MULTIPLE FOOTPRINT INDICATOR ASSESSMENT: IMPLICATIONS ON CONSUMER PREFERENCES AND WELFARE

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DECLARATION

I, Enoch Owusu-Sekyere, hereby declare that:

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DEDICATION

I dedicate this thesis to my wonderful and supportive family, especially my parents (Mr and Mrs Owusu-Sekyere) and fiancée (Elizabeth Nyameke) for all their financial, material and spiritual support, and sacrifices made throughout my education. Without your financial, material and spiritual support, and sacrifices, this dream would never have become a reality. Great thanks and appreciation go to my pastors, J.C. Nyamekye and George Sharneck, for their encouragement, prayers and financial support throughout my academic journey; I dedicate this work to them. Finally, this thesis is dedicated to Mr William Selover.

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ABSTRACT

Assessments of multiple environmental footprint sustainability indicators, such as water and carbon footprints, are regarded as cornerstones in achieving the world's sustainability goals and the reduction of the freshwater scarcity risk. Water and carbon footprint assessments are gaining much prominence because about four billion people face severe water scarcity across the globe amidst climate changes and population growth. Attaining environmental sustainability in terms of carbon emissions and water use, as well as economically efficient water use, requires detailed and thorough assessment that is not limited to a single indicator. The prevailing environmental impacts relating to water scarcity and carbon emissions in South Africa require in-depth and comprehensive information on water and carbon footprints to effectively guide South African policy and decision makers in formulating appropriate policies to guide freshwater use and reduce greenhouse gas (GHG) emissions. Hence, the main objective of this research was to conduct a multiple footprint indicator assessment of the dairy industry, with particular emphasis on the water and carbon footprints of milk produced and processed in South Africa. Additionally, the study assessed the impact of carbon and water footprint sustainability attributes on consumers' behaviour and welfare in South Africa. The economic productivity of water utilisation along the dairy value chain was also explored.

The Water Footprint Network assessment methodology was employed to examine the water footprint and economic water productivities of dairy products in South Africa for the periods 1996–2005 and 2006–2013. The findings reveal that the total water footprints of the selected dairy products considered in this study are higher than the global averages. During the latter period (1996 to 2005), South African dairy producers utilised more green water in their dairy production. Products such as butter and cheese, whether grated or not grated, powdered or not powdered, and blue-veined and cheese of all kinds, had the highest total water footprints among all the dairy products in South Africa. In terms of production system, the study reveals that dairy production under a sole grazing (mainly pasture-fed) system has high water footprints and low economic water productivities, relative to mixed production systems, for the period 2006–2013. Therefore, given that blue water is becoming scarcer in South Africa, it is imperative for dairy livestock producers to shift their production to a system that is economically productive and has low water footprints. The water footprints of most of the dairy products for period 2006–2013 have reduced by varying amounts, relative to 1996–2005,

which shows that water users along the dairy industry chains are managing water cautiously. The research findings have shown that dairy products have high economic water productivities, and suggest that profit maximising and environmentally sustainable dairy producers and water users should integrate both blue water sustainability and economic water productivity indicators in their production decisions.

Regarding economic water productivity assessments along the dairy value chain in South Africa, the findings from this research reveal that the value added to milk and water as it moves along the value chain varies from stage to stage, with the highest value being attained at the processing level, followed by the retail and farm gate levels, respectively. The conclusion drawn from this finding is that milk production in South Africa is economically efficient in terms of water use. However, water utilisation for feed production accounts for about 98 % of the total water footprint of milk with 3.3% protein and 4% fat. Despite the high proportion of water used in feed production, the study suggests that feed production is economically efficient in terms of cost and water use. It is worth concluding that not all economically water productive feed products are significant contributors to milk yield. Therefore, it is important for future ecological footprint assessments to take into account the value added to output products and economic water productivities along the product's value chain, rather than relying only on water footprint estimates.

The Life Cycle Assessment approach was applied to examine the carbon footprint of milk, as well as the parameters that account for the largest impact on the carbon footprint of milk produced under the total mixed ration (TMR) feeding system in South Africa. The total carbon footprint of milk with 4% fat and 3.3% protein produced and processed in South Africa was 2.72 kg CO_2e per kg. Specifically, methane accounted for 58% of the total carbon footprint, followed by nitrous oxide (31.6%) and carbon dioxide (10.5%), respectively. About 99% of the methane emissions emanated from enteric fermentation. More than half of the direct nitrous oxide emitted came from excreta and manure management. Fertiliser production and application alone accounted for about 78% of the total carbon dioxide emitted along the milk product chain. Findings from a sensitivity analysis revealed that, by reasonably changing one emission parameter, holding all the others constant, the total carbon footprint could increase considerably by about 17%. The study further highlights the point that the key parameters that need much attention in the estimation of GHG emissions are the methane emission factor for enteric fermentation and the emission factor for direct nitrous oxide emission, as well as dry matter intake. The main conclusion from these findings is that in order to attain more accurate and consistent carbon footprint estimates at national and regional levels, it is imperative to expand our knowledge on key practices, activities and parameters that affect key contributors to carbon footprints. This suggests the establishment of country- and regional-specific emission factors to be used as benchmarks for calculating carbon footprints at local and regional levels, and across industries.

The discrete choice experiment and latent class modelling technique were employed to examine consumers' stated preferences for water and carbon footprint-labelled food products from the viewpoint of low- and high-income South African consumers. It was interesting to find that there are varying consumers' preference attitudes towards environmentally sustainable attributes between low- and high-income classes. Thus, there are profoundly heterogeneous consumer segments within low- and high-income classes. This heterogeneity in preferences within both sub-samples is better explained at the segment level, rather than at the individual level. The study reveals that there are more distinct consumer segments among low-income consumers, relative to high-income consumers. It was found that the low-income class consisted of water sustainability advocates, carbon reduction advocates, keen environmentalists, and environmental neutrals. The high-income class, on the other hand, comprises keen environmentalists, environmental cynics, and environmental neutrals. The conclusion drawn from these findings is that the inherent significant variations in preferences for environmentally sustainable attributes across segments and income groups opens room for the formulation of feasible and segment-specific environmental sustainability policies and marketing strategies aimed at changing consumers' attitudes towards environmentally sustainable products. The study suggests the demographic targeting of consumer segments, sustainability awareness, and segment-specific educational campaigns designed to enhance subjective and objective knowledge of environmental sustainability as policy options that can be adopted to promote environmental sustainability and marketing of environmentally sustainable food products.

In terms of welfare implications, the study adopted the compensating surplus welfare estimation approach and ascertained that the welfare effects arising from water and carbon footprint sustainability policies will have varying effects on different consumer classes. This suggests that there are pertinent segmental equity issues that need to be addressed when designing environmental sustainability policies in South Africa. Future studies on preferences for environmentally sustainable products should not be limited to willingness to pay estimates only; rather, compensating surplus estimates should also be computed for efficient and effective policy guidance.

A conceptual framework is provided, which depicts relevant factors to be considered in order to fully understand consumers' preferences and choice of environmentally sustainable products in South Africa. Additionally, this research has provided a framework for environmental footprint labelling and methods for estimating and conveying footprint information on food products in South Africa. Generally, this research concludes that it is expedient to achieve an integration of multiple footprints indicator assessments that establish harmonisation and benchmarks for sustainable and economically efficient water use and GHG emission reduction in arid and semi-arid regions such as South Africa. Water and carbon footprint assessments comprise an expedient tool for evaluating the possible impact of food production and products on water resources and climate change.

