GreenCape

Regional Resource Flow Model: Livestock and Game Sector Report

Overview of the carbon and resource intensity of livestock, dairy, ostrich and game in the Western Cape

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Author:
Catherine Pineo

Prepared for:
Department of Economic Development and Tourism
Western Cape Government

Contact:
cathy@green-cape.co.za

Signature page

For the GreenCape Sector Development Agency

Name & Surname: Lauren Basson
Position: Strategic Initiatives Manager

______________________ ______________________

Signature: **Date:**

Name & Surname: Evan Rice
Position: Chief Executive Officer

______________________ ______________________

Signature: **Date:**

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Members of the project team:

Name	Organisation	Role
Pieter Janse van Vuuren	GreenCape Sector Development Agency	Analyst
Catherine Pineo	GreenCape Sector Development Agency	Analyst
Chris Millson	GreenCape Sector Development Agency	Project Manager
Lauren Basson	GreenCape Sector Development Agency	GreenCape Projects Manager
Jim Petrie	Department of Economic Development and Tourism, Western Cape Government	Technical Advisor

Project steering committee:

Details of the steering committee members are provided below. The contributions from the steering committee throughout the year is much appreciated.

Name	Organisation
Leann Cloete-Beets	Department of Agriculture, Western Cape Government
Bongiswa Matoti	Department of Agriculture, Western Cape Government
Thami Vilakazi	Department of Economic Development and Tourism, Western Cape Government
Lise Jennings-Boom	Department of Environmental Affairs and Development Planning, Western Cape Government
Karen Shippey	Department of Environmental Affairs and Development Planning, Western Cape Government
Lauren Hermanus	Department of Environmental Affairs and Development Planning, Western Cape Government
Harro von Blottnitz	University of Cape Town
Tatjana von Bormann	World Wildlife Fund
Wendy Engel	World Wildlife Fund
Andre Page	National Cleaner Production Centre

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List of acronyms

AFOLU	Agriculture, Forestry and Other Land Use
ANIR	Australian National Inventory Report
DAFF	South African Department of Agriculture, Forestry and Fishing
DBSA	Development Bank of South Africa
DEA	South African Department of Environmental Affairs (2010+)
DEADP	Western Cape Department of Environmental Affairs and Development Planning
DEDAT	Western Cape Department of Economic Development and Tourism
DEAT	South African Department of Environment and Tourism (1994 – 2009)
DOA	Western Cape Department of Agriculture
EEIO	Environmentally Extended Input Output
EU	European Union
FAO	Food and Agricultural Organisation of the United Nations
GDP	Gross Domestic Product
GHG	Greenhouse Gases
GWP	Global Warming Potential
IPCC	Intergovernmental Panel on Climate Change
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LSU	Large Stock Unit
LULUCF	Land Use, Land Use Changes and Forestry
MRIO	Multi Regional Input Output
RRFM	Regional Resource Flow Model
SAM	Social Accounting Matrix
SAPA	South African Poultry Association
TMR	Total Mixed Ration
WWF	World Wildlife Fund

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1. Background and aims

Agriculture has come under scrutiny both locally and globally due to concerns related to climate change (IPCC, 2007) and other environmental impacts such as land degradation, water depletion and pollution (Meisser et al., 2013b). As all food production has an environmental impact, strategies need to carefully consider the resource productivity of various food products and production systems, to assess the associated trade-offs and economic benefits. 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 (2013/15), the carbon intensity of the provincial economy was examined and the importance of the food value chain (i.e. agriculture, agro-processing and retail) was highlighted. As a result, the second phase (2014/15) examined the agriculture sector in greater detail; specifically focusing on the resource intensity of the Western Cape fruit, grain and animal production sub-sectors.

This report, which is one of several produced by the RRFM project, is specifically focused on the Western Cape animal production sub-sectors. Other reports have focused on wheat (Pineo, 2015), wine grapes (Janse van Vuuren, 2015a) and other fruit: e.g. pome fruit, stone fruit, table grapes and citrus (Janse van Vuuren, 2015b). The purpose of this report is to analyse the carbon intensity of the Western Cape livestock, dairy, ostrich and game sub-sectors. This report focuses on three areas: (a) high-level greenhouse gas emission estimates for these sub-sectors; (b) local studies which provide baseline estimates for different animals and production systems; and (c) an approach to consolidate these estimates and identify areas of uncertainty. Furthermore, the analysis examined the relative resource intensity of agricultural production and processing, including information on water and land use where possible.

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[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. Motivation for analysis

The agricultural sector has a significant effect on climate change, primarily through the production and release of greenhouse gases (GHGs) and through land transformation, which releases carbon stored in biomass and soils (IPCC, 2007). In South Africa, agriculture is responsible for 9.5% of the total GHG emissions in 2010[2] and is the second largest GHG contributor after the energy sector (78.7%). Within agriculture, livestock uses approximately 70% of agricultural land in South Africa (WWF, 2010) and is a major contributor to GHG emissions, highlighting it as a key sub-sector for the RRFM project.

2.1. The link between GHG emissions and climate change

Anthropogenic GHG emissions (i.e. GHG emissions related to human activities) is one of the primary causes of the greenhouse effect - the overall warming of the earth as atmospheric gases trap electromagnetic radiation from the sun. Different GHGs, such as carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) persist in the atmosphere for different lengths of time and absorb different amounts of heat. As a result, measures are needed to determine the relative effects of the different gases (Brander, 2012).

The global warming potential (GWP) is used to indicate the amount of warming caused by a GHG over a given period of time (usually 100 years). For comparative purposes, CO_2 is used as a reference gas for the GWP index; the GWP for all other GHGs is expressed relative to the warming ability of CO_2 and converted to carbon dioxide equivalents (CO_2e). This allows for emissions to be expressed as a single number and can be used to compare totals. In this study the term "carbon intensity" refers to the total CO_2e emissions associated with individual sub-sectors or animal categories.

2.2. The link between livestock and GHG emissions

Livestock directly contribute to GHG emissions through: (a) the emission of methane from animals (enteric methane); and (b) from the emission of methane and nitrous oxide from manure management (du Toit et al., 2013a-b). Methane and nitrous oxide compounds have higher GWP than carbon dioxide; they are 25 and 298 times more effective at trapping heat in the atmosphere respectively when compared to carbon dioxide (100 year timeframe; IPCC, 2006). Furthermore, recent estimations have increased the GWP of methane to 34 when considering climate carbon feedbacks (IPCC, 2013), which take into account the diminishing ability of oceans and soils to absorb carbon dioxide as the climate warms, and the production of additional CO_2 as CH_4 is oxidized in the atmosphere. This provides a strong motivation to examine mitigation strategies targeting livestock, particularly as recent estimates suggest livestock are responsible for 54% of the total national methane emissions (estimates for 2010; DEA, 2014).

Assessing GHG production and the potential impact on climate change is complex; the production of GHGs in livestock is affected by several factors; for example, the animal's digestive system, diet composition, feed quality and intake, production system and manure management (Borhan et al., 2012; Scholtz et al., 2012; Zervas & Tsiplakou, 2012; du Toit et al., 2013a). Ruminants, such as cattle and small stock, are the main contributors of methane in the livestock industry as their digestive process releases methane as a by-product of enteric fermentation (Stevens & Hume, 1995). Non-ruminants, such as poultry, equine and swine, also contribute to methane emissions due to enteric fermentation in the large intestine, but it is emitted in smaller quantities on a per animal basis (EPA, 2013). Thus policies to reduce GHG emissions from livestock generally focus on ruminants.

2.3. The importance of examining relative impacts and establishing baselines

Although there has been a call to drastically reduce livestock numbers and the consumption of livestock products, the potential environmental impact needs to be considered in the wider context; drastic

[2] When excluding carbon sinks (i.e. forestry and other land) which remove CO_2 from the atmosphere and thus reduce total GHG emissions (DEA, 2013).

interventions may have major impacts on employment, socio-economic development, the gross domestic product (GDP) and the economic viability of rural towns and associated communities (Meisser et al., 2013b).

As a result, further analysis of this sub-sector is essential to: (a) examine possible trade-offs between environmental impacts and economic benefits; and (b) establish baselines, in order to facilitate comparisons between production systems (e.g. commercial and communal), identify mitigation interventions and allow for benchmarking progress.

3. Analytical approach

One of the goals of the project was to obtain an understanding of the resource intensity of various sectors and sub-sectors. This was done using two types of approaches: 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 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 for the animal production sub-sectors 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.

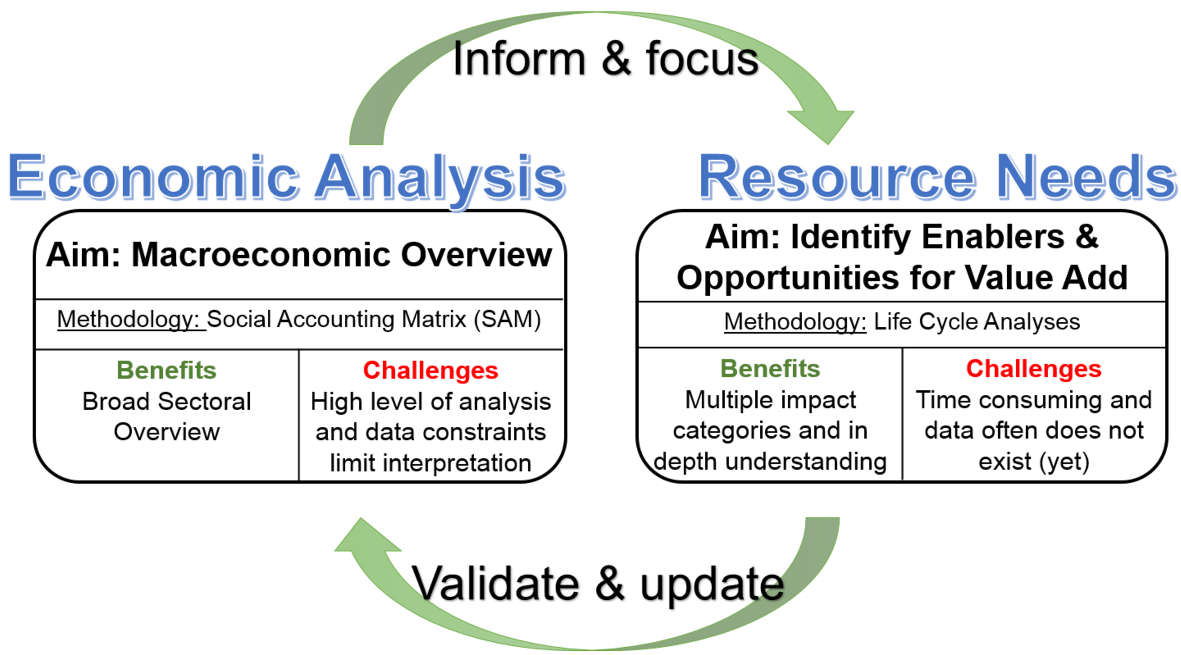

Figure 1: Project overview indicating the complimentary approaches used in the RRFM project.

