricultural Research Council and the DOA), particularly with respect to large-scale regional analyses.

This appendix provides examples of representative wheat farm budgets for the Western Cape and New South Wales in Australia (Figure 7 and Figure 8 respectively) and compares the budgets in terms of their ability to inform and develop regional LCIs. Furthermore, in light of the fact that the DOA is in the process of adjusting and streamlining Combud development, several recommendations have been made by the RRFM project based on the results of this feasibility study. These include: (a) improving the consistency and transparency of Combuds; (b) providing additional information to improve the accuracy of impact assessments; and (c) improving the accessibility of Combud data for analytical analyses (further details provided below).

10.3.1. Western Cape farming budgets

10.3.1.1. Available data

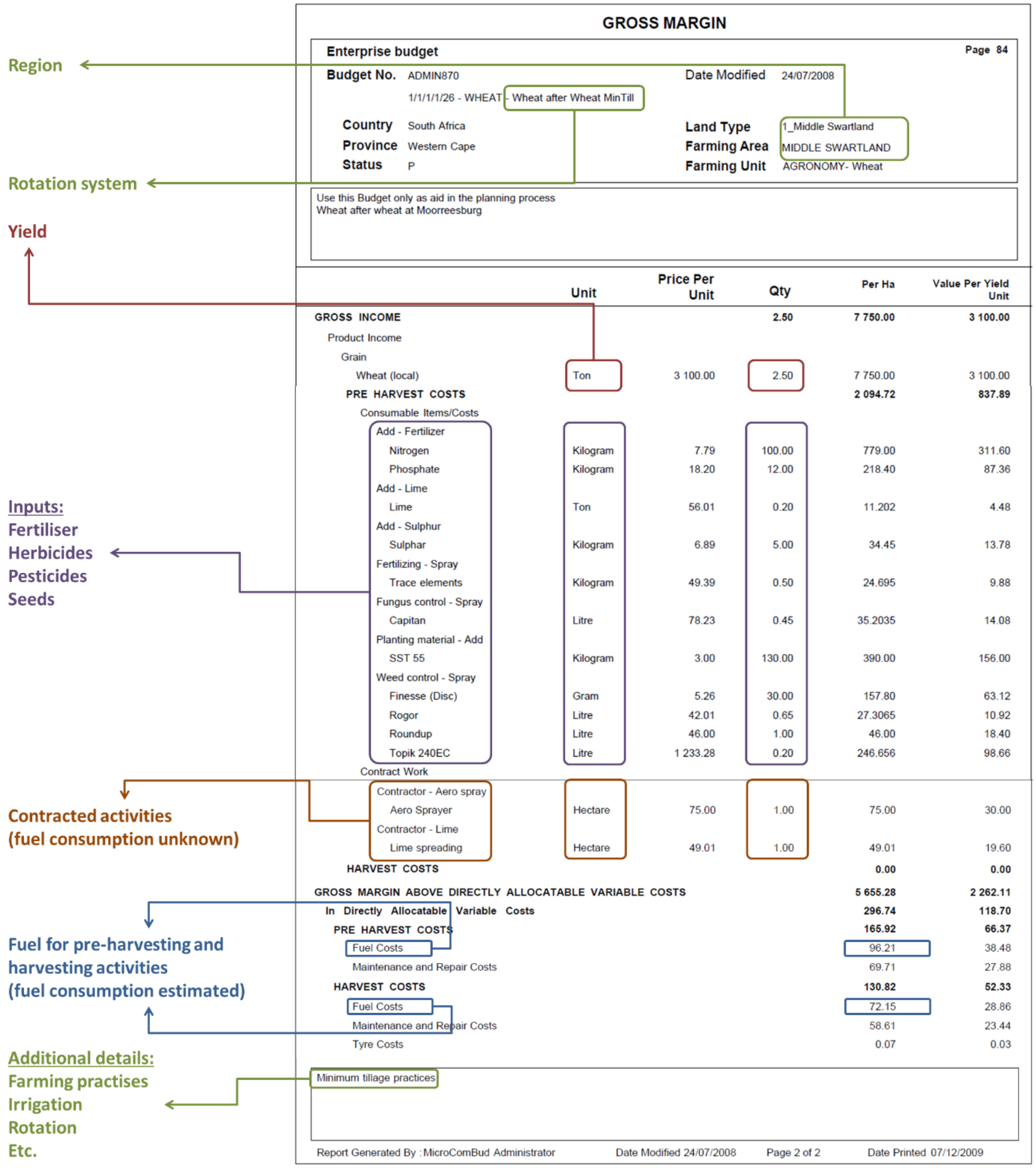
The Combuds were particularly useful in quantifying chemical inputs and wheat yields. In particular, Combuds provide details on the representative region and farming practises for a specific rotation system (see Figure 7; details highlighted in green) and contain a mass balance per hectare for inputs such as lime, fertilisers, pesticides, herbicides and seeds (highlighted in purple), as well as yield outputs (highlighted in red). Although fuel consumption was not quantified in physical terms, estimates could be made based on the economic balance provided for pre-harvest and harvest fuel per hectare (highlighted in blue).

10.3.1.2. Filling data gaps

As machinery and energy budgets were unavailable, the Combuds were supplemented with 2007 data from DOA wheat production trials, which are not publically accessible. Furthermore, details on irrigation water requirements were lacking and thus water footprinting was used to provide estimates for water consumption. Details on LCI inputs, calculations and assumptions are provided in the LCA methodology report (to be reviewed).

10.3.2. New South Wales (Australian) farming budgets

The Australian LCA Society (ALCAS) has been working with the Australian Department of Primary Industries to develop farming budgets that support the production of regional LCIs (NSW Department of Primary Industries, 2015a). As shown in the example in Figure 7, the Australian gross margin budgets include details on the representative region (i.e. New South Wales: central zone – west) and farming practises (i.e. no tillage), along with machinery use and herbicide and pesticide inputs (NSW Department of Primary Industries, 2015b). Furthermore, the budgets provide fertiliser inputs and wheat yields linked to several types of rotation systems (i.e. after canola, cereals and pulses).