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ALCA	Attributional Life Cycle Analysis
BAU	Business-As-Usual
BFAP	Bureau for Food and Agricultural Policy
BSI	British Standard Institute
CF	Carbon Footprint
CIE	Centre for International Economics
CLCA	Consequential Life Cycle Analysis
CSIR	Council for Scientific and Industrial Research
CWR	Crop Water Requirement
DAFF	Department of Agriculture, Forestry and Fisheries
DEA	Department of Environmental Affairs
DOE	Department of Energy
DWA	Department of Water Affairs
FAO	Food and Agricultural Organization
FD	Freshwater Depletion
FEI	Freshwater Ecosystem Impacts
FPCM	Fat and Protein Corrected Milk
FU	Functional Unit
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GWFS	Global Water Footprint Standard
IDF	International Dairy Federation
ILCD	International Reference Life Cycle Data System
INDC	Intended Nationally Determined Contribution
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
IWMI	International Water Management Institute

LC	Latent Class
LCA	Life Cycle Assessment
LUC	Land Use Change
MAV	Multi-Attribute Valuation
Milk SA	Milk South Africa
NT	National Treasury
PCR	Product Category Rules
SAMPRO	South African Milk Processors' Organisation
TMR	Total Mixed Ration
UHT	Ultra-High Temperature
VF	Variation Factor
WA	Water Availability
WF	Water Footprint
WFN	Water Footprint Network
WFP	World Food Program
WSI	Water Stress Index
WTP	Willingness to Pay
WU	Water Usage

LIST OF PUBLICATIONS

1. **Owusu-Sekyere, E**., Jordaan, H. and Hatem C. (2016). Evaluation of water footprint and economic water productivities of dairy products in South Africa. ***Ecological Indicators* 83(2017):32-34*.*** Publisher: Elsevier.

2. **Owusu-Sekyere, E**., Morné E. Scheepers and Jordaan, H. (2016). Economic water productivities along the dairy value chain in South Africa: Implications for sustainable and economically efficient water-use policies in the dairy industry. ***Ecological Economics* 134(2017): 22-28*.*** Publisher: Elsevier.

3. **Owusu-Sekyere, E.,** Morné E. Scheepers and Jordaan, H. (2016). Water footprint of milk produced and processed in South Africa: Implications for policy-makers and stakeholders along the dairy value chain. **Water 2016, 8, 322.** Publisher: MDPI

4. **Owusu-Sekyere, E**., Abdulai, A., Jordaan, H., Heterogeneous preferences and market potential for ecologically sustainable products in South Africa. **Food Policy** (Manuscript under review)

5. **Owusu-Sekyere, E**., Jordaan, H. Consumers' stated preferences for water and carbon footprint-labelled food products? Insights from low and high income South African consumers. (Manuscript).

6. **Owusu-Sekyere, E**., Jordaan, H. Compensating welfare estimates for water and carbon footprint sustainability policy changes in South Africa. (Manuscript)**.**

7. **Owusu-Sekyere, E**., Jordaan, H. Assessment of carbon footprint along the dairy value chain in South Africa. (Manuscript).

8. **Owusu-Sekyere, E**., Jordaan, H. Compensating welfare estimates for water and carbon footprint sustainability policy changes in South Africa. In the proceedings of the ***Agricultural Economics Society Annual Conference held at The Royal Dublin Society, Dublin, Ireland, on Monday 24th to Wednesday 26th of April, 2017.***

9. **Owusu-Sekyere, E**., Jordaan, H. Does race matter in consumers' stated preferences for water and carbon footprint labelled food products? Insights from black and white South Africans. **Paper accepted for presentation at the EGU General Assembly 2017, Austria, Vienna on Monday, 24 Apr 2017. Session ERE1.2 Energy and environmental system interactions – Policy and modelling.**

10. **Owusu-Sekyere, E**., Jordaan, H., Abdulai, A. Consumers' preferences and market potential for ecologically sustainable products in South Africa: Hybrid latent class modelling approach. A selected paper for the **30th International Conference of Agricultural Economists (ICAE 2018) in Vancouver, British Columbia, Canada, 28 July – 2 August 2018**

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND AND MOTIVATION

The ecological bearings of agricultural production associated with carbon and water footprints have constituted a relevant sustainability policy issue in recent years, across the globe. The agricultural sector accounts for about 30-35% of global greenhouse gas (GHG) emissions. This includes fuel consumption, transportation, emissions from soil, production of fertilisers, land use and land clearing for agriculture (Foley et al., 2011; Intergovernmental Panel on Climate Change (IPCC), 2007). Regarding water consumption, food production is considered as the major user of the available scarce water resources, accounting for about 86% of all global water use (International Water Management Institute (IWMI), 2007). Significant amounts of water are needed to produce food, feed and fibre to meet the ever-increasing demands (IWMI, 2007). Drastic changes in climate are currently regarded as constituting an imminent ecological problem, preventing countries from attaining environmental sustainability objectives (Galli et al., 2012). Variability in climate adds another dimension of stress to water resources by causing more erratic precipitation patterns and increased variability in river flows and aquifer recharge (Chapagain and Tickner, 2012).

Fresh water, however, is an alarmingly scarce resource (Ridoutt, 2011), with the strain on the world's water resources becoming more and more acute (Chapagain and Tickner, 2012). Statistics indicate that about one-third of the world's population faces difficulties in getting freshwater (IWMI, 2007). Significant amounts of water are used in the agricultural sector to produce food, feed, and fibre to meet the ever-increasing worldwide demands (IWMI, 2007).

South Africa is one of the countries with limited freshwater resources (Department of Water Affairs (DWA), 2013). The quantity of water demanded in various sectors of the country is higher than the supply (DWA, 2013). According to DWA (2012), 60% of freshwater in South Africa is used by irrigated agriculture, making this by far the largest single user of water in South Africa. Nonetheless, the agricultural sector is crucial for the food security needs of South Africa and sub-Saharan Africa as a whole (Department of Agriculture, Forestry and Fisheries (DAFF), 2011). According to DWA (2012), despite significant transfers from other catchments areas, water requirements still exceed availability in the majority of water management areas in South Africa. South Africa irrigates 1.5% of the total landmass to produce 30% of the total crops produced (DWA, 2013). Backeberg and Reinders (2009) reported that about 40% of useable runoff goes into irrigation farming in South Africa, while agricultural production in general uses more than 60% of the available water (DWA, 2013). Given this considerable amount of water consumed in the food production sector, pressure by government and other sectors is mounting on the food production sector regarding the effective management of freshwater resource to minimise water utilisation, without tampering with food production. Recent statistics from DAFF (2014) indicate that, despite the high water use and greenhouse effect emanating from the agricultural sector, its direct contribution to the Gross Domestic Product (GDP) of South Africa is less than 3%. This suggests that the agricultural sector is inefficient in the sense that it uses a greater share of the country's limited resources to generate only a small share of income. Furthermore, animal production systems require vast quantities of feed that is produced using water as an important input, aside from the significant contribution to GHG emission. Along the animal value chains, feed and forage production is the highest utiliser of freshwater, consuming about 95% of all the total volume of water utilised (Mekonnen and Hoekstra, 2010b; Mekonnen and Hoekstra, 2012).