3.1. Top-down approach

The top-down approach provided carbon intensity benchmarks for different economic sectors and sub-sectors. As high-level aggregated data was used in this analysis, the top-down estimates were used to provide preliminary benchmarks and identify key sectors and value chains for the bottom-up analysis.

3.1.1. Estimates for the animal production sub-sectors

The carbon intensity benchmarks provided for the livestock, dairy, ostrich and game sub-sectors are of particular interest for this analysis. There are two top-down provincial estimates provided for these sub-sectors, obtained by scaling the total national GHG emissions from agriculture. The totals were provided by either: (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 (DEA, 2014).

3.1.1.1. Overview of the 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 (as indicated in Figure 2) based on GDP output ratios provided by the Western Cape Social Accounting Matrix (DBSA, 2006).

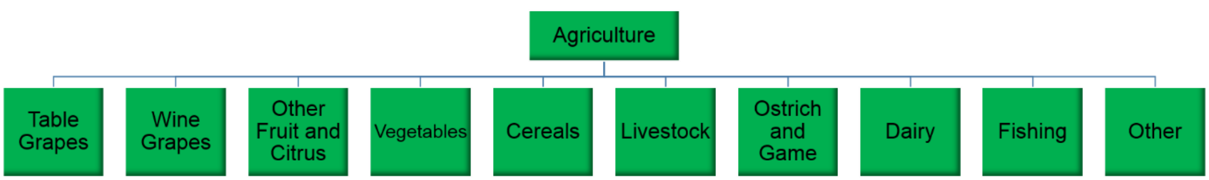

Figure 2: Agriculture sub-sectors in the Western Cape Social Accounting Matrix

For detailed on the Eora MRIO data and the methodology and assumptions refer to the economic analysis report (Janse van Vuuren, 2015c). A brief summary of the methodology and results for the agriculture, forestry and land use (AFOLU) sector in the national GHG inventory (DEA, 2013) is provided in Appendix 1.

3.1.1.2. Limitations of the analysis

It should be noted that the national GHG inventory contained several emission categories within the AFOLU sector (i.e. livestock, land, aggregate sources and non-CO_2 emissions on land, as well as harvested wood products). These categories were not scaled separately and allocated to various sub-sectors due to time constraints (the national GHG inventory was only recently finalised and published in November 2014); only the total agriculture GHG emissions were considered for comparative purposes. Further analysis of the national GHG inventory is planned for 2015/2016, including scaling national GHG emissions using Western Cape data: e.g. land use data from the provincial Department of Agriculture (DOA, 2013).

3.1.1.3. Exclusion of energy-related GHG emissions

The GHG emissions for the agriculture sector and sub-sectors estimates do not include GHG emissions from energy (fuel combustion, electricity, etc.) as these estimates are included in other sectors of the economy (e.g. GHG emissions associated with energy use in agriculture, forestry and fisheries is allocated to the energy sector in the national GHG inventory). This is in line with international recommendations (IPCC, 2007).

3.2. Bottom-up approach

The bottom up component of the RRFM project examines the resource intensity of various sub-sectors and provides a more accurate analysis of their inputs, emissions and potential impacts (e.g. climate change). Bottom-up estimates were developed for livestock, dairy and game in order to: (a) provide an understanding of the carbon intensity per sub-sector; (b) examine the total GHG contributions from various animal categories, from a provincial and national perspective; and (c) evaluate the accuracy of the top-down approach.

3.2.1. National baseline: Total GHG emissions from livestock

Previous agricultural GHG inventories were done on a national scale, using international guidelines developed by the Intergovernmental Panel on Climate Change (IPCC). These studies used IPCC default values (Tier 1 approach) for some or all emission calculations and excluded GHG emissions from game (Blignaut et al., 2005; DEAT, 2009; Otter, 2010).

The Tier 1 approach is limited; the assumptions are often not representative of South African systems and it fails to distinguish between different classes of animals (e.g. lactating sows, replacement sows, weaning piglets, boar pigs) and differences in production systems and their efficiencies (e.g. commercial: intensive and extensive, subsistence: emerging and communal) (du Toit et al., 2013b). As a result, more accurate estimates are required to improve GHG inventories and develop source and province-specific strategies (du Toit et al., 2013c).

To address this, more detailed GHG inventories for South African livestock have been developed and include provincial estimates for direct methane and nitrous oxide emissions from beef and dairy cattle (du Toit et al., 2013a), small stock (du Toit et al., 2013b), poultry, pigs, horses, donkeys, mules and ostriches (du Toit et al., 2013c) and game (du Toit et al. 2013d). These studies were recently used to update the national GHG inventory, which provides a national baseline for livestock (DEA, 2014) and were used to inform the Western Cape analysis (described below).

3.2.2. Provincial baseline: Establishing total GHG emissions for animal production sub-sectors

The GHG emissions from enteric fermentation and manure management was explicitly examined in this study as they form a large component of the agriculture sector's total GHG emissions (DEA, 2014). GHG emissions relating to feed production and land use were not considered due to lack of data.

3.2.2.1. Data collection

The direct methane and nitrous oxide emissions from different animal categories (e.g. cattle, sheep) and production systems (e.g. commercial, communal) were taken from studies that used provincial production data from 2010 (du Toit et al., 2013a-c) or from studies which estimated game large stock units (LSU) per province based on the carrying capacity of the land used for private game farming (du Toit et al., 2013d). Within these studies, population data was cross-referenced with production data provided by various national industry associations and organisations (e.g. slaughter numbers, wool production, milk production, etc.) for verification purposes. Key details on the methodology used by du Toit et al. (2013a-d) is described below.

Methodological approach

The published inventories were created using either a Tier 1 or Tier 2 approach. A Tier 1 approach was used for poultry (e.g. chickens) and equine (e.g. horses) due to the lack of activity data and as a result of their relatively small GHG contribution.

For the more significant animal production systems (cattle, sheep, goats and pigs), the IPCC Tier 2 methodology was adapted to a tropical production system and the authors calculated country-specific emission factors (where possible) or used the methodology and emission factors from the Australian

National Inventory Report (ANIR, 2009), which the authors believe is representative of South African conditions.

Emissions from different production systems (e.g. beef cattle: extensive and intensive, commercial and communal/emerging) were also disaggregated where possible; taking into account various factors such as herd and flock structures, country-specific live weights, veld-type for grazing, dry matter digestibility, and manure management system. Detailed data sources and methodology are outlined in the individual GHG inventories (du Toit et al., 2013a-d).

Assumptions regarding manure management

In extensive production systems (beef cattle, sheep, goats, donkeys, mules, ostriches and game), manure is deposited onto pastures and not directly managed. The nitrous oxide emissions from manure are voided and are reported under the agricultural soils section in a national inventory report, as per IPCC recommendations (du Toit et al., 2013d).

Intensive production systems (such as feedlot beef production, dairy, pigs and poultry) have direct nitrous oxide emissions due to manure management and this is included within their GHG emissions. For horses, it was assumed 40% of manure was managed in dry-lot systems and 60% was voided (du Toit et al., 2013c).

3.2.2.2. Analytical differences between the national and provincial baselines

Ostrich and commercial game GHG estimates were not included in the current national GHG inventory as: (a) poultry enteric GHG emissions were deemed negligible; (b) manure emissions are voided in extensive farming systems; and (c) there was uncertainty in population data. However, these categories were included in this provincial analysis as ostrich production is significant in the Western Cape and the GHG emissions from game (particularly from ruminants such as buffalo) may be significant. The provincial GHG emission estimates were available for these animal categories and these estimates were deemed to be as accurate as possible given current data restraints.

3.2.2.3. Results of the provincial analysis

GHG emissions per sub-sector

The RRFM project calculated the direct GHG emissions (measured in CO_2e) for three sub-sectors: (a) livestock, (b) dairy and (c) ostrich and game, in the Western Cape and South Africa, using the GHG inventories from du Toit et al. (2013a-d). Although ostriches can be classed under the livestock sector, they were aggregated with game farming (see Figure 1 on page 4) in order to follow the structure of the provincial social accounting matrix (SAM) used in the EEIO economic analysis (DBSA, 2006).

The direct GHG emissions per sub-sector are shown in Table 1 for the Western Cape and South Africa. The total GHG emissions were calculated from the methane and nitrous oxide emissions from the livestock studies using the IPCC GWP values for a 100 year time-frame (IPCC, 2001), as done in the national GHG inventory (DEA, 2014). One of the important outcomes from the GHG inventory studies was that South African specific emission factors for cattle, sheep and pigs were not comparable to IPCC default values for developing countries (du Toit et al., 2013a-b), emphasising the importance of developing region-specific emission factors.

From a high level perspective, the total direct GHG emissions contributed by animal production in the Western Cape is 2320 Gg CO_2e per year, with livestock, dairy and ostrich and game contributing with 1400 Gg, 780 Gg and 140 Gg CO_2e per year respectively. Detailed Western Cape GHG emissions per livestock category (cattle, sheep, poultry, etc.), animal type (e.g. Merino, other wool, non-wool and Karakul sheep) and production system (e.g. commercial and communal/emerging) are shown in Appendix 2.

Table 1: Summary of the total direct GHG emissions (in Giga grams CO_2 equivalents per year) emitted from animal production systems in the Western Cape and South Africa.

Agricultural sector	Animal	Type	GHG emissions [1] ($Gg\ CO_2e$ / year)	
			Western Cape	South Africa
Dairy	Cattle [2]	Dairy	777	3091
	Goat [2]	Milk	1.1	4.0
TOTAL			**779**	**3094**
Livestock	Cattle [2]	Beef	813	19236
	Sheep [2]	Merino	205	1872
		Other wool	91	830
		Non-wool	123	1127
		Karakul	0.41	4.6
	Goats [2]	Meat-type	31	865
		Angora	0.78	67
	Pigs [2]	-	32	932
	Other livestock	Donkeys [3]	-	35
		Mules [3]	-	3.3
		Horses [2]	19	137
	Chickens [2]	Broilers	82	796
		Layers	5.0	52
	Other poultry [3]	Ducks	-	0.32
		Geese	-	0.12
		Turkeys	-	1.2
TOTAL			**1403**	**25959**
Ostrich & Game	Ostriches [2]	-	110	184
	Game [4]	Grazers	17	-
		Mixed feeders	7.4	-
		Browsers	0.92	-
		Total	26	3034
TOTAL			**136**	**3218**

[1] The GHG emissions include direct enteric methane emissions, as well as direct methane and nitrous oxide emissions from manure (where relevant). The IPCC 100 year GWPs for methane and nitrous oxide were used (IPCC, 2001) in order to compare totals with the top-down estimates. GHG emissions using updated GWPs are available on request.
[2] GHG emissions calculated using 2010 population data (du Toit et al., 2013a-c).
[3] GHG emissions calculated using FAO national data (du Toit et al., 2013c).
[4] GHG emissions calculated from the estimated large stock units (LSU) per province, using surface area data from 2000. Land area used for game farming has not changed significantly between 2000 and 2010 (du Toit et al., 2013d).