GROSS MARGIN

Enterprise budget Page 84

Budget No. ADMIN870 **Date Modified** 24/07/2008

1/1/1/1/26 - WHEAT - Wheat after Wheat MinTill

Country South Africa **Land Type** 1_Middle Swartland

Province Western Cape **Farming Area** MIDDLE SWARTLAND

Status P **Farming Unit** AGRONOMY- Wheat

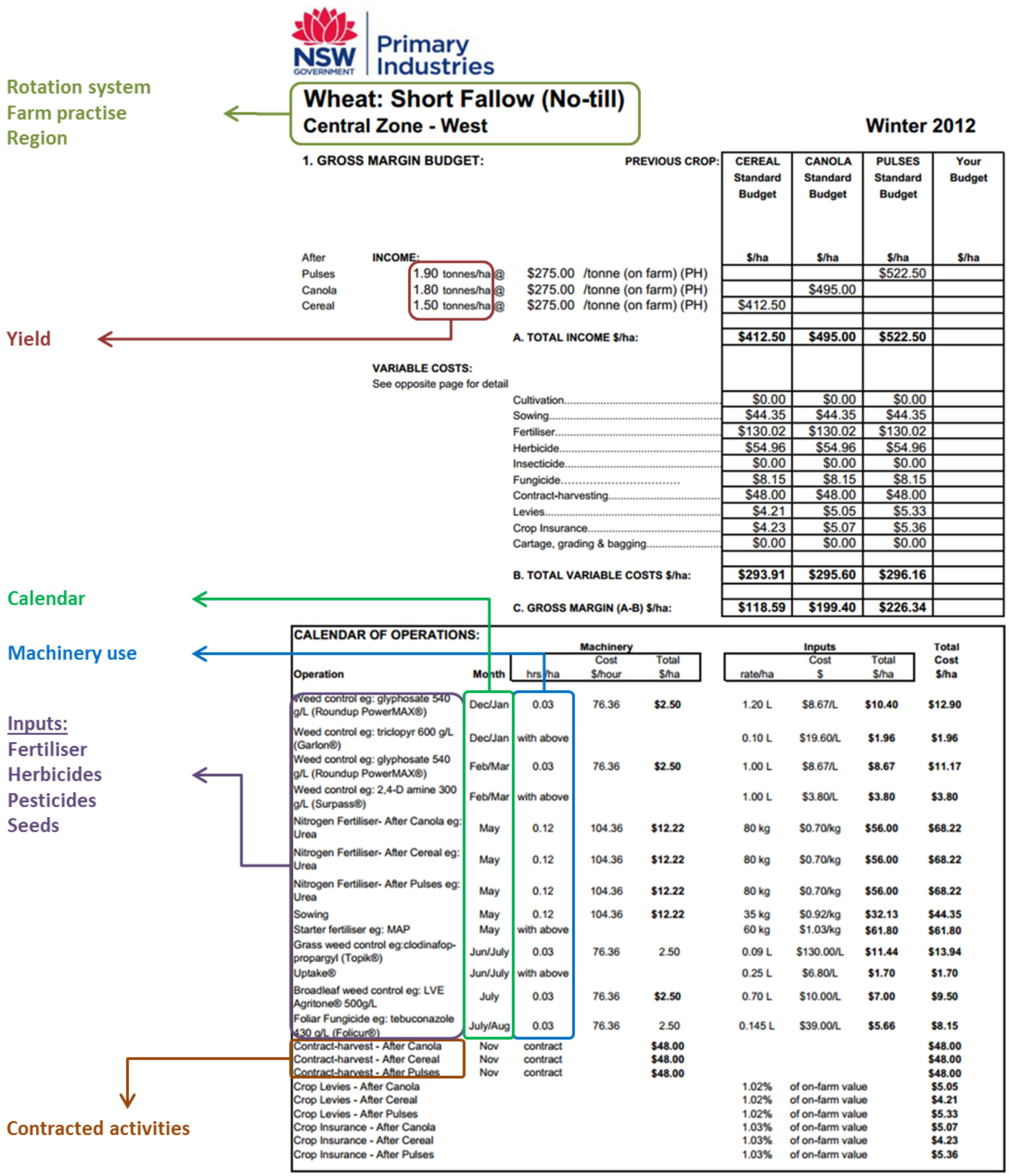
Use this Budget only as aid in the planning process
Wheat after wheat at Moorreesburg

	Unit	Price Per Unit	Qty	Per Ha	Value Per Yield Unit
GROSS INCOME			**2.50**	**7 750.00**	**3 100.00**
Product Income					
Grain					
Wheat (local)	Ton	3 100.00	2.50	7 750.00	3 100.00
PRE HARVEST COSTS				**2 094.72**	**837.89**
Consumable Items/Costs					
Add - Fertilizer					
Nitrogen	Kilogram	7.79	100.00	779.00	311.60
Phosphate	Kilogram	18.20	12.00	218.40	87.36
Add - Lime					
Lime	Ton	56.01	0.20	11.202	4.48
Add - Sulphur					
Sulphar	Kilogram	6.89	5.00	34.45	13.78
Fertilizing - Spray					
Trace elements	Kilogram	49.39	0.50	24.695	9.88
Fungus control - Spray					
Capitan	Litre	78.23	0.45	35.2035	14.08
Planting material - Add					
SST 55	Kilogram	3.00	130.00	390.00	156.00
Weed control - Spray					
Finesse (Disc)	Gram	5.26	30.00	157.80	63.12
Rogor	Litre	42.01	0.65	27.3065	10.92
Roundup	Litre	46.00	1.00	46.00	18.40
Topik 240EC	Litre	1 233.28	0.20	246.656	98.66
Contract Work					
Contractor - Aero spray					
Aero Sprayer	Hectare	75.00	1.00	75.00	30.00
Contractor - Lime					
Lime spreading	Hectare	49.01	1.00	49.01	19.60
HARVEST COSTS				**0.00**	**0.00**
GROSS MARGIN ABOVE DIRECTLY ALLOCATABLE VARIABLE COSTS				**5 655.28**	**2 262.11**
In Directly Allocatable Variable Costs				**296.74**	**118.70**
PRE HARVEST COSTS				**165.92**	**66.37**
Fuel Costs				96.21	38.48
Maintenance and Repair Costs				69.71	27.88
HARVEST COSTS				**130.82**	**52.33**
Fuel Costs				72.15	28.86
Maintenance and Repair Costs				58.61	23.44
Tyre Costs				0.07	0.03

Minimum tillage practices

Report Generated By :MicroComBud Administrator Date Modified 24/07/2008 Page 2 of 2 Date Printed 07/12/2009

Figure 7: Commercial enterprise budget for a representative dry land wheat farm in Middle Swartland in the Western Cape.