Additionally, the dairy industry requires good quality water for its significant contributions to gross value of animal production to be realised. The dairy industry has a significant impact on South Africa's total value of livestock production as it accounts for 14% total value of animal production (DAFF, 2014). About 7% of South Africa's gross value attained from agricultural production comes from the dairy industry (DAFF, 2014). Thus, the industry has great economic prospects and acts as a significant employer in major areas across the country. The dairy industry involves about 4000 milk producers. These milk producers provide jobs or work opportunities for about 60 000 people who work in various sectors in the dairy industry (DAFF, 2014). Furthermore, about 40 000 indirect jobs are created along the dairy product life cycle (DAFF, 2012). The conclusion drawn from these statistics is that the dairy industry plays a vital role in the country from social and economic points of view.

The dairy value chain is an elaborate chain, starting with feed production and ending with the processed dairy product on consumers' tables. Water is needed at all the stages along the value chain, with forage production using the highest proportion of all the volume of water utilised (De Boer et al., 2013). The fact that the dairy industry is using vast quantities of water to produce feed, coupled with the impact of animal production on the environment and energy resources, suggests that emphasis must be placed on the sustainable use of fresh water and energy, from both environmental and economic perspectives.

Besides the stress on water resources, the food and agricultural organization has revealed that animal production contributes about 18% of global GHG emissions, which is greater than the contribution from all forms of transportation (Rotz et al., 2013). The situation is critical in South Africa because, although agriculture uses up to 60% of the available water, only 12% of the total land area of the country is considered to be arable, with as little as 3% being "truly fertile" (DWA, 2013). Specifically, about 69% of South Africa's total land surface area is suitable for livestock agriculture (DWA, 2013) which is a significant contributor to GHG emission. This means that agricultural production in South Africa not only stresses the water resources, but also the environment. In terms of GHG emissions, the country is rated as the twelfth largest carbon dioxide (CO_2) emitter, globally. South Africa contributes to almost half of all the GHG emissions in Africa (National Treasury, 2010). Therefore, the South Africa intends to reduce GHG emissions significantly by 34% by the year 2020. By the year 2025, South Africa intends to cut down its GHG emissions by 42% (Department of Environmental Affairs (DEA), 2015).

Hence, a sustainability assessment of food and non-food products from various sectors of the economy should be conducted in a holistic and integrated manner. Sustainability assessments should not be limited to only water footprint assessments. Moreover, strategies to reduce GHG emissions along a given food production cycle may demand higher water consumption. In addition, policies and programmes aimed at achieving high quality and efficient water utilisation might require significant amounts of energy, which will in turn result in higher GHG emissions (Pfister et al., 2011; Ridoutt et al., 2014). This highlights the need to consider sustainability assessment in a holistic approach by considering water and carbon footprints in South Africa. Managing the scarce water resources and carbon emissions remains a fundamental ecological subject matter for governments and organisations with sustainability objectives (Hoekstra et al., 2011; Ridoutt et al., 2014). Therefore, a concurrent assessment or integrated approach to sustainability assessment is imperative for providing insightful ecological policy recommendations and for escaping any possible undesirable impacts that might arise from narrowing sustainability assessment to a single indicator, such as focussing only on a water footprint (Ridoutt et al., 2014). This is also called pollution swapping or problem shifting.

Integrating water and carbon footprint assessment could possibly assist producers, policymakers and governments by providing them with insights on multiple ecological issues, simultaneously. From an economic point of view, integrating water and carbon footprint assessments could possibly minimise costs, as the extra cost that would have been incurred in doing separate assessments would be avoided (Galli et al., 2012).

The assessment of water footprints has emerged as a useful tool for assessing water utilisation impacts and how water might be utilised in a sustainable manner in the food production sector (Ridoutt et al., 2010). The concept of water footprinting has good prospects for contributing towards the efficient use of freshwater (Hoekstra et al., 2011). Where a product is considered, its water footprint is defined as the volume of freshwater used to produce the product and depending on the scope, it can be examined along the complete value chain of the product, from the inputs up until when the end product reaches the consumer (Hoekstra et al., 2011). Furthermore, water footprints could possibly be used as a tool to address water issues through regional trade policies and consumer attitudes. Water footprints could be useful to the agri-food sector by guiding and informing policy formulation and integrated resource management at national level, and lead to improved understanding of water-related risks that could assist with water management at regional level. The water use information could help to identify opportunities for reducing water consumption at the local level.

Traditionally, the focus has been on minimising the impact of agriculture on freshwater through irrigation and drainage management. However, the yield from small, irrigated farm land might be equal to the yield from large, non-irrigated farm land. The conclusion drawn from this is that stress on land resources can be reduced by applying water (Deurer et al., 2011). Furthermore, efforts to reduce GHG emissions in food production may involve larger quantities of water. Similarly, policy alternatives aimed at attaining efficient water utilisation and ensuring water quality objectives might demand more energy, thereby intensifying GHG emissions. This implies that attention should be given to water and carbon footprint assessments in order to establish harmonisation between water use and carbon emissions (Finkbeiner, 2009; Weidema et al., 2008).

Improving consumers' awareness and understanding of water and carbon footprint indicators could potentially reduce the ever-increasing stress on available freshwater and the environment at large. Based on this, recent researchers have been progressing toward multiple footprint indicator approaches (Bernardi et al., 2012; Cucek et al., 2012; Díaz et al., 2012; Ewing et al., 2012; Galli et al., 2012; Hammond and Seth, 2013; Kanakoudis et al., 2012).

1.2 PROBLEM STATEMENT

Accounting for the total quantity of water consumed along the entire life cycle of products in the agricultural sector has received some attention in recent literature. The water footprints of beef cattle and sheep production systems in Australia and New Zealand have been examined (Ridoutt et al., 2014; Zonderland-Thomassen et al., 2014). Water footprint assessments of milk and milk products have been conducted in China (Huang et al., 2014), India (Amarasinghe et al., 2010), Germany (Drastig et al., 2010) and Argentina (Manazza and Iglesias, 2012). In the African context, the assessment of water footprints of crops and livestock products has also received some attention. For instance, in South Africa, Jordaan and Grové (2012) assessed the cumulative value added to water along the value chain of small-scale raisins and vegetables in order to determine the point along the value chain where most value is added to the water used. Owusu-Sekyere et al. (2016) evaluated the water footprint of milk produced and processed in South Africa. The total quantity of water utilised in the production of lucerne for feeding dairy cows has been quantified by Scheepers and Jordaan (2016). Mekonnen and Hoekstra (2010c) evaluated the water footprint of South African dairy foodstuffs.

The growing body of literature is limited to the quantification of water footprint indicators only. Very little multiple footprint indicator assessment has been done in South Africa to establish harmonisation between sustainable water use and GHG emissions through a water and carbon footprint assessment. Meanwhile, recent sustainability assessments have been shifting toward multiple footprint indicator assessments. For example, multiple footprint indicator assessments of carbon, water and land use for beef cattle and sheep production systems have been done (Bernardi et al., 2012; Ewing et al., 2012; Galli et al., 2012; Ridoutt et al., 2014; Rotz et al., 2013; Zonderland-Thomassen et al., 2014). However, most of these multiple indicator studies focused on developed countries, with little emphasis being placed on developing countries such as South Africa.