GHG emissions per animal type

Figure 2 below highlights the proportional contribution of various animals to the total GHG emissions from animal production and indicate differences between the Western Cape (outer circle) and South Africa (inner circle). Within primary animal production, dairy cattle and beef cattle are the major contributors to GHG emissions in the Western Cape (34% and 35% respectively), followed by Merino and non-wool sheep (9% and 5% respectively), ostriches (5%), other wool sheep (4%) and broiler chickens (3%). Further detail on the provincial GHG emissions for per animal type (cattle, small stock, mono gastric livestock and game) is discussed in Appendix 3.

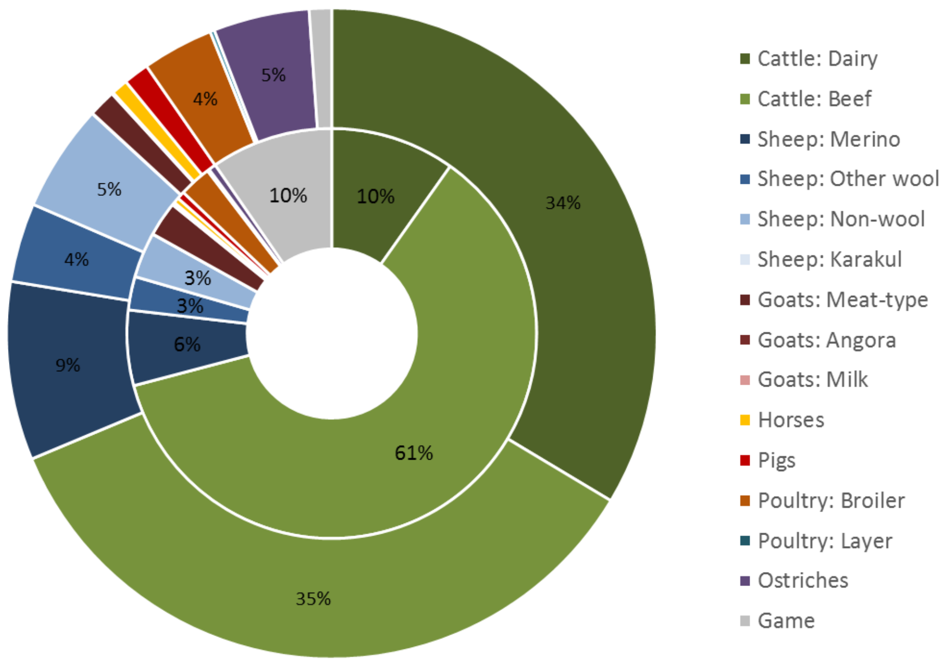

Figure 3: Proportion of GHG emissions from different animal production sectors for the Western Cape (outer circle) and South Africa (inner circle).

As shown in Figure 2, there are notable differences between the national and provincial profile. South African GHG emissions are primarily from beef cattle (61%). Also, game contributions are far more significant at a national level (10% compared to <0.1% for South Africa and Western Cape) while emissions from dairy cattle and ostriches are not as significant (10% and <1% respectively for South Africa, compared to 34% and 5% for Western Cape). This suggests that the Western Cape could choose to prioritise different animal production sectors for provincial mitigation strategies.

Although the GHG emission profile provides a carbon intensity baseline for the province, it is important to note that further work to express the GHG emissions relative to production (Gg CO_2e per kg of wool, meat etc.) or to contribution to the provincial GDP (kg CO_2e for wool per GDP contribution) is better measure of the productivity of sectors and value chains and provides information that may assist policy-makers in developing mitigation strategies. Relative resource intensity of agricultural products is addressed later in the report (Section 5).

4. Consolidation of the different approaches

This report attempts to provide estimates of the carbon intensity for the livestock, dairy and ostrich and game sub-sectors in the Western Cape, using both top-down and bottom-up approaches. Figure 3 demonstrates the different approaches and indicates what information was available for the analysis.

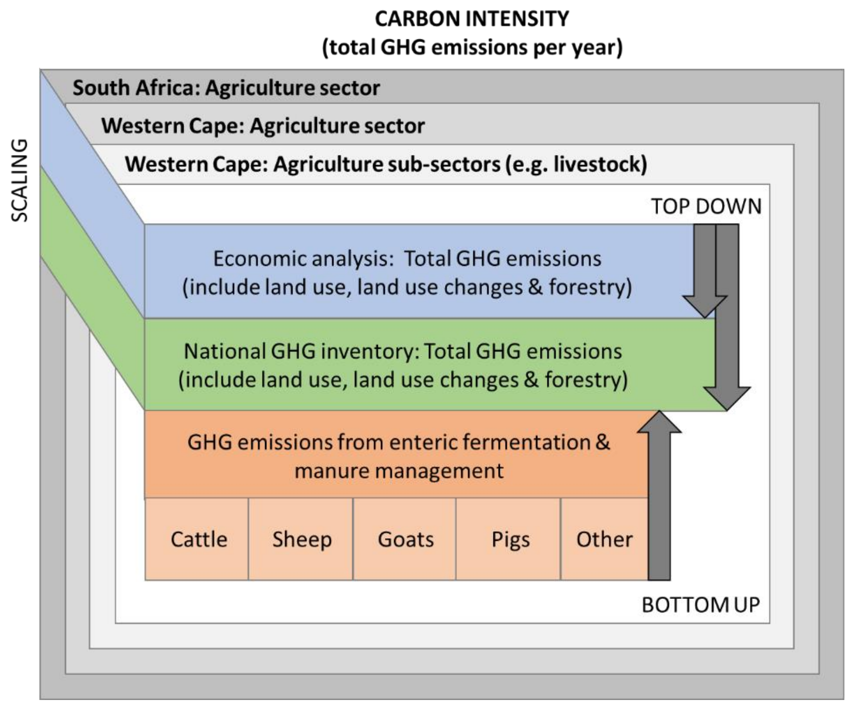

Figure 4: Approaches to estimate and validate the carbon intensity of the animal production sub-sectors in the Western Cape.

The estimates obtained from the different approaches were compared in order to partially validate the top-down estimates and indicate areas of uncertainty in the sub-sector benchmarks.

4.1. Comparison of top-down estimates

Table 2 summarises the GHG emissions for the agriculture sector as a whole and provides the estimates per sub-sector. There are large differences between the top-down estimates, with the estimates from the economic analysis approximately 77% higher than the estimates from the national GHG inventory. Although both top-down estimates included GHG emissions from land use (LU), land use changes (LUC) and forestry (F), there is uncertainty regarding the components included within these estimates.

4.1.1. Estimates from the economic analysis

The economic analysis was based on national data provided by the Eora (Janse van Vuuren, 2015c). The individual sources for the total GHG emissions are difficult to assess as the Eora MRIO model comprises of a very large database and uses numerous data sources (Lenzen et al., 2012; Lenzen et al., 2013). Emissions data are taken from several sources, including the Emissions Database for Global Atmospheric Research (EDGAR), Carbon Dioxide Information Analysis Centre (CDIAC), Intergovernmental Panel on Climate Change (IPCC), and a mix of other regional and national sources. As the methodological reports are currently unavailable (i.e. the reports have yet to be generated according to correspondence with Dan Moran from Eora), the exact data sources are currently unknown.

When examining the data sources that may have been used by the MRIO model, there are several pitfalls; for example, although the CDIAC data is based on South African-specific energy use, the data for GHG emissions related to land use and land use changes arises from a crude Africa figure[3] (Oak Ridge National Laboratory, 2011). Given the heterogeneity of Africa as a whole and the fact that South Africa is relatively developed, this appears to be a large abstraction from reality and thus is a source of uncertainty within the top-down analysis.

4.1.2. Estimates from the national GHG inventory

It has been noted that the national GHG emissions were recently updated to include land and harvested wood products as carbon sinks (Appendix 1), which is most likely not included in the Eora GHG emission data used for the economic analysis. This is observed by the fact that including the LULUCF category in the Eora model results in an increase in GHG emissions for agriculture while the inclusion of LULUCF in the national GHG inventory results in a net decrease (due to carbon sinks).

The difference in the top-down estimates suggest there is uncertainty regarding the contribution of these categories and that GHG emissions associated with land use and land use changes can have a large impact on total GHG emissions. Therefore, while the economic analysis using the Eora MRIO data (Janse van Vuuren, 2015c) provided a first pass indication of relative resource use, the national GHG inventory should be used to consider the resource intensity of sub-sectors, with further analysis required to provide adequate insight at a provincial level.

4.2. Comparison of the top-down and bottom-up estimates

The total GHG emissions from enteric fermentation and manure management are indicated in Table 2 and provide a partial estimate of the carbon intensity per sub-sector. When the GHG emissions from LULUCF are excluded, the top-down values from the economic analysis and the national GHG inventory are within the bottom-up range, particularly for the livestock sub-sector (1,920 to 1,510 vs. 1,400 Gg CO_2e per year respectively) and the dairy sub-sector (630 to 800 vs. 780 Gg CO_2e per year respectively), with a variation of 2 - 37% when compared to the bottom-up estimates. Thus the bottom-up estimates appear to partially validate the values obtained in the economic analysis.

There is a higher variation within the ostrich and game sub-sector (230 – 280 vs. 140 Gg CO_2e per year respectively), with the top-down scaled estimates 65 – 109% higher than the Western Cape value. This is most likely caused by scaling, which assumes that the carbon intensity and GDP output is similar across the agriculture sector. Thus animal production systems with low carbon intensities, such as extensive game farms, will be overestimated.

4.3. Consolidation of estimates

At present, data constraints limit any further analysis. The bottom-up GHG emission estimates are incomplete and do not include GHG emissions from other important categories (e.g. land use, land use changes). Although the RRFM plans to scale the national GHG emissions to the Western Cape using provincial land use data, there is a lack of data on soil carbon and there remains a great deal of uncertainty regarding land use changes and their impact, even at a national level. As a result, the current GHG emissions per sub-sector fall within a broad range defined by the bottom-up estimates, which are limited but appear to be the most accurate, and the top-down estimates, which may be less accurate but include additional GHG emissions and carbon sinks from land. Based on the analyses, the annual GHG emissions are: 950 – 1400 Gg CO_2e per year for the livestock sub-sector, 400 – 780 Gg CO_2e per year for the dairy sub-sector and 140 Gg CO_2e per year for the ostrich and game sub-sector.

[3] ftp://cdiac.ornl.gov/pub/Smith_Rothwell_Land-Use_Change_Emissions/

Table 2: GHG emission estimates for animal production sub-sectors, using top-down and bottom-up approaches. The scaled GHG emission estimates are indicated in grey.