Wheat: Short Fallow (No-till)
Central Zone - West

Winter 2012

1. GROSS MARGIN BUDGET:			**PREVIOUS CROP:**	**CEREAL Standard Budget**	**CANOLA Standard Budget**	**PULSES Standard Budget**	**Your Budget**
After	**INCOME:**			**$/ha**	**$/ha**	**$/ha**	**$/ha**
Pulses	1.90 tonnes/ha @	$275.00 /tonne (on farm) (PH)				$522.50	
Canola	1.80 tonnes/ha @	$275.00 /tonne (on farm) (PH)			$495.00		
Cereal	1.50 tonnes/ha @	$275.00 /tonne (on farm) (PH)		$412.50			
		A. TOTAL INCOME $/ha:		**$412.50**	**$495.00**	**$522.50**	
	VARIABLE COSTS: See opposite page for detail						
		Cultivation		$0.00	$0.00	$0.00	
		Sowing		$44.35	$44.35	$44.35	
		Fertiliser		$130.02	$130.02	$130.02	
		Herbicide		$54.96	$54.96	$54.96	
		Insecticide		$0.00	$0.00	$0.00	
		Fungicide		$8.15	$8.15	$8.15	
		Contract-harvesting		$48.00	$48.00	$48.00	
		Levies		$4.21	$5.05	$5.33	
		Crop Insurance		$4.23	$5.07	$5.36	
		Cartage, grading & bagging		$0.00	$0.00	$0.00	
		B. TOTAL VARIABLE COSTS $/ha:		**$293.91**	**$295.60**	**$296.16**	
		C. GROSS MARGIN (A-B) $/ha:		**$118.59**	**$199.40**	**$226.34**	

CALENDAR OF OPERATIONS:

		Machinery			**Inputs**			**Total**
Operation	**Month**	hrs/ha	Cost $/hour	Total $/ha	rate/ha	Cost $	Total $/ha	**Cost $/ha**
Weed control eg: glyphosate 540 g/L (Roundup PowerMAX®)	Dec/Jan	0.03	76.36	**$2.50**	1.20 L	$8.67/L	**$10.40**	**$12.90**
Weed control eg: triclopyr 600 g/L (Garlon®)	Dec/Jan	with above			0.10 L	$19.60/L	**$1.96**	**$1.96**
Weed control eg: glyphosate 540 g/L (Roundup PowerMAX®)	Feb/Mar	0.03	76.36	**$2.50**	1.00 L	$8.67/L	**$8.67**	**$11.17**
Weed control eg: 2,4-D amine 300 g/L (Surpass®)	Feb/Mar	with above			1.00 L	$3.80/L	**$3.80**	**$3.80**
Nitrogen Fertiliser- After Canola eg: Urea	May	0.12	104.36	**$12.22**	80 kg	$0.70/kg	**$56.00**	**$68.22**
Nitrogen Fertiliser- After Cereal eg: Urea	May	0.12	104.36	**$12.22**	80 kg	$0.70/kg	**$56.00**	**$68.22**
Nitrogen Fertiliser- After Pulses eg: Urea	May	0.12	104.36	**$12.22**	80 kg	$0.70/kg	**$56.00**	**$68.22**
Sowing	May	0.12	104.36	**$12.22**	35 kg	$0.92/kg	**$32.13**	**$44.35**
Starter fertiliser eg: MAP	May	with above			60 kg	$1.03/kg	**$61.80**	**$61.80**
Grass weed control eg:clodinafop-propargyl (Topik®)	Jun/July	0.03	76.36	2.50	0.09 L	$130.00/L	**$11.44**	**$13.94**
Uptake®	Jun/July	with above			0.25 L	$6.80/L	**$1.70**	**$1.70**
Broadleaf weed control eg: LVE Agritone® 500g/L	July	0.03	76.36	**$2.50**	0.70 L	$10.00/L	**$7.00**	**$9.50**
Foliar Fungicide eg: tebuconazole 430 g/L (Folicur®)	July/Aug	0.03	76.36	2.50	0.145 L	$39.00/L	**$5.66**	**$8.15**
Contract-harvest - After Canola	Nov	contract		**$48.00**				**$48.00**
Contract-harvest - After Cereal	Nov	contract		**$48.00**				**$48.00**
Contract-harvest - After Pulses	Nov	contract		**$48.00**				**$48.00**
Crop Levies - After Canola					1.02%	of on-farm value		**$5.05**
Crop Levies - After Cereal					1.02%	of on-farm value		**$4.21**
Crop Levies - After Pulses					1.02%	of on-farm value		**$5.33**
Crop Insurance - After Canola					1.03%	of on-farm value		**$5.07**
Crop Insurance - After Cereal					1.03%	of on-farm value		**$4.23**
Crop Insurance - After Pulses					1.03%	of on-farm value		**$5.36**

Figure 8: An extract of a gross margin budget for dry land winter wheat in the central (west) region of New South Wales in Australia.

10.3.3. Comparison of budgets in terms of LCI development

Although the budgets are similar, the Australian budgets are better suited for the development of LCIs as they are more detailed and transparent. Differences between the budgets and their effects on LCI development are highlighted below.

10.3.3.1. Fertiliser

The type and quantity of fertiliser has a significant effect on the impact of wheat production. The total quantity of fertiliser is not important per se when developing the LCI, but rather the input of nitrogen (N), available phosphate (P_2O_5) and water-soluble potash (K_2O) and where they are sourced from: e.g. urea, calcium ammonium nitrate, ammonium nitrate, ammonium sulphate, mono-ammonium phosphate (MAP), diammonium phosphate (DAP), single super phosphate, triple super phosphate, potassium chloride, potassium sulphate, etc.

This is where the major problem lies in terms of using Combuds for agricultural LCIs. At present, the details provided for fertilisers varies significantly between individual Combuds. For example, some budgets provide the commercial brand name of a fertiliser (e.g. 200 kg of Kysan per hectare), while others merely refer to "nitrogen" or "phosphate" fertiliser (see Figure 7). Furthermore, many of the budgets do not contain details on nutrient sources; e.g. only a few budgets specified limestone ammonium nitrate (LAN) as the nitrogen source for fertiliser.

As a result, a great deal of work was required to find fertiliser compositions (if the commercial brand was provided) or make educated assumptions regarding fertiliser compositions (if unknown). Based on national fertiliser market reports and detailed input from major fertiliser producers (i.e. Sasol and Omnia), this study assumed that nitrogen and phosphate provided in fertilisers were typically sourced from ammonium nitrate and super phosphate. Using a sensitivity analysis to examine the effect of the assumptions, it is clear that the nutrient source has a large influence on the impacts related to fertiliser inputs (e.g. global warming and eutrophication), suggesting that more detailed information is required for use in regional analyses.

Furthermore, several South Coast wheat budgets could not be analysed due to the input of a single fertiliser (i.e. "Adam Tas" fertiliser). This fertiliser is unknown to experts at the DOA and within large agricultural co-ops, suggesting it may be an informal name for a dated fertiliser blend. As the type of fertiliser (e.g. nitrogen, phosphate or a blend) is unknown, these budgets could not be used to develop LCIs.