The economic productivity of water along the dairy value chain has not been explored in South Africa. Existing literature on economic productivities are limited to that of Chouchane et al. (2015) in Tunisia, Mekonnen and Hoekstra (2014) in Morocco, and Schyns and Hoekstra

(2014) in Kenya. These authors also focused on economic water productivities of crops, but with no similar studies on livestock products.

Furthermore, neither the impacts of water and carbon footprint sustainability indicators nor information on consumers' behaviour and welfare have been explored. Therefore, we currently do not know how consumers will react to sustainability attributes presented through product labels. This has resulted in the lack of connection and understanding between the consumption activities and environmental pressures on freshwater and the environment, particularly in South Africa. Understanding consumers' attitude towards environmentally sustainability will help in identifying consumers' preferences and choices, and will also aid in identifying possible markets for sustainable food products.

Therefore, current knowledge is insufficient for understanding whether, how and why consumers, water users and managers might shift to more sustainable consumption and economically efficient production and consumption patterns in South Africa. Meanwhile, the current environmental impacts related to water use and carbon emissions in South Africa require in-depth and comprehensive information on water and carbon footprints to effectively guide South African policy and decision makers in formulating appropriate policies to guide freshwater use and reduce GHG emissions. Unfortunately, there are little or no knowledge on the benchmarks for water and carbon footprint sustainability to direct the government and institutions interested in environmental issues on what specific policies should be formulated at regional and national levels to ensure sustainable water utilisation and carbon emission reduction.

1.3 AIMS AND OBJECTIVES

The aim of this study is to conduct a multiple footprint indicator assessment of the dairy industry and to assess the impact of carbon and water footprint sustainability attributes or indicators on consumers' behaviour and welfare in South Africa. Part of the focus was placed on feed crops and irrigated pastures in South Africa. A multiple footprint indicator assessment of the complete value chain of milk produced in South Africa was evaluated to obtain the water and carbon footprints of milk production. The final value of the water used, economic productivity and carbon emitted in milk production was explored, and finally, the welfare implications of water and carbon footprint sustainability policy changes were assessed. This was the first step towards forming an integration of a multiple footprint indicator assessment that establishes harmonisation and benchmarks for the economical and environmentally sustainable use of freshwater and reduction of GHG emissions in South Africa. Furthermore, this study constitutes the first step taken towards establishing benchmarks for the assessment of consumers' preference and willingness to pay and of the welfare measures arising from water and carbon footprint sustainability assessment, particularly in Africa. The aim of the study was achieved through pursuing the following specific objectives:

Objective 1: To assess the water footprint and economic water productivities of dairy products in South Africa. The focus was placed specifically on milk produced and processed in South Africa, as well as on feed crops used in the dairy sector.

Objective 2: To assess the carbon footprint for the dairy industry in South Africa in order to raise awareness about GHG emission and to suggest ways to reduce carbon emission in the dairy industry.

Objective 3: To model consumers' heterogeneous preferences and willingness to pay for water and carbon footprint information in South Africa. This helps in understanding consumers' sustainability behaviour and the segment of South African consumers whose welfare is improved or reduced by sustainability policy changes. The findings provide benchmarks for policymakers in formulating effective and efficient sustainability policies.

1.4 ORGANISATION OF THE THESIS

The thesis is organised into eight chapters. The background and motivation of the study, an explanation of the research problem, and the objectives of the study were outlined in Chapter 1. Chapter 2 is devoted to a review of literature and concepts pertaining to a multiple footprint indicator assessment of the South African dairy industry. The chapter comprises five main subsections. Subsection 2.1 gives an overview of the global and South African dairy industry. Subsection 2.2 provides a detailed review of literature on water footprint and economic water productivity assessments. Discussed under that subsection are the global water scarcity situation, the state of water in South Africa, theoretical discussions on the concept of water footprint and economic water productivity, and methods of assessing water footprint and economic water productivity. Subsection 2.3 provides detailed discussions on carbon footprint assessment in the dairy industry. The subsection offers a comprehensive comparison of GHG emissions and the dairy industry, global GHG emission trends and challenges in the future, and methods of assessing carbon footprints. The Life Cycle Assessment (LCA) methodology, sources of GHG emissions, and an application of LCA methodology to South African dairy products are further discussed under this subsection. Sub-section 2.4 discusses relevant literature on consumers' preferences and welfare measurements. This consists of discussions on consumers' awareness of sustainability attributes, consumers' preferences and willingness to pay for sustainability attributes, methods of estimating consumers' preferences and willingness to pay for sustainability attributes, and procedures for estimating consumers' welfare measures. Subsection 2.5 provides a summary and conclusion for Chapter 2.

Chapter 3 consists of two articles. The first article deals with the evaluation of water footprint and economic water productivities of dairy products in South Africa in order to determine the quantity of water utilized along the dairy production chain and how efficient water is being utilized in the dairy industry of South Africa. The second article focuses on the evaluation of economic water productivities along the dairy value chain in South Africa and its implications for sustainable and economically efficient water-use policies in the dairy industry.

In Chapter 4, an assessment of the carbon footprint for milk produced and processed in South Africa was done, from cradle to farm gate, in order to raise awareness about GHG emission and to design strategies to reduce carbon emission in the dairy industry. The chapter also reveals key parameters that contribute significantly to the carbon footprint of milk and GHG emissions as a whole. The chapter is presented in an article entitled "Assessment of carbon footprint of milk along the dairy value chain of South Africa".

Chapter 5 deals with the modelling of consumers' heterogeneous preferences and willingness to pay for water and carbon footprint information, and assesses the welfare implications of water and carbon footprints sustainability policies on consumers in South Africa. Chapter 5 is presented in two articles. The first article is centred on consumers' stated preferences for water and carbon footprint-labelled food products from the viewpoints of low- and high-income classes in South Africa. The second article estimates the compensating welfare measures of water and carbon footprint sustainability policy changes in South Africa.

In Chapter 6, a comprehensive conceptual model that depicts relevant factors that need to be taken into consideration when assessing consumers' preferences and choice of environmentally sustainable attributes in South Africa is presented and discussed. The seventh chapter presents a framework developed for environmental footprint labels in South Africa. Chapter 7 is divided into six subsections, with a List of References. The first subsection introduces the state of environmental footprint labelling in South Africa. The next subsection gives an overview of environmental sustainability and footprints labelling of food products across the global food industry. The third subsection presents methods for estimating and conveying footprint information on food products in South Africa. Subsection 7.4 outlines proposed labelling designs that could be adopted by agribusinesses and food companies to convey footprint information on food products in South Africa. The next section presents details for the practical application and implementation of environmental sustainability labels among different stakeholders in the food industry in South Africa. The last subsection summarises and concludes the chapter.

Chapter 8 provides the summary, conclusions and recommendations drawn from this study. Also included in this chapter are suggestions for future research and policy options that could be adopted by different stakeholders towards sustaining the environment in terms of efficient water usage and management, as well as carbon reduction strategies.