Approach	Source / Calculation	GHG emissions ($Gg\ CO_2e$ per year)				
		National	Western Cape			
		Total Agriculture Dry land	Total Agriculture Dry land	Animal production sub-sectors [4]		
				Livestock	Dairy	Ostrich & Game
Top-down: Scaled national estimates	EEIO economic analysis (2010): Total (include LULUCF) [1]	110 730	26 210	4100	1700	610
	National GHG inventory (2010): Total (include LULUCF) [2]	25 710	6090	950	400	140
Bottom-up: Provincial estimates	Enteric & manure GHG emissions (2010) [3]	-	-	1400	780	140
Validation: Bottom-up comparison to the relevant top-down estimates	EEIO economic analysis (2010): Sub-total (exclude LULUCF)	40 880	9680	1510 (8% higher)	630 (19% lower)	230 (65% higher)
	National GHG inventory (2010): Sub-total (exclude LULUCF)	51 790	12 260	1920 (37% higher)	800 (2% lower)	280 (109% higher)
Consolidation: Total per sub-sector	**Range between top-down and bottom-up approaches (include LULUCF) [5]**	**-**	**-**	**950 - 1400**	**400 - 780**	**140**

[1] Economic analysis: total GHG emission estimates obtained using an environmentally extended input output model (EEIO), using input output data for South Africa (2010). Estimate includes GHG emissions from land use, land use changes and forestry (LULUCF).
[2] The national GHG inventory does not include direct GHG emissions from game and there are uncertainties within the soil and land use categories. Nationally, the total 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) (Table 5.1; DEA, 2014). The land use, land use changes and forestry (LULUCF) GHG emissions are referred to as FOLU in the national GHG inventory documentation.
[3] Provincial estimates for dairy, livestock and game enteric and manure GHG emissions provided by several studies (du Toit et al., 2013a-d). Methane and nitrous oxide emissions converted to CO_2e using the same GWP used in the national GHG inventory (IPCC, 2001).
[4] GHG emissions based on 2010 population data, except game where large stock unit numbers were estimated (du Toit et al., 2013d).
[5] Assume the total agricultural GHG emissions from the recent national GHG inventory are the most accurate top-down measure of carbon intensity per sub-sector.

5. The relative carbon and resource intensity of animals and animal-based products

5.1. Assessing production efficiency

The production efficiency, which varies between production systems (e.g. conventional, organic, intensive and extensive), is a key factor in determining the relative resource intensity and impact of production systems. Organic systems, which are often perceived as low input systems which may provide a means of sustainable production (Scollan et al., 2010), are also associated with low outputs; at least four studies on US milk production indicated that milk production is 15% - 27% lower in organic systems than in conventional ones (Capper et al., 2009a). Furthermore, the organic systems were more resource intense (land, feed, water, etc.) per unit of milk and were associated with greater environmental impacts when compared to conventional systems. Even within conventional systems, technological advances have also played a significant role in improving production and resource efficiency: modern conventional systems require less resources, produce less waste and have a smaller environmental impact than older systems, for both milk production and beef production (Capper et al., 2009b; Capper, 2011).

5.1.1. The production efficiency in South Africa

Meisser et al. (2013b) discusses the production efficiencies of various systems in detail and provide benchmarks for the commercial production of beef and dairy cattle, pigs, sheep, and goats in South Africa. Specifically, Meisser et al. (2013b) examines biological efficiencies (take-off or slaughter rates, feed efficiency, etc.) which are partially under the control of the farmer. The key conclusion from the analysis was that improvements in the biological production efficiency should be a priority as it can have a substantial effect on reducing the relative water use and GHG emissions per unit product. For example; the relative amount of feed, water and methane emissions per kilogram of beef can be reduced by more than 20% if the calving rate is improved by 20% (Meisser et al., 2013b). The key results for various animal categories are highlighted below.

5.1.1.1. Beef cattle and swine production

It was noted that improvements could be made in commercial beef and pork production in comparison to developed countries, however the major scope for improvement was in small-scale categories (i.e. emerging farming) with low access to markets and negative biological factors (low reproductive rates, high mortality and incorrect herd / flock composition).

5.1.1.2. Sheep and goat production

Although the off-take rates for South African commercial sheep and goats is low compared to some countries, this is accounted for by the inclusion of wool sheep and mohair-producing goats which have low slaughter rates due to the emphasis on fibre-production.

5.1.1.3. Poultry production

In contrast to other animals, the South African broiler industry compares favourably with global competitors when examining production efficiency (1.8 – 2.0 kg of feed required per kg chicken meat), however, the major impacts on competitiveness are disease and increasing feed costs (SAPA, 2010a; SAPA, 2010b).

5.2. Assessing the relative resource intensity

This study provided provincial GHG emission baselines for various animals and animal production sub-sectors (see Section 4). Although useful for benchmarking purposes, these baselines only provides a partial insight into the value and impact of animal-based products as it only assesses the carbon intensity of the first stage of the value chain: animal production.

There is a need to examine the **relative** carbon and resource intensity of animals and animal-based products in order to examine possible opportunities, constraints and trade-offs. This has been assessed using a variety of approaches:

Approach 1: A simplistic approach which provides the relative carbon intensity for a group of products sourced from a single animal category (e.g. sheep products). As these estimates do not consider the full life cycle and value of individual products, the carbon intensities are regarded as crude and incomplete.

Approach 2: A more robust approach which uses carbon footprints to assess the carbon intensity of products across a value chain or life cycle. Although the results are product-specific the study is still limited to assessing GHG emissions and the impacts related to GHG production (e.g. climate change).

Approach 3: A rigorous approach using life cycle assessments (LCAs), which consider the resource use and impact across several stages of a product's life cycle; e.g. from resource extraction to the farm gate (cradle-to-gate) or from resource extraction through to retail, use and disposal (cradle-to-gate). Although the LCAs provide detailed information (e.g. material, water and energy use and their related impacts), the amount of relevant agricultural LCAs are limited. This is due in part to the extensive data requirements required to develop life cycle inventories (LCIs), particularly as South Africa has yet to develop a LCA database.

The studies which used these different approaches is discussed in greater detail, with the key results summarised in Table 3 below.

Table 3: The relative carbon intensity (i.e. CO_2e) of animal products.

Category	Enteric fermentation and manure management						Carbon footprint [7]		
	National methane emissions [4] (CH_4)			National GHG emissions [5] (CO_2e)			National carbon intensity [6, 7] (CO_2e)	Provincial LCAs [8, 9]	Carbon intensity of developed countries [9] (CO_2e)
	Gg / yr	g / kg	kg / R1000	Gg / yr	kg / kg	kg / R1000	kg / kg	kg / kg	kg / kg
Beef cattle: meat [1]	557	707	42.3	12811	16	973	25 - 35	-	14 – 32
Dairy cattle: milk [1]	130	49.9	14.3	2990	1.1	329	1.3 - 1.5	On farm: 1.0 - 1.6 With processing: 1.3 – 1.9 With retail & consumption: 1.7 - 2.9	0.84 - 1.4
Sheep: mutton, lamb & wool [1]	151	853	39.1	3473	20	899	-	-	-
Goats: meat & mohair [1]	18	1027	35	414	24	805	-	-	-
Pigs: meat [2]	7.64	-	-	176	-	-	-	On farm: 3.8 With slaughtering: 4.4 With shipping: 4.5	Pork: 3.9 – 10
Poultry: meat & eggs [2]	3.28	-	-	75	-	-	-	-	Chicken: 3.7 – 10 Eggs: 3.9 - 4.9
Game: products, hunting, translocation & translocation [3]	132	-	19.1	3036	-	439	-	-	-

[1] Commercial production systems. Meat production for communal and small scale livestock sectors are currently unknown.
[2] GHG emissions are too low to calculate realistic estimates per kg product and per R1000 GDP contribution (Meisser et al., 2013b).
[3] Unable to quantify.
[4] Methane emissions expressed relative to national production and GDP figures from 2008/9 (DAFF, 2010).
[5] Converted using the same GWP from IPCC (IPCC, 2001) as used in the national GHG inventory.
[6] Beef meat: includes GHG emissions from grass burning, slaughtering and processing.
[7] Milk: assumed total carbon intensity includes other farm and processing emissions as done for beef meat - limited information provided (Meisser et al., 2013b).
[8] Results from Western Cape-specific LCAs for milk (cradle-to-fork: on farm, processing, distribution, retail and consumer) and pork (cradle-to-overseas port: provision of raw materials and feed, pig farming, slaughterhouse and waste treatment).
[9] Summary of LCAs for developed countries (De Vries & de Boer, 2010).

5.2.1. Approach 1: Assessing the partial carbon intensity of animal products

5.2.1.1. Overview

Some work has been done to examine the carbon intensity of animal products at a national level (Meisser et al., 2013b), expressing methane emissions from enteric fermentation and manure management of livestock (du Toit et al., 2013a-d) in relation to the amount of animal product generated (e.g. meat) and its contribution to GDP (DAFF, 2010). For the purpose of this report, the methane emissions provided by Meisser et al. (2013b) were converted to carbon dioxide equivalents using the GWPs (IPCC, 2001). The results are summarised in Table 3.

5.2.1.2. Results

Nationally, dairy production has the lowest GHG emissions per kilogram of milk (1.1 kg CO_{2e} per kg of milk), while beef meat, sheep products (mutton, lamb and wool) and goat products (meat and Mohair wool) are associated with higher GHG emissions (16 kg, 20 kg and 24 kg CO_2e per kg product respectively).

Relative to their GDP contributions, dairy production and game have the lowest emissions (329 and 439 kg CO_2e per R1000 GDP contribution), followed by goat products, sheep products and beef meat (805, 899 and 973 kg CO_2e per R1000 GDP contribution). Poultry and pig products were not estimated due to accuracy uncertainties (Meisser et al., 2013b).

5.2.1.3. Key conclusions

The study provided rough estimates of the relative carbon intensity of products (or product groups), however the intensities were expressed relative to **national** GDP contributions, thus their significance may differ in the provincial context. Providing more accurate provincial estimates are envisioned for the next phase of the project (2015/16), where the carbon intensity from total enteric and manure GHG emissions (results from the provincial baseline analysis provided in Table 1) is expressed relative to Western Cape production and GDP contributions.

It's important to note that these estimates provide a **partial** insight into the relative productivity of animal production; the estimate excludes other production-related GHG emissions (e.g. GHG emissions associated with land use changes, energy use and fodder production), which may make up a significant proportion of the carbon intensity. For example, enteric methane and manure GHG emissions only make up 44 – 72% of the total carbon footprint for raw (unprocessed) milk production in the Western Cape (Notten & Mason-Jones, 2011), with 28 – 56% contributed from other sources. As a result, the carbon intensity of land use, feed production etc. should be included to obtain accurate intensities associated with animal production. This can be done by: (a) scaling the national GHG inventory estimates to the Western Cape using provincial consumption and land use surveys (DOA, 2013); and (b) using estimates from life cycle analyses (e.g. carbon footprints and life cycle assessments), which are described below.

5.2.2. Approach 2: National GHG emission benchmarks for beef and milk production

5.2.2.1. Overview

Meisser et al. (2013b) provided more detailed national estimates of the carbon intensity of beef and milk, including additional on-farm GHG emissions (e.g. grass burning) and contributions from slaughtering and processing. Details are summarised in Table 3.