In comparison, the Australian budgets simply provide the nutrient source (e.g. urea and MAP) and the quantity of fertiliser required. Estimates of nitrogen and phosphate inputs can be calculated give the nutrient sources and thus this level of detail is preferable to the use of informal or commercial brand names.

10.3.3.2. Herbicides, pesticides and fungicides

The Australian budgets identify the active ingredients used in herbicides and other chemicals. Furthermore, the concentration is supplied in the Australian budgets (e.g. application of 1.2 L/ha of glyphosate at a concentration of 540 g/L), which allows the input of potentially harmful chemicals to be easily included in LCIs.

In contrast, the Combuds usually only provide a commercial name (e.g. Roundup). This requires: (a) additional research to identify the active ingredient in each herbicide; and (b) assumptions to be made regarding the particular type of Roundup herbicide used and thus the concentration of glyphosate applied: e.g. Roundup SuperMAX®, Roundup ULTRA®, Roundup PRO® Concentrate, Roundup PRO® contain 540, 480, 445, 356 g glyphosate per L respectively (CDMS, 2015). This is both time-consuming and produces uncertainties within the impacts related to chemical inputs (e.g. ecotoxicity).

10.3.3.3. Machinery and fuel use

The Australian budgets provided information for machinery use, including operation hours per hectare (Figure 8) and sufficient detail on the machinery assumptions (e.g. budget based on a tractor with 196 kW / 263 HP power take-off and 242kW / 325 HP engine power). However the budget excluded other agricultural machinery inputs (tillage implements, combine harvester, etc.) and fuel inputs.

The Western Cape Combuds provided fuel costs, which could be used to calculate total fuel consumption. However a disaggregation of fuel type and consumption per activity (sowing, fertilising, application of herbicides, etc.) and an indication of the number of times an activity occurs per year (e.g. application of pesticides and herbicides occurs twice a year) would be valuable in providing insight and evidence into the benefits of different farming practises (e.g. no tillage vs. conventional systems).

The machinery and energy budgets related to the specific Combuds used for the analyses could not be provided by the DOA due to problems regarding the software system. As a result, additional work was required to obtain estimates from internal DOA and university studies. Furthermore, neither the Australian nor Western Cape budgets include fuel use by contractors, which underestimates the energy requirements and requires contacting individual contractors to obtain additional information.

10.3.3.4. Other

The inclusion of a calendar of operations in the Australian budgets is useful when altering climatic parameters for emission models (e.g. modelling phosphate emissions in surface water run-off) and developing water footprints. As a result, it would be beneficial to have similar details included within the Western Cape Combuds, in order to more accurately estimate environmental impacts.

10.3.4. Recommendations for Combud development

Based on this feasibility study, the RRFM project has several recommendations for the adjustments of Combuds if they are to be used for large-scale regional resource analyses. These are:

10.3.4.1. Consistency and transparency

To develop LCIs across different regions and production systems, there needs to be a level of consistency in the budgets, particularly regarding: (a) names and descriptions of inputs: e.g. avoid the use of informal or unspecific names for fertilisers; and (b) units of measure: e.g. fertiliser quantities varied between tonnages and kilograms, chemicals varied between grams and litres.

Furthermore, transparency is required regarding: (a) the concentration of active ingredients in chemicals; and (b) the primary source of nutrients (nitrogen, phosphate and potash) in the applied fertilisers: e.g. urea, ammonium nitrate, single super phosphate and potassium chloride.

10.3.4.2. Provision of additional information

Machinery and fuel use information is important for agricultural LCAs. As a result, details regarding the type of fuel (e.g. diesel or petrol) and the basic machinery use for various on-farm activities (sowing, tilling, application of chemicals and fertiliser, etc.) is required. In particular, LCI development requires:

(a) The machinery used for each activity: e.g. tractor with a tilling implement, tractor with a plough, combine harvester, etc.

(b) The power specifications: e.g. 250 kWh tractor (as a minimum level of detail).

(c) The frequency of the activity: e.g. number of sprays per year.

(d) The operation time per hectare.

(e) The fuel use per hectare.

Examples of additional details required for LCI development are shown below in Table 8.

Table 8: Examples of the additional machinery and fuel consumption data required in Combuds to develop farm-based life cycle inventories

Activity	Machinery	Details	Activity frequency (ha/yr)	Operation time (hr/ha)	Fuel consumption (L/ha)
Spraying pesticides and herbicides	Tractor Sprayer	250 kWh 10-20L tank	2 sprays	0.4	0.6
Tilling	Tractor Tilling implement	250 kWh 6-tine, steel	1 tilling pass	0.2	0.3

10.3.4.3. Accessible formats for data analysis

The Combuds were provided in formats that were difficult and time-consuming to analyse (i.e. provided as hard copies or electronic pdfs). In order to create and update LCI databases for large-scale regional analyses, Combud data needs to be accessible in an appropriate format (e.g. electronic spreadsheets). Without improvements in data accessibility, the feasibility of using Combuds for similar analysis is limited.

10.4. Appendix 4: Structure of the inventory

LCAs comprise of foreground and background systems. The foreground system includes the LCA activities for which data are collected and modelled in the study, while the background system includes the activities for which generic and existing data are used (i.e. data provided by LCA databases such as ecoinvent®).

10.4.1. Foreground data

The majority of foreground inventory data (e.g. seed, fertiliser, pesticide, herbicide and fuel inputs) was sourced from the provincial Commercial Enterprise Budgets (Combuds) provided by the Department of Agriculture (DOA). Other sources were required to obtain estimates for building and machinery inputs (e.g. shed use, tractor use) and to disaggregate total fuel use. This is explained in more detail in the LCA methodology report (to be reviewed).

10.4.2. Background data

To develop LCAs, foreground systems need to be linked to background data (e.g. the production of fertiliser, pesticides and agricultural machinery) which was not collected in this study. Background data were supplied by ecoinvent® global or rest-of-world databases (Ecoinvent Centre, 2010), although these "average" LCA datasets are primarily based on data from developed countries and regions (e.g. USA and Europe). There are no local or even Southern African Developing Country (SADC) datasets for agricultural production systems and South African-specific datasets are limited to electricity and a few mining processes and products. The background datasets cannot be published due to licensing conditions but the datasets used in the LCAs will be identified in the detailed methodology report (to be reviewed).