CHAPTER 2

LITERATURE REVIEW AND CHOICE OF CONCEPTUAL MODELS

Chapter 2 is a review of literature pertaining to a multiple footprint indicator assessment of the South African dairy industry, as well as the implications of the multiple footprint indicators on consumers' preferences and welfare in South Africa. The chapter consists of five main sections. Section 1 gives an overview of the global and South African dairy industry. The second section provides a detailed review of literature on the assessment of the water footprint and economic water productivities of dairy products. Discussed under this section is the global water scarcity situation, the state of water in South Africa, theoretical discussions on the concept of water footprint and economic water productivity, and methods of assessing water footprint and economic water productivity. The third section provides detailed discussions on carbon footprint assessment in the dairy industry. Specifically, the section provides a comprehensive comparison of GHG emissions in the dairy industry, global GHG emission developments and challenges in the future, and methods of assessing carbon footprints. Also included in Section 3 are detailed discussions of the LCA methodology, sources of GHG emissions, and the application of the LCA assessment method to South African dairy products. Section 4 discusses relevant literature on consumers' preferences and welfare measurements. Specifically, Section 4 discusses consumers' awareness of sustainability attributes, consumers' choices and WTP for sustainability attributes, methods of assessing consumers' choices and WTP for sustainability attributes, and methods of estimating consumers' welfare measures. The final section of the chapter provides a concise conclusion from the various subsections discussed.

2.1 OVERVIEW OF THE GLOBAL AND SOUTH AFRICAN DAIRY INDUSTRY

2.1.1 THE GLOBAL DAIRY INDUSTRY

The history of dairy farming traces back thousands of years. Since then, dairy production has been an integral part of agricultural production. Many years ago, cows were reared basically for pulling farm implements and for carting purposes, while some were used for breeding new draught animals for farming. Later on, some Indo-European nomadic farmers in the East begun using fresh milk for consumption and since then, milk production became part of livestock farming. Milk became a popular drink in the 18th century (IDF, 2011). Dairy cow rearing has shifted from small-scale farming to more specialised enterprises (IDF, 2011). However, statistics indicate that dairy herd sizes vary largely from one region to another, with a global average of 2.4 per dairy cow (Hemme and Otte, 2010).

Statistics from the Food and Agricultural Organization (FAOSTATS, 2014) indicate that Africa's milk production increased by 72% from 2000 to 2012 (Table 2.1 below). The figures for dairy cows have improved by 57%. Output per dairy cow has improved by 9 % in Africa. In South Africa, milk production increased by 33% from 2000 to 2012, as shown in Table 2.1. Figures for dairy cows and dairy output per cow have improved by 1% and 31%, respectively. Asia has recorded the highest increase (80%) in milk output compared with the rest of the regions, probably due to the larger increase in number of dairy cows (43%). In America, there has been an increase of 12% in dairy cows, while milk output has increased by 25% and milk output per dairy cow by 12%, over the period of 2000 to 2012. Milk production in Europe has been low, as indicated by the low percentage increase of 0.30 %, as a result of the decrease of 26 % in the number of dairy cows from 2000 to 2012. However, Europe has experienced a higher increase in milk yield per cow (35%). Oceania has increased milk production by 28% as a result of an increase in dairy cows and a higher milk output for each dairy cow relative to the other regions. Oceania has the second highest milk yield per cow, after Europe. Thus, there is the need to increase dairy cow numbers and improve upon the dairy output per cow in South Africa.

In the Caribbean, there was a reduction in the number of dairy cows from 2000 to 2012, but milk production has been in the ascendancy as a result of increases in yield of milk per cow. Globally, milk production increased by 27 % from 2000 to 2012. However, both dairy cow population and milk yield per cow recorded increases of 23% and 4%, respectively. The global upsurge in milk output from each dairy cow is low as a result of factors such as changing climatic conditions that affect the performance of dairy cows, diseases, and poor breeding and feeding.

Beside the milk production, the dairy industry contributes to beef supply (Gerber et al., 2010). FAOSTATS (2014) indicates that about 13% of total meat supply emanates from the dairy industry. Livestock production contributes significantly to dietary protein intake. For instance, livestock provide, on the average, 28% of the global protein intake (FAO, 2009).

Table 2.1: Dairy statistics across different regions (2000–2012)

	Dairy cows (million)			Milk production (Million tonnes)			Milk yield (tonnes per cow)		
Year	2000	2012	Change	2000	2012	Change	2000	2012	Change
Africa	42.53	66.87	57.23%	19.91	34.31	72.33%	0.47	0.51	8.51%
South Africa	0.99	1.00	1.01%	2.54	3.37	32.68%	2.57	3.37	31.13%
Asia	73.14	104.93	43.46%	94.45	169.77	79.75%	1.29	1.62	31.01%
America	47.87	53.62	12.01%	145.65	181.74	24.78%	3.04	3.39	11.51%
Europe	50.93	37.69	-26.00%	209.72	210.34	0.30%	4.12	5.58	35.44%
Oceania	5.56	6.76	21.58%	23.15	29.60	27.86%	4.16	4.38	5.29%
Caribbean	1.16	1.12	-3.45%	1.52	1.67	9.87%	1.31	1.49	13.74%
World	220.04	269.88	22.65%	492.87	625.75	26.96%	2.24	2.32	3.57%

FAOSTATS (2014)

Developed countries rely on livestock products for about half of their protein intake, compared with developing countries where only 23 % of protein intake comes from livestock products (FAO, 2009). Globally, 10 % of protein intake is obtained from dairy products alone, while accounting for 6 % of total energy intake.

In conclusion, it is evidenced from the discussions that the dairy sector has been part of agricultural production for decades. The industry has grown from small- to large-scale commercial production, with substantial increases in global milk production and numbers of dairy cows. Africa’s milk production has improved significantly over the years. However, production is affected mainly by variation in climatic conditions. This provides the rationale for research to formulate strategies and recommendations to improve the dairy industry by reducing the negative impacts of climate change, while increasing milk yields and performance of dairy cows.

2.1.2 THE SOUTH AFRICAN DAIRY INDUSTRY

The dairy industry in South Africa is of great significance to the economic development of the country and the world at large. Globally, the South African dairy industry contributes 0.5 % of the world's total milk production (DAFF, 2012). Internally, about 7 % of the total gross value of agricultural contribution emanates from the dairy industry. The industry contributes to employment creation, which in turn improves the standard of living of people working along the dairy value chain. Existing statistics from DAFF (2012) reveal that the industry reduces unemployment significantly, as it includes more than 4 000 milk producers and employs over 60 000 workers on various dairy farms. Indirectly, the industry is found to provide job opportunities for about 40 000 people, and this estimated number of people consists of all those working along the entire dairy value chain, such as in feed production, processing, and manufacturing of packaging materials, just to mention a few. The dairy products from the industry come from four main breeds of cattle. The four main breeds of cattle in the country comprise the Holstein, Jersey, Guernsey and Ayrshire breeds. The products from the industry consist of raw milk, pasteurised milk, full cream milk, fermented milk, powdered milk, yoghurt, cheese, sweetened milk, unsweetened concentrated milk, butter, and ultra-high temperature (UHT) milk. The product prices received by the producers determine the gross value of milk produced.