5.2.2.2. Results and key conclusions

These national estimates are still fairly crude but provide a benchmark of 25 - 35 kg CO_2e per kg beef and 1.3 - 1.5 kg CO_2e per L milk, which is within the upper range of carbon footprints from developed countries

(De Vries & de Boer, 2010). Furthermore, these results are comparable to those reported in a Western Cape milk LCA (1.3 – 1.9 kg CO_2 per L processed milk; Notten & Mason-Jones, 2011).

5.2.3. Approach 3: The resource intensity and impact of pork and milk production in the Western Cape

Detailed estimates of carbon and resource intensities associated with livestock production are provided by life cycle assessment (LCA) studies. LCAs, which can include a carbon footprinting component, provide a holistic view of a system, considering the potential impacts across the lifetime of a product or service. There are two LCA studies of particular importance to this analysis: Western Cape LCAs for pork (Devers et al., 2012) and milk (Notten & Mason-Jones, 2011). A brief summary of the relevant components and results are described below.

5.2.3.1. Pork production

Overview

A comparative LCA of Western Cape and Flemish pork production examined several impacts related to: (a) the production of raw materials and feed, (b) pig farming, (c) slurry treatment, (d) the slaughterhouse, and (e) the shipping of pork to a distribution centre (Devers et al., 2012). The resource use and impacts associated with the pre-farm and on-farm activities was of particular interest for this agricultural analysis and provided the relative resource intensity for pig production. Furthermore, the importance of slaughtering activities in relation to energy use and carbon intensity was highlighted in the study and provides motivation for a post-farm analysis.

Results

In brief, the total carbon footprint of the Western Cape supply chain is 4.5 kg CO_2e per kg pork, which is comparable to estimates from developed countries (LCA results range from 3.0 – 10 kg CO_2e per kg pork; De Vries & de Boer, 2010). The production of slaughter pigs, including feed and raw material inputs into the piggery and the treatment of slurry, has a carbon footprint of 3.8 kg CO_2e per kg (84% of the total), while slaughtering activities were also significant; contributing 0.56 kg CO_2e per kg (12% of the total) to the value chain. The production of pigs was also the major contributor to other impacts, contributing 98% and 82% to potential eutrophication and acidification respectively (0.0033 kg PO_4e and 0.052 kg SO_2e per kg pork).

Key conclusions and recommendations

The energy use and total carbon footprint was 41% and 44% lower respectively for Flemish pork when compared to imported Western Cape pork. The slaughterhouse and pig farming activities were highlighted as showing the greatest relative difference and scope for improvement (Devers et al., 2012).For example, the electricity consumption of pig farms in the Western Cape is almost double when compared to Flanders due to the use of heat bulbs rather than central heating in the piggery (Devers et al., 2012). In addition, local slaughterhouses are ten times more carbon-intense due to higher electricity consumption (1.66 MJ per kg pork compared to 0.28 MJ per kg pork) and the coal-based electricity generation mix of South Africa. Thus focused efforts to improve electricity efficiency and employing the use of alternative energy sources on farms and in slaughterhouses may reduce the impact of Western Cape pork.

It was also noted that the Western Cape scored poorly in all impact categories when the quantity of pork meat (i.e. kg pork) is used as the basis of comparison. However, no spatial factors taken into account. Regional and local environmental impacts (e.g. eutrophication and acidification) are more harmful in Flanders than in the Western Cape because of the higher farming intensity. As a result, the Western Cape could be competitive when impacts are measured in terms of the production area, particularly as the impacts of transport to Europe was minimal (3.7% of the carbon footprint). Therefore, Devers et al. (2012) recommended that future studies of intensive livestock or poultry production chains assess impacts based on the unit of product (e.g. kg of meat) and the production area (e.g. per hectare), particularly when measuring eutrophication and acidification impacts.

5.2.3.2. Western Cape dairy production

Overview

An LCA on fresh milk production in the Western Cape analysed the impacts along the full supply chain (Notten & Mason-Jones, 2011). The impacts included global warming potential (i.e. a measure of the carbon footprint), acidification, eutrophication, fossil fuel depletion, water depletion and biodiversity (which reflected the impacts of land use). The study highlighted environmental hotspots and trends, although the small sample size (5 farms) and limited consumer sample restrict the use of the study for assessing the magnitude of impacts in the province as a whole.

Results

The total impacts of milk from production to consumer is summarised below in Table 3. The proportional contributions from the dairy farm and processing stages of the LCA were specifically indicated for each impact category, as our analysis is focused on the on-farm production milk with a view to extend the analysis into processing. The raw milk production, which includes off-site feed production, has the highest contribution to all impacts (26 - 99%), although the contribution to fossil fuel depletion (non-renewable energy use) was not as dominant (26 – 37% contribution to fossil fuel depletion vs. 51 - 99% contributions for the other impacts).

Table 4: Total impact of milk in the Western Cape over its entire value chain (i.e. milk production and processing through to distribution, retail and the consumer) and a detailed breakdown of the percentage contributions from two life cycle stages: milk production and processing.

<table>
<tr><th rowspan="2">Impact category</th><th rowspan="2">Total impact at the consumer (per L milk)</th><th colspan="3">Contributions (%)</th></tr>
<tr><th>Raw milk production*</th><th>Milk processing</th><th>Total: Raw milk production and processing</th></tr>
<tr><td>Global warming potential (kg CO_2e)</td><td>1.7 - 2.9</td><td>51 - 58</td><td>10 - 18</td><td>61 - 70</td></tr>
<tr><td>Eutrophication potential (kg PO_4e)</td><td>0.004 - 0.009</td><td>85 - 92</td><td>2 - 4</td><td>88 - 94</td></tr>
<tr><td>Acidification potential (kg SO_2e)</td><td>0.018 - 0.026</td><td>60 - 73</td><td>6 - 16</td><td>71 - 79</td></tr>
<tr><td>Fossil fuel depletion (kg oil equivalents)</td><td>0.45 - 0.58</td><td>26 - 37</td><td>11 - 20</td><td>38 - 55</td></tr>
<tr><td>Water consumption* (m^3 water)</td><td>0.52 – 1.27</td><td rowspan="2">96 - 99</td><td rowspan="2">1 - 3</td><td rowspan="2">99 - 100</td></tr>
<tr><td>Water depletion** (m^3 fresh water extracted from ecological reserve)</td><td>0.13 - 0.40</td></tr>
<tr><td>Land occupation (m^2)</td><td>2 - 31</td><td rowspan="2">97 - 98</td><td rowspan="2">>1</td><td rowspan="2">97 - 98</td></tr>
<tr><td>Biodiversity** (m^2 of threatened land)</td><td>Critical land: 0.02 - 1.2
Endangered land: 0.11 - 0.44
Vulnerable land: 0.07 - 0.78</td></tr>
</table>

*Water consumption refers to soil and extractive water (i.e. blue and green water)
**Water depletion and biodiversity are indicators developed specifically for this milk LCA. See the full report for details (Notten & Mason-Jones, 2011)

As the focus of our study was the resource intensity of agricultural production (i.e. on-farm impacts), the contributions to the dairy farm carbon footprint are summarised below in Table 4. The range indicates the significant variation between the five dairy farms.

Table 5: Percentage contributions to the impact of raw milk production in the Western Cape (i.e. up to farm gate)

Impact category	Contributions to the impact of raw milk production (per L milk)						
	Enteric methane	Manure	Purchased feed	Transport to farm	Fertiliser, pesticides & herbicides	On-farm electricity use	On-farm diesel use
Global warming potential (kg CO_2e)	26 - 40	18 - 32	5 - 41	1 - 8	2 - 15	6 - 14	2 - 6
Eutrophication potential (kg PO_4e)	-	36 - 84	8 - 62	0.2 - 2	1 - 2	1 - 10	0.4 – 2.0
Acidification potential (kg SO_2e)	-	52 - 81	4 - 38	-	2 - 4	6 - 14	1 - 4
Fossil fuel depletion (kg oil equivalents)	-	-	14 - 77	3 - 17	3 - 40	13 - 36	3 - 12

Carbon footprint

The overall carbon intensity of milk over its entire life cycle was 1.7 - 2.9 kg CO_2e per litre of milk across a section of farming systems (intensive, stall-based and pasture-based systems), farm sizes and geographical areas. The farm was highlighted as the most carbon-intensive portion of the supply chain (1.0 - 1.6 kg CO_2e per litre of milk), although the processing, retail and consumer stages of the supply chain were higher than reported globally (0.30, 0.24 and 0.34 kg CO_2e per litre of milk respectively). The carbon footprint of the dairy farm is comparable to other developed countries (De Vries & de Boer, 2010) and significant variation was also reported in the UK, where the carbon footprint of dairy farms was 0.83 kg to 2.8 kg CO_2e per L milk across production systems (DairyCo, 2012).

Water use

In terms of water use, 520 - 1270 litres of water was required per litre of milk. This included “green” water (rainwater consumed from crop production) and “blue” water (consumption of surface and groundwater, e.g. for irrigating crops and used for feed and drinking water). The majority of green and blue water was used for growing feed and for pasture, while direct water use on the farm and across the supply chain was small (<3%). The milk LCA also examined the significance of water use by considering where the water was extracted and how it impacts the health of the ecosystem. A total of 130 - 400 litres of water per litre milk was extracted from catchments operating below their ecological reserves, i.e. from water catchments under stress (Notten & Mason-Jones, 2011).

Land use

Land requirements ranges from 2000 – 3100 m^2 per year per 1000 L milk at the consumer. Intensive farms require less land for the dairy farm itself, however when the land use for growing feed off-site is considered the land use is similar to pasture farms. Using a biodiversity indicator developed by the study, 10 - 70% of the land use was “threatened” (vulnerable, critical and endangered), with pasture-based systems having a lower impact relative to intensive systems.

Key conclusions and recommendations

As highlighted previously, improved productivity (e.g. higher milk yields per cow, increased longevity and reduced herd replacement rate) can reduce the relative resource intensity of dairy farms (DairyCo, 2012; Meisser et al., 2013b).

Within the Western Cape, suggested interventions for the dairy farms included: (a) reducing enteric methane emissions by improving feed formulations; (b) evaluating where purchased feed is grown, as the choice in feed supplier can reduce a farm’s water and biodiversity impact; (c) improve water and energy efficiency in irrigation; and (d) the use of bio-digesters to reduce methane emissions from manure, off-set heat and electricity costs and provide compost. The study also emphasised that the impacts related to water and land use were not straight-forward; the impacts are not directly linked to total consumption or land area, but rather to the location of the farm (Notten & Mason-Jones, 2011).

The authors also noted that there was potential for interventions beyond the dairy farm. These included: (a) utilising economies of scale in diary processing; (b) the use of energy efficient and alternative technologies for heat and steam pasteurisation; (c) reducing electricity consumption of display fridges in retail stores; and (d) measures to extend the shelf life of milk and thus avoid wastage (Notten & Mason-Jones, 2011).