10.4.2.1. Imported inputs

Inputs that are typically imported (e.g. potassium chloride), or whose supply source was unknown (e.g. agricultural machinery), were linked to global market activities. A market activity is a consumption mix of a certain product in a certain geographical region. It is a collection of all activities with the same reference product and includes average transports of that product, as well as losses in trade and transport. The market activity does not transform inputs, it simply transfers the intermediate exchange from one transforming activity to another (e.g. tractor at the supplier to tractor at the consumer). For more information see ecoinvent® documentation.

10.4.2.2. Domestic inputs

For inputs whose production processes generally occur locally (e.g. diesel production, calcium ammonium nitrate production), ecoinvent® background processes were altered to allocate 100% of the electricity input to the South African electricity mix, rather than using a global market electricity mix. This was done as South Africa has a coal-intense (i.e. high carbon) electricity mix in comparison to other countries. A schematic diagram of the foreground and background inventories and processes for the wheat LCAs is shown in Figure 9.

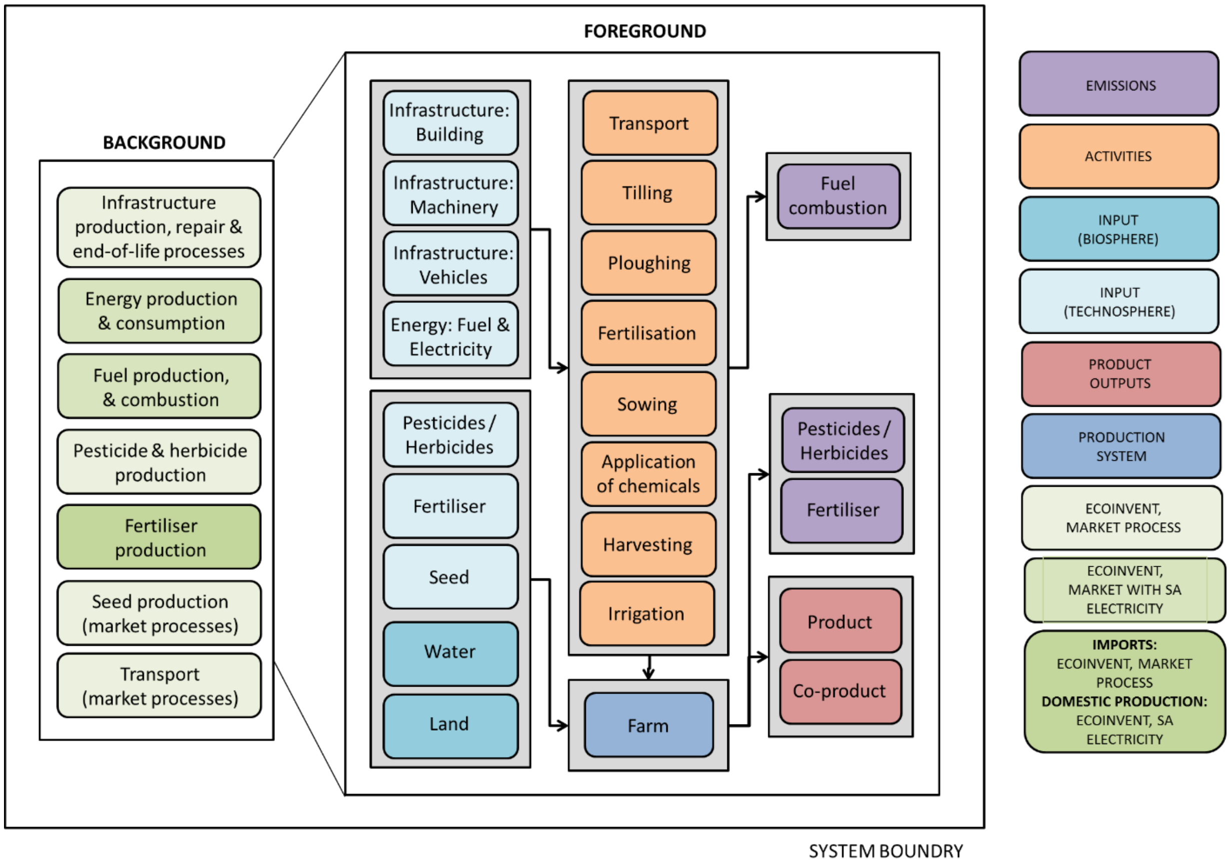


Figure 9: Schematic overview of the foreground & background inventories and processes in a wheat LCA

10.4.3. Allocation

Attributional allocation was used for the background data (default allocation method for ecoinvent®). Specific comments relating to allocations regarding mixed cropping systems and the co-production of straw and wheat are discussed below.

10.4.3.1. Mixed cropping systems

One of the remaining methodological challenges of agricultural LCAs is the inclusion of crop rotation effects, which can cause changes in physical, chemical and biological properties of the agricultural land over time (e.g. presence and availability of nutrients) and cannot be easily measured. LCA studies, focusing on only one vegetation period, have a limited ability to include those crop rotation effects.

For this project, the benefits of crop rotation and interaction with livestock were not modelled. As done in ecoinvent® and AusAgLCI methodology (Grant, 2014), each crop (in this case wheat) was treated independently and there was no allocation of the impacts or benefits of one crop on the following crop.

In theory, aggregating impacts from similar wheat farms (i.e. dry land wheat farms within homogenous farming areas) using different crop rotation systems (e.g. wheat after wheat, wheat after medics, wheat after lupin, or wheat after a fallow period) may provide average impacts associated with wheat across rotation systems and may be worth considering for large-scale regional analyses within the grain sub-sector.

10.4.3.2. Co-production of straw with wheat

There was no allocation of impacts between the co-products as the chosen farming budgets did not report the co-production of wheat and straw (i.e. 100% of impacts was allocated to the production of wheat). For further development of regional wheat LCAs, it's worth noting that some Combuds reported the co-production of wheat and straw (e.g. Combud budget number ADMIN785 1/1/1/1/549 produces 1.5 tonnes wheat and 2.5 tonnes straw per hectare). However, the AusAgLCI methodology report indicates that straw represents less than 1% of the value of wheat on Australian farms (Grant, 2014) and thus the impacts association with production could be wholly allocated to wheat if economic allocation was utilised.

10.4.4. Process modelling and inventory flows

The LCA software used in the study was Umberto NXT Universal (ifu Hamburg GmbH, 2015). Foreground data was used to create wheat production models and ecoinvent v3.1 was used to model the background processes, substituting in the South African electricity grid mix for materials that are locally produced. Transportation was included for all significant mass flows or any transport over long distances. Details on the assumptions and inventory flows related to transport, seeds, pesticides and herbicides, fertiliser, energy, infrastructure, land and irrigation will be provided in the LCA methodology report (to be reviewed).