Milk production is very favourable in mild temperate zones with good rainfall for pasture management and feed production. Farmers who operate inland for milk production are forced to operate under intensive systems of production, which results in high feeding costs, since they rely on feedlots. The contributions of milk production from the various provinces are presented in Figure 2.1 below. As shown in the figure, the Eastern Cape Province is the highest contributor, accounting for 27 % of the total milk produced in the country. The Western Cape and KwaZulu-Natal Provinces are the second highest contributors, with 24 % contributions each (DAFF, 2012). The Free State Province contributes 13 % to the total milk production of the country, with the North West and Mpumalanga Provinces contributing 5 % and 4 %, respectively. The remaining provinces contribute 3 % to the total milk production. The high contributions from the Eastern and Western Cape Provinces, as well as KwaZulu-Natal Province, are probably attributable to the favourable climate and good pasture regimes for livestock production (DAFF, 2012).

According to Milk SA (2014), annual milk purchases in South Africa rose from 2 843 000 tonnes in 2012 to 2 906 000 tonnes in 2013. This represents about a 2.17 % increase in milk purchases. The 2013 purchases increased to 2 983 000 tonnes in 2014, representing about a 2.58 % increase.

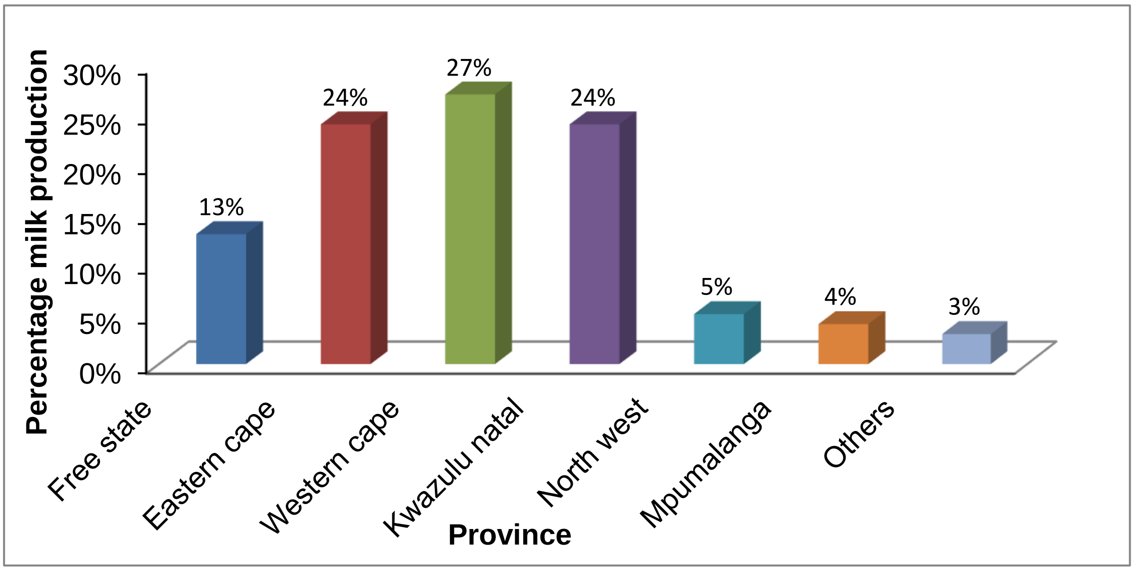

Figure 2.1: The contributions of milk production from the various provinces

Source: DAFF (2012)

The production of dairy products in South Africa does not meet the local demand, and accordingly the country relies on imports to supplement the deficit in demand. Table 2.2 below shows the import quantities of dairy products from 2009 to 2014. The table shows that total imports for dairy products increased from 32 373 tonnes in 2009 to 59 103 tonnes in 2012, representing about 45 % increment in imports. However, the quantity of imports reduced to 35 674 tonnes in 2013 and later increased to 40 199 tonnes in 2014, although lower than the imports in 2012.

Table 2.2: Trend in annual imports for dairy products 2009–2014 (Tonnes)

Product	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
Milk & cream	10 902	11 119	8 324	15 240	4 267	6 992
Milk, concentrated	5 385	6 771	7 895	13 257	7 115	9 836
Buttermilk & yoghurt	1 381	1 379	2 131	2 146	1 591	2 086
Whey & modified whey	6 260	7 268	9 445	9 266	11 165	9 480
Butter & other milk fats	3 201	2 192	3 153	6 107	3132	2 071
Cheese & curd	5 245	6 331	6 765	13 084	8 403	9 731
Total	32 373	35 061	37 714	59 103	35 674	40 199

Source: Milk SA (2014)

In terms of specific products, the statistics indicate that there were higher imports of milk and cream in 2009 and 2010. However, the value dropped in 2011 and then increased to about 15 240 tonnes in 2012, after which it decreased again. The imports of concentrated milk increased from 5 385 tonnes to 13 257 tonnes in 2012. The value decreased to 9 836 tonnes in 2014 (Milk SA, 2014). The imports of buttermilk and yoghurt recorded the lowest import figures among all the dairy products. However, the highest importation was made in 2012, when 2 146 tonnes of buttermilk and yoghurt were imported. The imports of whey and modified whey recorded an increase from 6 260 tonnes in 2009 to 9 445 tonnes in 2011, with a slight decrease in 2012. However, increases in imports of whey and modified whey were observed in 2013 and 2014 (Milk SA, 2014). Similarly, the imports of cheese and curd increased from 5 245 tonnes in 2009 to 13 084 in 2012. After 2012, the value of imports reduced to 8 403 tonnes in 2013 and later increased to 9 731 tonnes in 2014. The import figures for the dairy products fluctuate from year to year, as shown by the rise and fall of the import quantities.

The import figures give an indication that there are opportunities for dairy producers to increase their production to meet the ever-increasing demand for dairy products amid increasing human population. Meyer et al. (2013) opined that there was an opportunity for milk production to increase by 2.5% annually in order to meet the local demand for dairy products. It is expected that about 3.3 million tonnes of milk need to be produced by 2020 to meet the demand of the populace (Milk SA, 2014). The projected amount of milk needed cannot be attained without access to freshwater and also the role of water in the dairy industry cannot be overemphasised. Hence, there is the need to consider sustainable and economically efficient water management strategies in order to sustain the production of dairy products in the South African industry.

2.2 ASSESSMENT OF WATER FOOTPRINT AND ECONOMIC WATER PRODUCTIVITY

2.2.1 BACKGROUND

The global water scarcity phenomenon has become a major issue of concern to governments, organisations, policy-makers, water-users, and water managers. It is estimated that about four billion people across the globe face severe water scarcity (Mekonnen and Hoekstra, 2016).

The pressure on freshwater resources is attributable to population growth, climate variation, pollution of existing water resources, and urbanisation, among other things (Jefferies et al., 2012). In many parts of the word, the quantities of water supply do not meet the quantity demanded by the various sectors of the economies. Hence, there is pressure on governments and policy makers to identify sectors of their economy that are inefficient in water use, as well as high water consumption activities. Food production has been identified as the major user of the available scarce water resource; accounting for about 86 % of all the global water use (IWMI, 2007). However, given the fact that food production is vital for human survival and the indispensable role of water the food sector, it is imperative to design strategies and measures to make the utilisation of water in the food sector efficient and sustainable.