6. Conclusions and recommendations

Knowledge on the relative resource intensity of key agricultural commodities will be important to strategic decision makers; especially given the current focus by provincial government on supporting agriculture and developing agro-processing, while simultaneously striving to develop a greener, low carbon economy. As agricultural production is carbon-intense, utilises a high proportion of land and may be severely affected by water scarcity issues (Meisser et al., 2013b), an understanding of the intensities is vital to understanding the relative opportunities and impacts in these sectors.

This report provided an analysis of the carbon intensity of the Western Cape livestock, dairy, ostrich and game sub-sectors. The carbon intensity is particularly important for some export supply chains where there is demand for low carbon products (e.g. European Union) and in terms of developing provincial mitigation strategies. A complete GHG inventory for agricultural emissions does not currently exist for the Western Cape (DEAT, 2009; WCG, 2013), although an updated national GHG inventory has recently been released (DEA, 2013). Carbon intensity baselines were calculated using both top-down and bottom-up approaches. The top-down approach provided estimates of GHG emissions per sub-sector and the bottom-up approach was used to partially validate the estimates provided by the economic analysis. The bottom-up approach also provided a more detailed understanding of the proportional contributions of GHG emissions from various animal types and highlighted the relative importance of commercial beef cattle, dairy cattle, sheep and ostriches in the Western Cape. Major gaps in the bottom-up analysis included estimates of GHG emissions from land use and land use changes. Approaches to address these gaps are not currently feasible; however, the RRFM project will refine the top-down estimates from the national GHG inventory by scaling GHG emissions using Western Cape land use (2015/16) and update the baselines for the sub-sectors.

Resource productivity is linked to production efficiency. Alternative production and management systems can be utilised to improve the resource intensity associated with animal production systems and animal-based products. This is discussed in greater detail within the individual GHG inventory studies (du Toit et al., 2013a-d), with efforts to improve production efficiency highlighted as paramount for enhancing competitiveness and resource productivity (Meisser et al., 2013b). National studies have indicated that the competitiveness of primary animal production is low, predominantly due to production inefficiencies. This is especially true for commercial cattle and pigs, primarily due to low reproductive rates. Alternatively, the poultry industry is on par with global competitors, however major concerns for the industry include disease, rising feed costs and subsidised imports (Meisser et al., 2013b). Addressing inefficiencies may be a relatively simple way to reduce carbon and water footprints per unit product and it has been recommended that commodity organizations, farmer support bodies and research institutions take the lead to address this. Furthermore, intensive poultry, piggeries and dairy farms were recommended to use covered dams or lagoons in manure management, in order to reduce methane emissions (Meisser et al., 2013b).

In this study, the importance of using a life cycle based approach was highlighted in order to understand the relative resource intensity and impact of products and make strategic decisions regarding possible trade-offs. Although the current analysis focused specifically on the primary stage (i.e. animal production), detailed LCAs have indicated the relative resource intensities and impacts associated with Western Cape milk and pork products. Furthermore these LCAs highlighted several possible opportunities to improve resource efficiency and reduce environmental impacts in the production and processing of the products, including improvements in feed formulations and energy efficiency (Notten & Mason-Jones, 2011; Devers et al., 2012). Further analysis of the resource intensity of Western Cape food and other animal-related products (e.g. GHG emissions per kg ostrich meat) 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), with details provided in Section 7 below.

7. Moving forward

7.1. Examining the carbon intensity of the value chain

Although the total carbon intensities per animal type (Table 1) and production system (Appendix 2) are useful in assessing the carbon intensity within the provincial sub-sectors, they do not represent the carbon intensity of the product as a whole: they exclude GHG emissions associated with other stages of the value chain, specifically agro-processing. By extending this analysis to include agro-processing (as has been done for milk and pork), the **relative carbon intensity** of key animal products in the Western Cape can be considered and used for benchmarking within local and global markets.

7.2. Examining the resource productivity of agro-processing

There is a need to examine the **economic opportunities** and **resource constraints** within agro-processing, particularly as it has been highlighted as a key ‘game changer’ for the province (Project Khulisa, 2014) and understanding its resource needs are key to ensure the planned expansion is done sustainably. To address this, the RRFM project plans to examine agro-processing in greater detail using a meta-analysis to examine the relative resource intensity and value-add of agricultural products (2015/16). A summary of the information available for an analysis of agro-processing is provided in Appendix 4.

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9. Appendices

9.1. Appendix 1: Summary of agriculture, forestry and other land use

The GHG emissions from the agriculture, forestry and other land use (AFOLU) sector in the national GHG inventory (DEA, 2013) were used to create top-down estimates of GHG emissions for provincial sub-sectors. These top-down estimates were compared to the GHG emission estimates from the economic analysis (see "consolidation of sub-sector estimates"). A brief summary of the scope of the inventory and an overview of the AFOLU sector is provided below.

9.1.1. Scope of the inventory

The scope of the national inventory is important for comparative purposes. The emissions from the AFOLU sector were based on IPCC 2006 guidelines (IPCC, 2006) and the GWPs used for the calculation of the total GHG emissions (CO_2e emissions) are outdated – the GWPs used were those published in the IPCC third assessment report (IPCC, 2001). The AFOLU GHG inventory contained several emission categories which are detailed below in Table 5.

Table 6: Emission categories included within the agriculture, forestry and other land use (AFOLU) sector in the national GHG Inventory (DEA, 2014).

Category	Sub-category	IPCC section
Livestock	Enteric fermentation	3A1
	Manure management [1, 2, 3]	3A2
Land [4]	Forest land [5]	3B1
	Cropland	3B2
	Grassland	3B3
	Wetlands	3B4
	Settlements	3B5
	Other land	3B6
Aggregate sources & non-CO_2 emissions on land	Biomass burning [6]	3C1
	Liming	3C2
	Urea application	3C3
	Direct N2O emission from managed soils[2]	3C4
	Indirect N2O emission from managed soils	3C5
	Indirect N2O emission from manure management	3C6
Other	Harvested wood products	3D

[1] Manure management includes all emissions from confined, managed animal waste systems.
[2] Methane emissions from livestock manure produced in the field during grazing are included under manure management (Section 3A2) however the nitrous oxide emissions from this source are included under direct nitrous oxide emissions from managed soils (Section 3C4).
[3] Methane emissions from managed soils are regarded as non-anthropogenic and are not included (IPCC 2006 guidelines).
[4] Land use includes land remaining land as well as land conversions. This only includes mineral soil carbon pools (organic soils estimated insignificant, dead organic matter excluded due to insufficient data).
[5] Losses of carbon dioxide emissions from biomass burning for forest land are included under "losses due to disturbance in the forest land" (Section 3B1) and not in "biomass burning" (Section 3C1).
[6] Section 3C1 deals with non-carbon dioxide emissions from biomass burning in all land use types.

For the AFOLU sector, the updated inventory contained: (a) improved methodologies in the livestock category; (b) new land use maps; and (c) methodological changes, such the inclusion of harvested wood products, the inclusion of woodlands in forest land and updating the land sub-sector data to include carbon dioxide losses from fires in forest lands.

Specifically within the livestock category, the inventory included: (a) a greater disaggregation of the livestock populations; (b) updated activity data; and (c) more appropriate enteric and manure management CH4 emission factors based on recent studies (du Toit et al., 2013a-d). Despite these improvements, the inventory for the AFOLU sector is incomplete. The categories that were excluded due to lack of data are summarised below (Table 6).

Table 7: Categories excluded from the AFOLU sector in the national GHG inventory (2013).

Excluded categories [1, 2]	Reason
Harvested wood products	Insufficient data
Land use change	Insufficient data, large uncertainties
Dead organic matter	Information required over a 20 year period (IPCC 2006 default time period), data not available
Ostrich and game (including buffalo) [3]	Poultry enteric fermentation GHG emissions assumed negligible, insufficient and uncertain population data

[1] Fuel combustion emissions were excluded from the AFOLU sector but not from the national GHG inventory (DEA, 2013). The emissions are included in the energy sector, under the agriculture, forestry and fisheries category.
[2] Rice cultivation and the "other" category was excluded as they are not applicable to South Africa.
[3] Enteric emissions from buffalo and other wildlife are estimated to contribute a further 10% to enteric GHG emissions (du Toit et al., 2013d).

Importantly, the land category in the updated inventory does not include dead organic matter within the soil component due to insufficient data. Furthermore, although both "land remaining land" and "land converted to other lands" has been included in the finalised national GHG inventory, the version sent out for public comment (Witi & Stevens, 2013) states that land use changes were not initially included due to insufficient data and large uncertainties. This appears to have been rectified by the use of a basic IPCC Tier 1 approach, however the estimates may not be as accurate as other areas analysed within agriculture. As a result, it is important to note that the land use category is far from complete and requires further data validation.

9.1.2. Overview of the AFOLU sector

The AFOLU sector is an overall source of GHG emissions with fluctuations primarily caused by land use changes. In 2010, GHG emissions were reduced by 19,871 Gg CO_2e from land-based sinks and 6,205 Gg CO_2e from harvested wood products, resulting in total GHG emissions of approximately 25,714 Gg CO_2e for the AFOLU sector. Livestock contribute 28,986 Gg CO_2 (56%) and aggregate sources and non-CO_2 emissions on land contribute 22,803 Gg CO_2 (44%).

9.1.2.1. Livestock

Within the AFOLU sector, methane emissions were responsible for 38.5% of GHG emissions in 2010 (DEA, 2014). Livestock emissions decreased between 2000 and 2010, from 31,119 to 28,986 Gg CO_2e per year. Enteric fermentation accounted for an average of 93% of the GHG emissions from livestock, with cattle as the largest contributors (82%): 88% from beef cattle and 12% from dairy cattle. Following this are the contributions from sheep (14%) and goats (3%).

9.1.2.2. Land and harvested wood products

The land component is estimated to be a carbon sink, varying between -8,119 and -24,585 Gg CO_2e per year in 2000 to 2010. Annual fluctuations are primarily the result of changes in carbon stocks in forest lands and land use changes in croplands. Harvested wood products, which were included for the first time in the inventory, also act as a carbon sink with estimates of -5,025 to -9,419 Gg CO_2e per year. No particular trend was apparent within the 10 year period.

9.1.2.3. Aggregated and non-CO_2 emission sources

Emissions from aggregated and non-CO_2 emission sources fluctuated annually, with estimates between 22,184 to 23,863 Gg CO_2e per year in 2000 to 2010. Fluctuations are primarily driven by changes in biomass burning, as well as liming and urea application.

For further details on livestock, land, harvested wood products and aggregate sources and non-CO_2 emissions on land please see the national GHG Inventory (DEA, 2014).

9.2. Appendix 2: Calculated GHG emissions from South African studies

The total methane, nitrous oxide and carbon dioxide equivalent emissions per animal type and production system are shown below in Table 7 and are based on several published studies (du Toit et al., 2013a-d). GHG emissions were calculated using the GWP published in the IPCC third assessment report (TAR) (IPCC, 2001). Although there are updated GWPs available (IPCC, 2007; IPCC, 2013), the 2001 GWPs were used by the national GHG inventory and were used in the analysis for comparative purposes. Total GHG emissions calculated using the updated IPCC GWPs are available on request.