10.4.5. Limitations of the LCIs

10.4.5.1. Geographical, technological and temporal scope

The inventories were developed for wheat in two representative farming areas within the Western Cape (Middle Swartland and the North-West region) and were based on technology from 2007. As a result, the geographical, technological and temporal scope is limited and the LCIs may be outdated depending on the rate of change within production systems. With this in mind, it is beneficial to consider developing LCIs within a framework which can be updated over time.

10.4.5.2. Uncertainty

It is recommended that data providers add uncertainty estimates to the inventory data. Where specific uncertainty data is not available, the uncertainty can be estimated using the approach developed by ecoinvent® which uses basic uncertainty factors for different types of flows. The uncertainty can then be adjusted based on the data quality characteristics of the flows.

This was not done for wheat LCAs, as the aim was to conduct a feasibility study for the Western Cape rather than provide accredited inventory data. However, this will be required if regional LCIs are to be developed for use by Western Cape producers and global suppliers. Details on the uncertainty analysis used by Australia are provided in the AusAgLCI methodology report (Grant, 2014).

10.5. Appendix 5: Life cycle impact assessment

10.5.1. Impact assessment methodology

Life cycle impact assessment (LCIA) was performed using the ReCiPe (Goedkoop et al., 2008) valuation systems available in ecoinvent®, using midpoint metrics over a 100 year timeframe and with no normalization to a target or weighting of different impact categories. The impact categories used for this study include climate change, terrestrial acidification, freshwater eutrophication and water depletion.

10.5.2. Climate change

Climate change is characterised by global warming potentials and is measured in terms of kg CO_2 emitted to the air. This category has a large number of international agreements and methodologies with standardised calculations, unlike most environmental indicators (Goedkoop et al., 2008). The GHG flows are based on IPCC methodologies and include direct and indirect GHG emissions associated with wheat production. Flows relating to soil carbon exchange have been excluded (as done in the AusAgLCI methodology) due to an insufficient causal link between farm processes and emission sources and a lack of consensus in international methodology (Grant, 2014).

10.5.3. Terrestrial acidification

Terrestrial acidification is characterised by terrestrial acidification potentials and is measured in terms of kg SO_2 emitted to the air. Atmospheric deposition of inorganic substances (e.g. sulphates, nitrates and phosphates) causes a change in acidity in the soil. As most plant species have a defined optimum soil acidity, changes in levels of acidity will cause shifts in species occurrence (Goedkoop, 1999; Hayashi, 2004).

10.5.4. Freshwater eutrophication

Freshwater eutrophication is characterised by freshwater eutrophication potentials and is measured in terms of kg P emitted to freshwater. These emissions have the potential to increase biological activity, change species composition and result in excess algae production, which may affect the water quality (Goedkoop et al., 2008).

Phosphorus flows are estimated by the method used by ecoinvent® (Nemecek et al., 2007), while the Australian NIR methodology (DCCEE, 2011) was used to estimate nitrate flows, as done for the Australian Agricultural LCIs. This methodology was preferentially chosen instead of the Swiss-based methodology utilised in ecoinvent®, as there was insufficient local data to utilise the models and the AusAgLCI methodology report provided detailed leaching and emission factors (Grant, 2014). The AusAgLCI factors were also regionalised, which allowed the project to select factors from a region with climate similar to its own (South Australia, which has a Mediterranian climate), rather than use European estimates.

Both phosphorus and nitrate are responsive to fertiliser inputs. Ideally, the models would use regional data for leaching and run-off (using GIS layers for agro-ecological regions and land use) and to estimate net export of soil, which is relevant for phosphorus emissions to water. However, the time and data constraints in the Western Cape limited the analysis to the use of regional Australian factors and did not account for spatial and temporal variation in weather and soil conditions. The work required to successfully complete this was beyond the scope of this project.

10.5.5. Water depletion

Water depletion is characterised by water depletion potentials and is measured in terms of m^3 of water use. Water extraction can cause very significant damages to ecosystems and human health, however modelling the impacts is challenging. As a result, this category is not as developed as other impact categories and the inclusion of an indicator that simply expresses the total water use is recommended (Goedkoop et al., 2008).

For the foreground system, freshwater (blue water) extracted for wheat production (for irrigation) was included in the inventory. The farming budgets lacked information on water use and, as a result, the blue water footprints were used to provide these estimates. Rainfall (green water) is not included in the inventory due to a lack of clarity and international consensus in terms of how to treat natural processes or rainfall and runoff within farming systems.

10.5.6. Excluded category indicators

10.5.6.1. Land use

Land use and land use changes are important impact indicators for LCAs, particularly for agricultural production. However, the methodology for assessing impacts relating to land use is still in development and the annual farming budgets used for the analysis did not indicate any land use changes from arable land (i.e. the wheat budgets analysed in the study were based on wheat produced in rotation with other field crops - production did not occur on land transformed from pasture, forest land, etc.).

Although land occupation and transformation was included in the inventory, land transformation was entered as two flows which cancelled each other out (e.g. “transformation from arable land” and “transformation to arable land”) as recommended by the AusLCI guidelines. This simply states what the land was prior to occupation and what it will be after the application, thus the emissions and impacts related to land use changes was not included in the LCIA.

10.5.6.2. Ecotoxicity

Ecotoxicity is driven by the use of chemicals in cropping systems. Current ecoinvent® methodology is limited as it only measures the ecotoxicity within the farm boundary (i.e. allocates all chemical emissions to soil and ignores emissions lost through surface or groundwater from the farm boundary). Although the impact category was not included in the wheat impact assessment, a basic measure of ecotoxicity is possible given the detailed pesticide, herbicide and fungicide information provided in the LCIs.

A better approach to examine ecotoxicity is to use the PestLCI model to examine flows of chemicals to soil, water and air (Dijkman, 2012), however the model needs to be adapted to regional conditions. Australia have utilised this approach, modifying climate-related parameters (temperature, precipitation, evaporation, solar radiation), soil characteristics (depth, proportion sand, silt and clay, pH, organic content, bulk density), and field data (slope) for Australian conditions. This was beyond the current scope of the project, although may be necessary if regional LCIs are developed further.

10.6. Appendix 6: Relative impacts of wheat production

Appendix 6 contains additional details on the LCIA phase of the wheat LCA studies.

10.6.1. Relative impacts of wheat production

To indicate the magnitude difference between the irrigated and dry land wheat production systems, the impact results were expressed relative to irrigated wheat. Irrigated wheat was associated with the highest values within each impact category, with the exception of freshwater eutrophication per hectare of planted wheat. The results are shown in Figure 10 (overleaf) and were expressed: (a) per tonne of wheat; and (b) per hectare of wheat planted. Water depletion was not included as the differences were significantly larger (>2000-fold higher than the dry land systems).