South Africa is a dry country. The country's current water resources are insufficient to meet the growing demands of its people (DWA, 2013). The scarcity of freshwater limits agricultural production in certain parts of the country. It also affects the food security status of many people in the country, as well as in neighbouring countries and Africa at large. According to DWA (2013), agriculture is the single largest user of water. The pressure on water resources increases with population growth, and as such, the agricultural sector will have to be efficient and economical in terms of water use in order to maintain or increase its food production to meet the increasing food demand (Nieuwoudt et al., 2004). Although agriculture in South Africa uses up to 60 % of the available water, only 12 % of the total land area of the country is considered to be arable, with as little as 3 % "truly fertile" (DWA, 2013). This suggests that producers must be economically efficient in water use to gain the most from the limited arable land. Given that agriculture utilises the largest share of the country's water resources, other sectors are expecting the food and agricultural sector to minimise water utilisation, without tampering with crop yields. These sectors are competing for the same limited water resources and consequently water must be used with greater efficiency.

Currently, water resources used in South Africa are allocated to various economic sectors, but information on the precise usage is lacking. For example, the agricultural sector is noted to be the prime consumer of water in South Africa, although there is no specific information on economic productivity of water per type of crop across the different provinces. Nevertheless, this information is very relevant in understanding whether, how and why water users and managers in the agricultural sector might shift to more sustainable and economic crop production patterns, as well as crop choice. Hence, the present study adopts the Water Footprint Network concept and approach to address the issue of economic water productivity for selected crops in South Africa. This concept was chosen because it gives a comprehensive assessment of freshwater utilisation along the entire production cycle. It gives an all-inclusive indicator of freshwater usage and can be examined along with the traditional and restricted measures of water withdrawal. This concept is gaining prominence because it gives a comprehensive assessment of freshwater utilisation for the product(s) in question (Hoekstra, 2003).

The assessment of the water footprint of products in the agricultural sector has received some attention in recent literature in developed countries (Drastig et al., 2010; De Boer et al., 2013; Huang et al., 2014; Matlock et al., 2012; Manazza and Iglesias, 2012; Ridoutt et al., 2014; Zonderland-Thomassen et al., 2014). Amarasinghe et al. (2010) assessed water footprints of milk production in India. Water footprint analyses of milk production in Germany and Argentina have been explored (Matlock et al., 2012; Manazza and Iglesias, 2012). These increasing studies have focused on developing countries and quantification of water footprint indicators, and to some extent on the environmental impact, with little emphasis being placed on the economic aspect of water use, particularly in Africa. However, assessing the footprint estimate alone is not enough as it only offers volumes of water used and does not articulate “what to do” (Hoekstra et al., 2011). The economic aspect of the water footprint indicators has received little attention. The few existing studies are limited to that of Chouchane et al. (2015) who assessed the economic water and land productivities for some selected crops in Tunisia and the similar assessments done for case studies in Morocco and Kenya (Mekonnen and Hoekstra, 2014; Schyns and Hoekstra, 2014). These studies focused only on crops, with no emphasis on livestock products. It is clear that studies on economic productivities of water in Southern Africa are minimal, particularly in the dairy industry.

Few researchers have linked the economic aspect of water to the water footprint indicators in South Africa. For instance, Jordaan and Grové (2012) assessed the cumulative value added to water along the value chain of small-scale raisin and vegetable production in order to determine the point along the value chain where most value is added to water. Similarly, Scheepers (2015) evaluated the value added to water along the lucerne dairy value chain in South Africa. However, these studies did not assess economic productivities of water, but rather the value added to water. Therefore, current knowledge is insufficient to effectively for guiding South African policy and decision-makers, water users and managers in formulating appropriate policies to guide freshwater use and for economically efficient water use.

The present study attempts to fill the gap in knowledge by assessing the economic water productivities of selected crops and dairy products in South Africa. We estimated economic water productivities across different provinces for policy purposes. The economic water productivity is the value of the marginal product of the agri-food product with respect to water, and is calculated by multiplying the physical productivity by the price of the product (Chouchane et al., 2015; Molden, 2007; Playan and Matoes, 2006). The economic productivity gives an indication of the income that was generated per cubic metre of water utilised.

2.2.2 THE GLOBAL WATER SCARCITY SITUATION

The global water scarcity situation poses risks to human survival and world sustainability because water is essential in almost every facet of human activity (Rosenberg, 2010). Water is regarded as one of the main influencers of global economic and political stability. The world is faced with the task of controlling drought and floods, and the attainment of water security poses great tactful and development challenges and opportunities for the present and future generations. IWMI (2007) has stated that access to the minimum of clean, freshwater should be the first among any meaningful human right.

IWMI (2007) opined that the worldwide water shortage crisis is taking a new shape in the 21st century. This is because water is irreplaceable, unlike oil which is finite resource. What is important to note is that the increasing global food demand is exhausting the global freshwater resources at a rate double relative to population growth (IWMI, 2007). Hence, the world is heading towards an unsustainable and inaccessible food supply that would be required to meet the increasing demand. The water shortage problem is worsened by huge incompetency in water management and by wastage in all parts of the world. This rising water scarcity leads to formidable environmental and political challenges (IWMI, 2007). Tension is rising globally between those who have water and those who do not have water (IWMI, 2007).

Governments and stakeholders all over the world have realised the need for both environmental and political solutions to control the growing global water scarcity crisis (Rosenberg, 2010). The Millennium Ecosystem Assessment (MEA) (2005) re-iterated that mankind is depleting water resources at a faster and higher rate, compared with the rate at which the natural water cycle replenishes the aquifers.

The MEA established that about 3.5 billion people in various countries will be susceptible to freshwater scarcity to the extent that it will be difficult to feed people in these countries by 2025. People who will find themselves in this situation will rely on imported grain and stable international markets. The water scarcity situation will impact on food security challenges, which in turn will intensely impact on food accessibility and price instability across the African and Southern Asian regions (Global Water Issues, 2011). The water crisis is directly allied to climate change through vast changes and extremes of water-related occurrences (e.g. floods), and Global Water Issues (2011) have outlined alternative ways of addressing the global water crisis. These include:

1. Ground water mining.
2. Countries promising developments toward improved and sustainable efficiencies in freshwater use.
3. Development of saviour technologies for water desalination.
4. Development of genetically modified, low-water-using crops.

The trend in global water outcomes in future depends on how effectively and efficiently the countries with sufficient water will manage their increasingly precious water resources (Global Water Issues, 2011). The world's water-rich countries have competitive advantages and are economically powerful nations. However, these attributes can be achieved by transforming the domestic water economy through well-designed water management strategies and efficient allocation of water resources. Water needs to be regarded as a valued economic asset. This means that economic productivities of water must be given great attention since these give an indication of economically productive water use activities.

Generally, food production uses much of the world's water resources. Water required for food production is estimated to be about 70 times greater than the water required for drinking, bathing and washing (Global Water Issues, 2011). The situation is expected to worsen since the global food demand is projected to double by 2050, and that suggests that the water required for achieving global food security is expected to be double (Solomon, 2010). Water and food security are, and will continue to be, formidable challenge for the global world. Hence, there is a global need for a thorough assessment of water resources and food production technologies that minimise water consumption. For instance, in Western Europe and the U.S.

Midwest, farmers have adopted high-yielding and water-efficient crops which can use the moisture provided by rainfall alone to produce optimum yields.