Table 8: Total direct GHG emissions (in Giga grams CO_2 equivalents per year) emitted from animal production systems in the Western Cape and South Africa.

Livestock	Type	Production system	GHG emissions [1, 2] (Gg CO_2e / year)			
			CH_4	N_2O	Total CO_2e	
			Western Cape	Western Cape	Western Cape	South Africa
Cattle	Dairy	Commercial	32	0.13	777	3091
	Beef	Commercial	22	-	495	12123
		Communal	11	-	258	6349
		Feedlot	0.18	0.0014	4.6	764
		Total	35	0.0014	813	19236
Total			**67**	**0.13**	**1534**	**22327**
Sheep	Merino	Commercial	8.1	-	186	1696
		Communal	0.84	-	19	177
		Total	8.9	-	205	1872
	Other wool	Commercial	3.6	-	82	752
		Communal	0.37	-	8.5	78
		Total	4.0	-	91	830
	Non-wool	Commercial	4.9	-	112	1021
		Communal	0.50	-	12	105
		Total	5.4	-	123	1127
	Karakul	Commercial	0.016	-	0.38	4.3
		Communal	0.0017	-	0.039	0.37
		Total	0.018	-	0.41	4.6
Total			**18**	**-**	**420**	**3834**
Goats	Meat-type	Commercial	0.53	-	12	343
		Communal	0.83	-	19	522
		Total	1.4	-	31	865
	Angora	Commercial	0.034	-	0.78	67
	Milk	Commercial	0.047	-	1.1	4.0

Total			**1.4**	**-**	**33**	**936**
Equine	Horses	Not stated	0.67	0.012	19	137
	Donkeys	Not stated	-	-	-	35
	Mules	Not stated	-	-	-	3.3
Total			**0.67**	**0.012**	**19**	**275.3**
Swine	Pigs	Commercial	1.20	0.0023	28	180
		Communal	0.019	0.0020	1.0	12
Total			**1.22**	**0.0043**	**29**	**193**
Chickens	Broiler	Commercial	0.26	0.24	77	747
	Broiler breeders	Commercial	0.017	0.016	5.1	49
		Total	0.27	0.26	82	796
	Layer	Commercial	0.060	0.012	4.9	51
	Layer breeders	Commercial	0.00070	0.00014	0.057	0.58
		Total	0.061	0.012	5.0	52
Total			**0.33**	**0.27**	**87**	**848**
Other poultry	Ducks	Not stated	-	-	-	0.32
	Geese	Not stated	-	-	-	0.12
	Turkeys	Not stated	-	-	-	1.2
Total			**-**	**-**	**-**	**1.7**
Ostriches	Ostriches	Not stated	4.8	-	110	184
Total			**4.8**	**-**	**110**	**184**
Game	Grazers	Game farming	0.76	-	17	-
	Mixed feeders	Game farming	0.32	-	7.4	-
	Browsers	Game farming	0.040	-	0.92	-
Total			**1.1**	**-**	**26**	**3034**
GRAND TOTAL FOR ANIMAL PRODUCTION SECTORS			**95**	**0**	**2315**	**31492**

[1] Total GHG emissions include direct enteric methane emissions, as well as direct methane and nitrous oxide emissions from manure (where relevant), based on population data from 2010.
[2] Total GHG emissions (CO_2e) were calculated using the GWP from IPCC (2001): CH_4 = 23, N_2O = 296. These GWP are lower than the updated values: CH_4 = 25 – 34, N_2O = 298 (IPCC, 2007; IPCC, 2013).

9.3. Appendix 3: Summary of the GHG emissions per animal type

9.3.1. Cattle

A detailed study calculated the GHG emissions per province from dairy and beef cattle (du Toit et al., 2013a). For dairy cattle, the herd structure and two major production systems were considered in calculating enteric methane emissions; a pasture-based and a total mixed ration system (TMR) system. The calculated GHG emissions only refer to commercial production, as dairy cattle in the communal/emerging sector had low milk yields that excluded them from the definition and were thus incorporated under communal beef cattle.

As beef cattle production systems in SA are mainly extensive and based on natural pastures (i.e. veld), the herd structure, production system and diet was considered in the calculation of GHG emissions, with three types of veld considered: sweetveld, sourveld and mixed veld. The proposition of veld per province was estimated and seasonal variation in veld quality and digestibility was taken into account when calculating diet intake and GHG emissions. Feedlot cattle emissions were based on the intake of specific diet components calculated from a feedlot diet analysis (ANIR, 2009) and based on the assumption that cattle remain in the feedlot for approximately 110 days.

GHG emissions from the manure management of dairy, beef and feedlot cattle were calculated using a combination of IPCC default values and country-specific values (du Toit et al., 2013a). Direct nitrous oxide emissions from manure were reported for dairy and beef feedlot production systems and were voided for extensive production systems, as recommended by the IPCC (IPCC, 2006).

For dairy cattle, the volatile solid component of manure was calculated (ANIR, 2009), and the type of manure management system was considered, with both the pasture-based and TMR production systems primarily using lagoon management systems (90% and 88.5% respectively). For beef cattle, the different manure management systems associated with extensive and feedlot (intensive) systems were considered. Beef cattle production is mainly extensive with manure deposited directly onto pastures and thus is not actively managed. As manure-based methane emissions from extensive livestock systems appears to be minimal (in environmental conditions similar to South Africa), manure emissions were calculated using emission factors from ANIR and other studies (Gonzalez-Avalos & Ruiz-Suarez, 2001; ANIR, 2009). For intensive feedlot systems, manure is primarily managed by “dry packing” (du Toit et al., 2013a) and thus a drylot system was used to estimate potential GHG emissions.

Nationally, dairy and beef cattle contribute 3,090 and 19,240 Gg CO_2e per year respectively, with beef cattle in extensive systems being the largest contributor (83%), followed by dairy (14%) and then beef cattle in intensive feedlot systems (3%). The Western Cape contributed 25% (780 Gg CO_2e per year) and 4% (810 Gg CO_2e per year) to the national GHG emissions associated with dairy and beef cattle respectively. In the Western Cape, dairy cattle comprise a far larger proportion of emissions allocated to cattle production (51% of provincial emissions) in comparison to beef cattle, which contribute 32%, 17% and <0.5% respectively from commercial (extensive), communal/emerging (extensive) and commercial feedlot (intensive) systems respectively.

Authors reported that South Africa-specific enteric methane emission factors for concentrate-fed and pasture-based dairy cattle production systems were higher than the IPCC default values for developing countries and factors reported for developing countries (du Toit et al., 2013a). In addition, the beef cattle methane emission factors for commercial and communal/emerging production systems were also higher than the IPCC default values for developing countries, although similar to those reported by other developing countries (du Toit et al., 2013a). This highlights the importance of using Tier 2-based calculations for animal production sectors which have relatively large GHG contributions.

9.3.2. Small stock

The study examined the GHG emissions from sheep and goats, taking into consideration breed type, live weights per age and breed, flock compositions, differences in production systems (e.g. a live weight reduction for communal animals) and diet, amongst others (du Toit et al., 2013b).

The Western Cape small stock sector contributed 450 Gg CO_2e per year (20% of the Western Cape emissions from livestock and ostriches). Commercial sheep production was responsible for the majority of emissions (84%), with Merino, non-wool, other wool (i.e. dual purpose breeds) and Karakul sheep contributing 49%, 29%, 22% and <1% respectively. Western Cape goat production (commercial and communal/emerging) was responsible for 33 Gg of emitted CO_2e per year, with meat-type, milk and Angora goats emitting 94%, 3% and 2% respectively. The communal/emerging meat-goat sector was significant within goat production, comprising of 58% of total provincial emissions from goats (calculations based on provincial emission data published by du Toit et al., 2013b).

The authors of this study noted that the commercial or communal emission factors calculated for South African sheep and goats were not comparable with IPCC default values for developed or developing countries. As a result, it was recommended that provincial small stock emission studies be implemented to develop accurate baseline figures and support mitigation protocols (du Toit et al., 2013b). Furthermore, the South Africa-specific methane emission factors (calculated in kg methane per head per year) varied according to sheep type (with Karakul sheep having the lowest factor, followed by Merino, non-wool and other wool sheep breeds) and production system (with commercial goat and sheep production associated with higher factors), suggesting changes in the stock type and production system may be a strategy for reducing emissions within this sector.

9.3.3. Monogastric livestock

As the non-ruminant (monogastric) livestock sector is a minor contributor compared to ruminant GHG emissions, there is a limited amount of research to quantify direct emissions from these sources. As a result, only swine GHG emissions were based on IPCC Tier 2 calculations, while those from equines and poultry were based on IPCC Tier 1 default values.

For the Western Cape, non-ruminant livestock (specifically pigs, horses, chickens and ostriches) are responsible for 250 Gg CO_2e emissions per year (11% of total provincial livestock and ostrich GHG emissions), in comparison to ruminants (beef cattle, sheep and goats) which annually emit 1,990 Gg CO_2e (89% of total provincial livestock emissions) (calculations based on provincial emission data published by du Toit et al., 2013c). Within the monogastric livestock, ostrich production systems have the highest contribution (45%), followed by chicken production (35%), pigs (12%) and horses (8%). Further information on these animal categories is detailed below:

9.3.3.1. Pigs

Nationally, pig production is responsible for approximately 190 Gg CO_2e per year, with the Western Cape contributing 15% (30 Gg CO_2e per year). Within the Western Cape, the commercial sector is responsible for 96% of GHG emissions from pig production (calculations based on provincial emission data published by du Toit et al., 2013c). The calculated emission factors for pigs are higher than IPCC default factors for developing countries but comparable to developed countries such as North America, Canada and Australia (du Toit et al., 2013c).

Manure is the largest direct GHG emission source in commercial and communal pig production (du Toit et al., 2013c). Liquid manure storage is the most common practice in South African commercial production, (93.5% of manure management systems employ this approach, according to a report to the authors from the South African Pork Producers Organisation). The communal sector differs in terms of manure management: the extensive or semi-intensive production systems are associated manure deposited on pasture or stored in drylot systems. Although drylot systems have higher nitrogen emission factors than lagoon or slurry systems (0.02 compared to 0.001 N_20-N per kg N excreted), the methane conversion factors for liquid manure management systems (such as lagoon systems or slurries) are far higher than drylot systems or spreading on pastures, with factors of 90% and 35% compared to 1.5% and 0.5% respectively (ANIR, 2009). Thus, the production system and manure management are factors which affect GHG emissions and should be considered in mitigation strategies, along with the fibre content of the diet which can influence the amount of methane emitted from pigs (Verge, 2009).