Climate change and acidification impacts for dry land production is 76 - 92% lower than the impacts for irrigated wheat (per tonne and per hectare). Eutrophication impacts are similar on a per hectare basis (dry land is 2 - 10% of the impact for irrigated wheat) but dry land wheat is 20 - 78% higher than irrigated wheat on a per tonne basis, due to the higher yields within the irrigated system.

10.6.2. Activity contributions to impacts

As shown for climate change in Figure 4, the contributing activities for terrestrial acidification and freshwater eutrophication are shown below in Figure 11 and Figure 12. The contributing activities for water depletion are not indicated as the total water depletion for irrigated wheat was significantly higher than dry land wheat, with the on-farm water use for irrigation making up the majority of the impact (>99%).

The field emissions from fertiliser use is a major contributing activities for both acidification (14 - 57%) and particularly eutrophication (67 – 98%), although electricity consumption for irrigation is also significant for irrigated wheat (75% for acidification and 27% for eutrophication). Within acidification, the indirect impacts from fertiliser production are also significant (8 - 50%). As recommended with respect to climate change, interventions to improve the fertiliser efficiency and the water and energy efficiency of irrigation would reduce the impact of wheat.

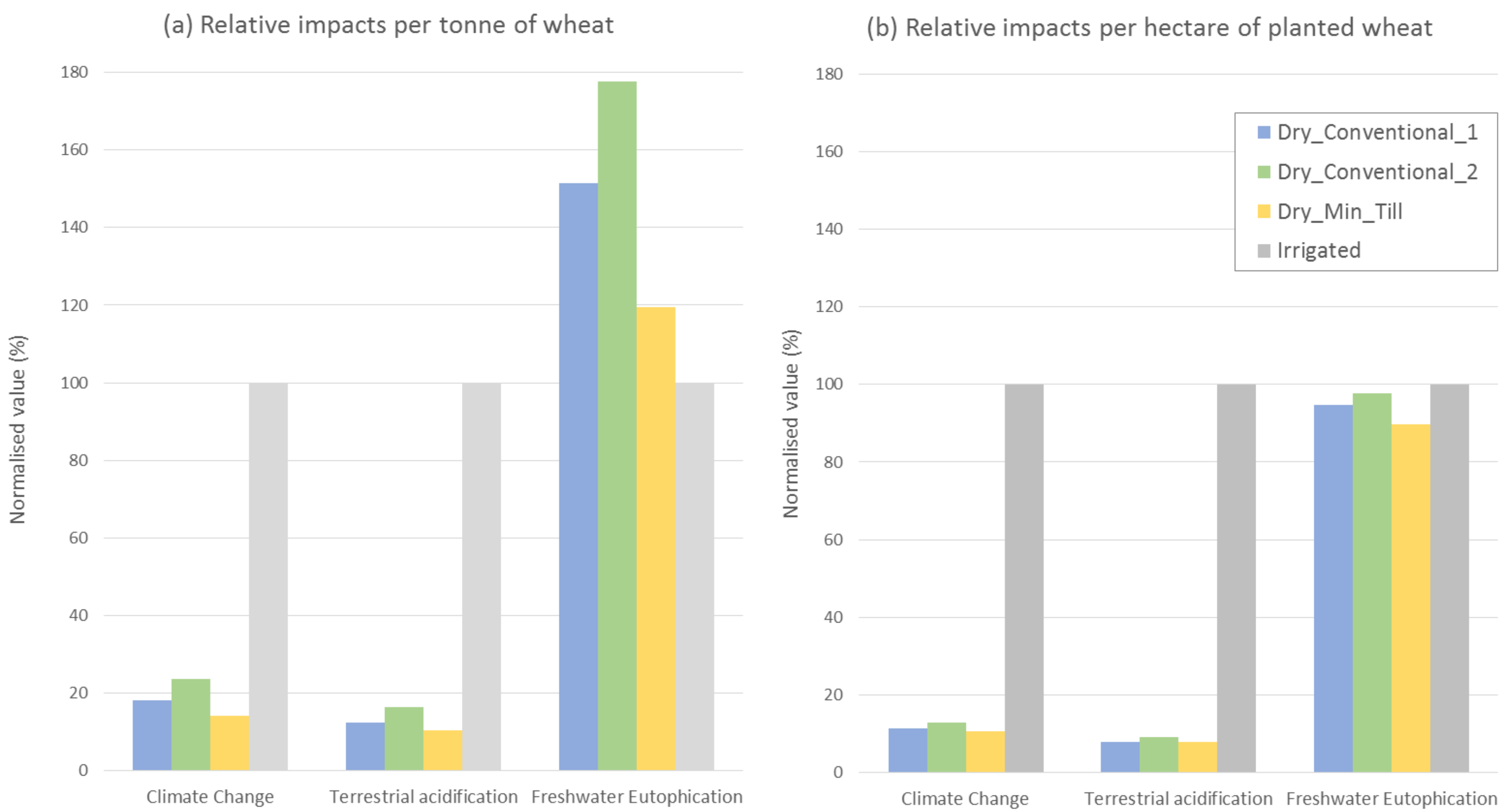


Figure 10: Impacts of wheat production expressed (a) per tonne of wheat and (b) per hectare of planted wheat. Impact of dry land wheat production is expressed relative to irrigated wheat.