It is worth noting that there was a large discrepancy between the national GHG emissions associated with the pork industry when comparing the recent GHG inventory (7.87 Gg methane per year, 0.04 Gg nitrous oxide per year; based on 2010 data) (du Toit et al., 2013c) and the previous GHG inventory commissioned by Department of Environment and Tourism (53.1 Gg methane per year, 0.89 Gg nitrous oxide per year; based on 2004 data) (DEAT, 2009). This was primarily explained by a wide variation in population numbers between inventories, due to major differences in national statistics and industry figures. In addition, the previous GHG inventory was done on a Tier 1 level using default values for methane and nitrous oxide, resulting in methane emission factors being far higher; 20.73 kg methane per animal per year (DEAT, 2009) compared to the South Africa-specific emission factor of 13.19 kg methane per animal per year (du Toit et al., 2013c).

9.3.3.2. Chickens

The poultry industry is the largest direct nitrous oxide producer within the non-ruminant livestock industries, and the GHG emissions associated with chicken production are primarily from manure (du Toit et al., 2013c). As a result, the calculations were based on the Tier 1 approach and excluded enteric methane emissions (IPCC, 2006). It was assumed that broiler production used a 34 day growth period with an average of eight production cycles per year (based on a South African commercial chicken producer for "Rainbow Chickens") and Australian emission factors were used to calculate the GHG emissions. It is important to note that: (a) only emissions from commercial production were examined, as data on communal chicken populations is not available; and (b) the population data for the classes of poultry were obtained from the South African Poultry Association (SAPA), which aggregated the Western Cape and Northern Cape provinces. As a result, the emissions were split evenly between these provinces.

Nationally, chicken production is responsible for 850 Gg CO_2e per year, with the broiler industry responsible for the majority of GHG emissions (94%). Although enteric methane emissions were not included, du Toit et al. (2013c) estimates that these emissions may increase the national total methane emissions from chicken production by 68%, based on USA poultry enteric emission factors (Burns et al., 2008). This suggests that further work to develop Tier 2 South African poultry emission factors may be necessary for accurate estimates.

In the Western Cape, poultry GHG emissions are estimated to be 87 Gg CO_2e per year, with the majority of the emissions from the broiler industry (94%) (calculations based on provincial emission data published by du Toit et al., 2013c). Provincial emissions from chicken production are estimated to be ~10% of the national total, however, due to the aggregated Western and Northern Cape population figures, the actual total may lie between 0 - 20%.

9.3.3.3. Equine

Equine (horses, donkeys and mules) are minor contributors to the livestock GHG emissions. Only provincial emissions associated with horses could be estimated, with Western Cape responsible for 14% of national horse GHG emissions (19 Gg CO_2e per year; calculations based on provincial emission data published by du Toit et al., 2013c). South African emissions from donkeys and mules were based on national population data sourced from the Food and Agriculture Organisation of the United Nations (FAO). The emissions are minimal, even at a national level, with a total of 38 Gg CO_2e per year (<0.05% of the total GHG emissions allocated to the livestock and ostrich sectors). As a result, we can assume the emissions are negligible.

9.3.3.4. Ostriches and other poultry

Previous GHG inventories did not include ostriches and other poultry (ducks, geese and turkeys). Although other poultry are minor sources, which are not usually included in emission inventories (ANIR, 2009), South Africa is a major supplier of ostrich products globally (Brand & Jordaan, 2011) and 60% of ostriches are located within the Western Cape (based on a report from the National Ostrich Processors of South Africa to the authors). As a result, the GHG emissions from ostriches should be considered in provincial and national studies.

Ostriches are non-ruminants and were included in the monogastric livestock study conducted by du Toit et al. (2013c), using an IPCC Tier 1 approach and Australian emission factors from ANIR (2009). In the Western Cape, ostriches directly contribute 110 Gg CO_2e per year and make up 5% of the livestock sector GHG emissions (calculations based on provincial emission data published by du Toit et al., 2013c). In contrast to South African trends (where chicken and pig production are more significant), the Western Cape ostrich GHG emissions exceed chicken production emissions by 27%.

9.3.4. Game

Previous GHG inventories excluded game, which is a significant national sector within agriculture. Recently, a South African study calculated the methane and nitrous oxide emissions from privately owned game animals utilizing different diets (55%, 65% and 75% digestibility for grazers, mixed feeders and browsers respectively). As there is a great deal of uncertainty in the estimation of GHG from game (primarily due to conflicting individual population numbers), game emissions were calculated according to the grazing capacity of the province. This takes into consideration both the surface area used for game farming and the ecological carrying capacity of the land, which was disaggregated into five regions: grassland, lowveld, bushveld, kalahari and karoo. Based on the proportion of animal types per ecological region, game populations per province were estimated in terms of large stock units (LSU).

The commercial game industry in South Africa emits an estimated 3,030 Gg of CO_2e per year (calculations based on provincial emission data published by du Toit et al., 2013d). The Western Cape, which contains 2.56% of South Africa’s total game farm surface area, is responsible for only 0.85% of the total GHG emissions from commercial game farming, with 68%, 29% and 4% emitted by grazers, mixed feeders and browsers respectively. Although the significance of game emissions in the Western Cape is minimal, it is worth noting that: (a) the authors (du Toit et al., 2013d) have also reported estimates of methane emissions per animal for selected game species (e.g. elephant, giraffe, eland, etc.), which could be used by individual game farms to estimate their carbon footprint; and (b) the emission factors for some game species have been compared to commercial livestock (giraffe, eland and buffalo were compared to commercial beef cattle and small antelope were compared to small stock animals), which may be useful when considering land use changes within the agricultural sector.

9.4. Appendix 4: Mapping agro-processing

Several national and provincial studies have provided information on the resource use and impact of livestock and livestock products. Table 9 and 10 summarise the information available to examine resource use and impacts of animal-based products. Although the data available is limited for some products, the estimates could be used to inform a provincial meta-analysis of agro-processing and map resource intensity and economic trade-offs. This will be considered in the next phase of the project. Key studies which describe stages beyond primary animal production (i.e. agro-processing) are described in greater detail below.

9.4.1. Water consumption of dairies and abattoirs

Current estimates for various dairy products are provided by Meisser et al. (2013b) and indicate high variation; in some cases water required to process the same product may vary by more than 100%. These are 2.0 - 3.2 L water per litre UHT milk, 10 - 27 litre water per kilogram semi-hard cheese, 15 - 20 litre water per kilogram milk powder and 7 - 10 litre water per kilogram yoghurt. Furthermore, global and South African water use estimates range from 80 to 540 L per kg of red meat, which suggests efforts to examine water consumption within dairies and abattoirs may be beneficial.

Water consumption targets for these industries are available (Steffen, Robertson & Kirsten Inc., 1989a-c), however they are dated and recent estimates from dairies suggest that some processors are unaware of or do not comply with targets (Meisser et al., 2013b) Red meat abattoirs have a specific water intake of 1.36 to 2.04 m^3 per cattle unit with targets set at 1.10 - 1.75 m^3 per cattle unit. For poultry abattoirs, the specific water intake was 17 - 20 L per bird with targets set at 15 – 20 L per bird (depending on the grading of the abattoir).

9.4.2. The resource intensity and impact of wool processing in South Africa

A South African LCA case study focused on wool production sourced from Merino sheep in the Eastern Cape and included processing and dying stages (Brent & Hietkamp, 2003). Although the details of the inventory (inputs and emissions) are useful, the comparison of different impact methodologies was the primary motivation for the study rather than an analysis of the production system itself. Furthermore, the study is dated and the resource use and impacts related to sheep production are not necessarily representative of the Western Cape, unlike the pork and dairy studies. As a result, the input to this stage of the analysis was limited; however, the study may be of use when examining agro-processing.

9.4.3. The resource intensity and impact of the processing of pork and milk in the Western Cape

As described earlier in the report, the Western Cape pork and milk LCAs provide details on several life cycle stages, including the stages relevant to agro-processing (Devers et al., 2012; Notten & Mason-Jones, 2011).

Table 9: Map of the national and provincial baseline information available for resource use and impacts of animal production / products

Study type	Product	Area	Scope	Per unit product									Per R1000 GDP contribution
				Resource			Impact						Impact
				Water use	Land use	Energy use	Carbon footprint	Eutrophication	Acidification	Fossil fuel depletion	Biodiversity	Other	Carbon footprint
National baseline	Beef	South Africa	On farm: enteric fermentation and manure GHG emissions	X	X	X	y	X	X	X	X	X	y
			On farm, grass burning, slaughtering, processing	X	X	X	y	X	X	X	X	X	y
			Abattoir	T	X	X	X	X	X	X	X	X	X
	Milk	South Africa	On farm: enteric fermentation and manure CH4 emissions	X	X	X	y	X	X	X	X	X	y
			On farm, milk processing	X	X	X	y	X	X	X	X	X	y
			Dairy processing	P	X	X	X	X	X	X	X	X	X
			Dairy processing	T	X	X	X	X	X	X	X	X	X
	Sheep products	South Africa	On farm: enteric fermentation and manure CH4 emissions	X	X	X	y	X	X	X	X	X	y
			Abattoir	T	X	X	X	X	X	X	X	X	X
	Goat products	South Africa	On farm: enteric fermentation and manure CH4 emissions	X	X	X	y	X	X	X	X	X	y
	Pork	South Africa	On farm: enteric fermentation and manure CH4 emissions	X	X	X	?	X	X	X	X	X	?
			Abattoir	T	X	X	X	X	X	X	X	X	X
	Poultry products	South Africa	On farm: manure CH4 emissions	X	X	X	?	X	X	X	X	X	?
			Abattoir	T	X	X	X	X	X	X	X	X	X
	Game products, hunting, translocation & translocation	South Africa	-	X	X	X	X	X	X	X	X	X	y
Provincial baseline	Beef, dairy, sheep and goat products, pork, poultry, game	Western Cape	On farm: enteric fermentation and manure GHG emissions	X	X	X	FW	X	X	X	X	X	FW

Table 10: Map of the LCA information available for resource use and impacts of animal production / products

Study type	Product	Area	Scope	Per unit product									Per R1000 GDP contribution
				Resource			Impact						Impact
				Water use	Land use	Energy use	Carbon footprint	Eutrophication	Acidification	Fossil fuel depletion	Biodiversity	Other	Carbon footprint
LCA	Milk	Western Cape	On farm, processing, retail and consumer	Y	Y	X	Y	Y	Y	Y	Y	X	X
LCA	Pork	Western Cape	Pre-farm, on-farm, slaughterhouse, waste (slurry) treatment, overseas transport	X	X	Y	Y	Y	Y	X	X	X	X
LCA	Wool	South Africa	Sheep production, wool production	M	M	M	M	M	M	M	X	M	X

Legend

Y	Yes - Detailed estimates from Western Cape LCA studies (Notten & Mason-Jones, 2011; Devers et al., 2012).
y	Yes (partial) - Partial estimates for South Africa (Meisser et al., 2013b).
M	Maybe - Estimates from a South African LCA case study (Brent & Hietkamp, 2003).
P	Current estimates for dairy products (Meisser et al., 2013b).
T	Target benchmarks for dairies, red meat and poultry abattoirs (Steffen et al., 1989a-c).
?	Values too low to estimate relative carbon intensity accurately (Meisser et al., 2013b).
FW	Possible to estimate given provincial production and GDP values (GHG emissions provided in this study).
X	No data available (to our knowledge)