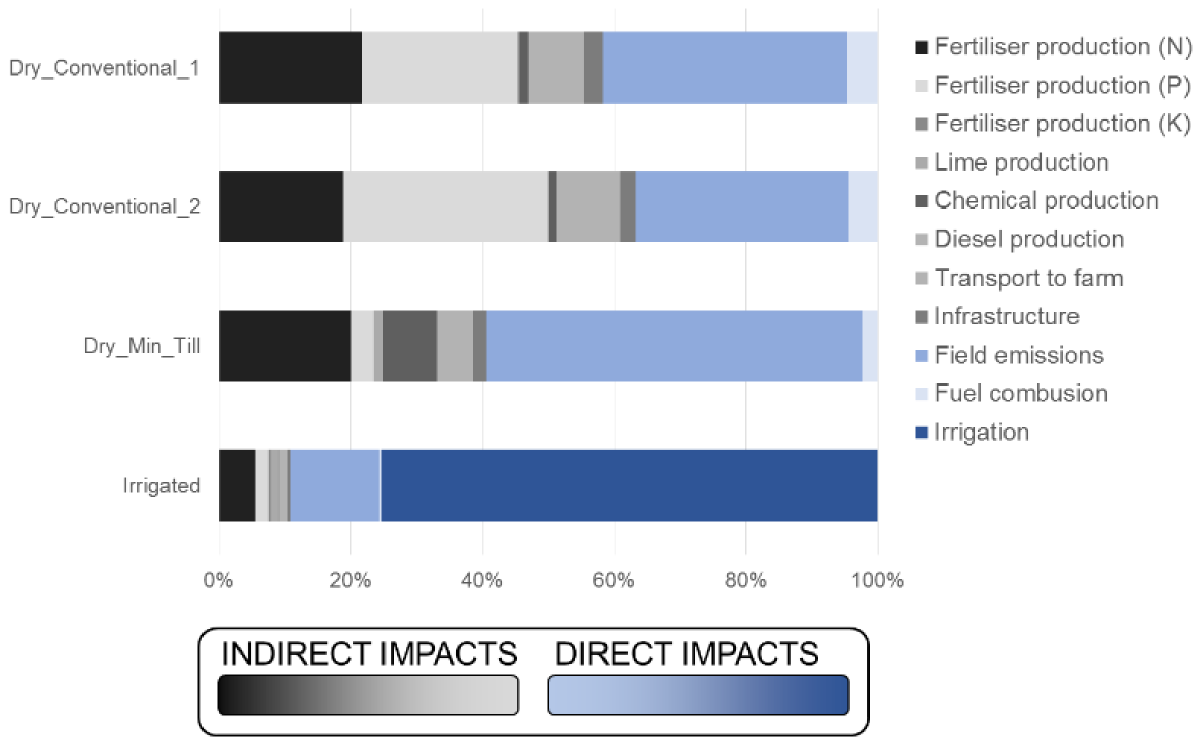


Figure 11: Activity contributions (%) to total terrestrial acidification associated with wheat production.

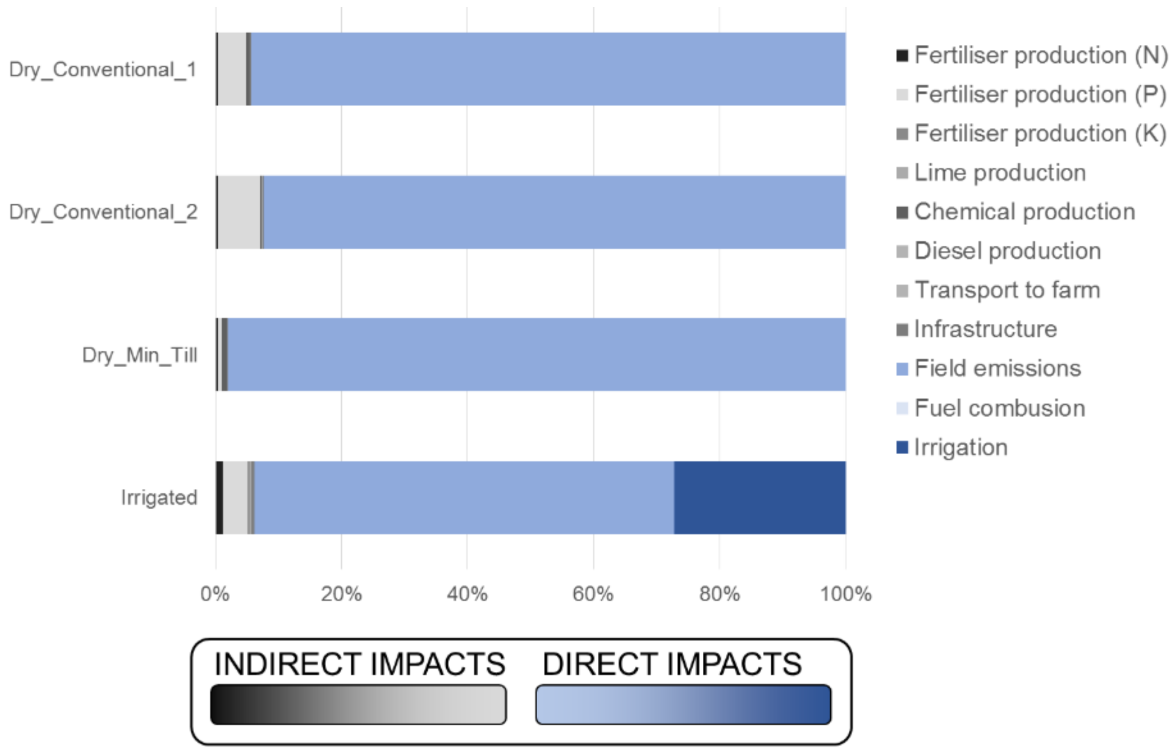


Figure 12: Activity contributions (%) to total freshwater eutrophication associated with wheat production

10.7. Appendix 7: Consolidation of approaches

The benchmark estimates of carbon intensity for wheat and the grain (field crop) sub-sector is shown in Table 9. The LCA approach provided intensity estimates for dry land and irrigated wheat. These bottom-up estimates were then used to calculate overall benchmarks for wheat and the grain (field crop) sub-sector, with the assumption that the carbon intensities would be similar across crop types and production areas. These bottom-up benchmarks, which do not include GHG emissions associated with land use change, are similar to the top-down estimates for the grain sub-sector (described in Appendix 1) and are the best benchmarks available at present.

Table 9: Comparison of carbon intensity benchmarks for the Western Cape wheat and grain sub-sector using bottom-up and top-down approaches

Approach	Western Cape commodity or sub-sector	Details	Carbon footprint*		Total GHG emissions for 2007**	
			Production-based (kg CO_2/t)	Area-based (kg CO_2/ha)	Production-based (Gg CO_2)	Area-based (Gg CO_2)
Bottom-up approach	Wheat	Dry land	330 - 550	990 - 1210	180 - 300	220 - 270
		Irrigated	2340	9360	90	100
		Total	-	-	270 - 380	320 - 370
	Field crops*** (Grain sub-sector)	Dry land	330 - 550	990 - 1210	380 - 630	450 - 550
		Irrigated	2340	9360	550	360
		Total	-	-	930 - 1180	820 - 920
Top-down approach	Grain sub-sector**** (without LULUCF)	National GHG inventory	-	-	1320	
		Eora	-	-	1050	

*Carbon footprints provided by wheat LCAs
**Total GHG emission for wheat and for field crops were calculated using production and area data from the Stats SA Census of Commercial Agriculture 2007 (Stats SA, 2011).
***Assume carbon footprint for wheat is representative for all grain crops (barley, maize, oats, etc.) and that the field crops represent the grain sub-sector.
****Total GHG emissions estimated for the grain sub-sector, excluding GHG emissions from land use, land use changes and forestry (LULUCF).