Managing the global water crisis in order to supply food to meet the doubling food demand by 2050 requires efficient and increased productivity of available water (Solomon, 2010). The improvement in water productivity hinges on the type of crop, location, agricultural practices, and water conservation techniques. This means that the thorough assessment of water productivities for different types of crops at different locations, under different agricultural practices and conservations technologies, needs to be given much attention globally. This will guide water managers and users in their choice of crops per location, to produce more crops per drop, and to be economically efficient in water use. The above discussion shows the urgent need for water productivity assessments across countries. Hence, the next section discusses the water scarcity situation in South Africa.

2.2.3 THE STATE OF WATER IN SOUTH AFRICA

The current state of water in South Africa is a threat to human survival and sustainable development unless proper counteractive measures are taken (DWA, 2013). Hence, there is intense pressure on stakeholders in charge of water resources, since freshwater is getting increasingly scarcer in South Africa. The degree of scarcity has been the subject of research by hydrologists who are intent on quantifying and understanding the relationship between rainfall and stream flow, as well as between rainfall and groundwater recharge. The limited rainfall is unevenly distributed, inefficiently used and characterised by droughts. The available water resources are monitored and regulated by the Department of Water Affairs (DWA). DWA (2013) has reported that the country's water infrastructure is subject to ageing effects related to internal and external stresses, and inadequate maintenance and capital renewal. The lack of capacity and funds, the shortage of skilled personnel to implement and supervise the maintenance of existing water resources, and fading institutional memory comprise part of the challenges faced by the Department of Water and Sanitation.

The country's average total surface water amounts to about 49 200 million cubic meters per annum (Water, 2012). About 10%, representing 4 800 million m^3 of the total surface water, emanates from Lesotho, yearly (DWA, 2013). This implies that South Africa relies on water resources from neighbouring countries to meet its current water demand. In order for South Africa to maintain its natural environment, ecological reserves should remain in the rivers.

Table 2.3 below presents the yearly average natural runoff and estimated ecological reserves for different rivers in South Africa. As shown in the table, the ecological reserves and the desired quantities vary from one catchment area to another, subject to the requirement to preserve the present ecological state. The principal water source for South Africa is surface water, accounting for about 11 000 m^3 per annum (DWA, 2013). Only about 10 % of the surface water comes from groundwater; ground water is widely used in rural and arid areas. Significant volumes of water originate from return flows from major urban and industrial developments to streams.

A critical review of the water resource scarcity in South Africa has revealed that the demand for water in South Africa is expected to reach an amount of 17.7 billion cubic metres in 2030 (United Nations Development Programme, 2012). Relating this to current supply, which hovers around 15 billion cubic metres, it will be difficult to supply the projected demand for water by 2030.

Table 2.3: Annual mean natural runoff and provisional estimates of ecological reserve (million m^3 per annum)

Water Management Area	Natural Mean Annual Runoff	Ecological Reserve	Difference	Total Local Yield
Limpopo	985	156	829	282
Luvuvhu/Letaba	1185	224	961	310
Crocodile West	855	165	690	693
Olifants	2 042	460	1 582	611
Inkomati	3 539	1 008	2 531	943
Usutu to Mhlatuze	4 780	1 192	3 588	1 010
Thukela	3 799	859	2 940	738
Upper Vaal	2 423	299	2 124	1 723
Middle Vaal	888	109	779	201
Lower Vaal	368	48	320	50
Mvoti to Umzimkulu	4 798	1 160	3 638	527
Mzimvubu - Keiskamma	7 241	1 122	6 119	855
Upper Orange	6 981	1 349	5 632	4 557
Lower Orange	502	69	433	(1 007)
Fish to Tsitsikamma	2 154	243	1 911	437
Gouritz	1 679	325	1 354	277
Olifants/Doring	1 108	156	952	335
Breede	2 472	384	2 088	868
Berg	1 429	217	1 212	501
Total for SA	**49 228**	**9 545**	**39 683**	**13 911**

Source: DWA (2013)

What is worse in the scenario is that the above-mentioned estimates did not account for the possible impacts of climate variations, which can further aggravate the water crisis. DWA

(2013) has further opined that a small reduction in the country's rainfall, and corresponding rise in irrigation water, could lead to water deficit of about 3.8 billion m^3. This shows that the agricultural sector is at risk, since there is an uneven distribution of rainfall and restriction on irrigation requirements in order to keep the watercourses flowing.

South Africa's water security is related to water quality and availability. The CSIR (2010) reported that the quality is declining as a result of pollution, mainly caused by industrialisation, development, etc. This poses serious threats to human survival in the years ahead. Cooperation between water managers and water users, such as farmers, is one of the ways of ensuring efficient water usage. More emphasis has been placed on food production due to its large water consumption status. Irrigation is the largest user of groundwater (DWA, 2013). Despite the high water usage in agriculture, the contribution of the sector to Gross Domestic Product (GDP) is minimal (DAFF, 2014). This implies that the agricultural sector is water inefficient in terms of freshwater use for crop and livestock production. There is, therefore, the need for a detailed assessment of the agricultural sector to identify areas of high water usage and how this can be managed in a sustainable manner.

South Africa's water scarcity situation demands a multipronged intervention because the country has a high water usage intensity of about 31 % and this is rated very high, compared with the world standards (Global Water Partnership, 2010). The effect of climate change will cause some provinces and communities in the country to become drier, while increasing water demand. This will bring about more stress and difficulty in meeting domestic water needs and supplying water to agricultural and industrial users. The South African National Planning Commission has proposed several interventions to deal with the water scarcity situation. Among these are building novel technologies to intensify water supplies and recycle used water, improving water management, and enhancing efficient municipal and industrial water use, as well as guarding water resources against contamination. Most of these interventions are related to the management of water resources, emphasising the need to design appropriate management strategies and policies aimed at ensuring efficient and sustainable water use. It is unfortunate that the above-mentioned discussions did not include a detail assessment of the various crops grown in the country and of how high-water-use crops can be managed in a sustainable and economical manner. Moreover, the dairy industry has been ignored in terms of water use. Hence, it is important to assess the economic productivity of water for the various crops grown in the various provinces of the country in order to identify economically productive and non-productive crops in terms of water use.

2.2.4 THE CONCEPT OF WATER FOOTPRINT AND ECONOMIC WATER PRODUCTIVITY

2.2.4.1 THE CONCEPT OF WATER FOOTPRINT ASSESSMENT

Conceptually, a water footprint is internationally rooted in two approaches. These are the Water Footprint Network methodology (Hoekstra et al., 2011) and Life Cycle Assessment (LCA) methodology. The Water Footprint Network concept has gained prominence since its introduction in 2003 by Hoekstra. Later development by Hoekstra et al. (2011) described the water footprint as an all-inclusive indicator of freshwater usage and can be examined along with the traditional and restricted measures of water withdrawal. The overall goal of the water footprint concept is to investigate the sustainability of freshwater use and this is attained by relating the water footprint to the freshwater availability (Hoekstra and Mekonnen, 2011; Hoekstra et al., 2012).

Hoekstra et al. (2011) classified water footprints into blue, green, and grey. The blue water footprint is referred to as the volume of surface and groundwater consumed along a product's life cycle. Consumptive water use refers to the loss of surface or groundwater from a catchment (Hoekstra et al., 2011). The losses can occur through incorporation into the product, evaporation, or when the water runs into a different catchment. The green water footprint is the rainwater that evapotranspired through the vegetation and is incorporated into the product. The volume of freshwater needed to reduce the pollutants to ambient levels is referred to as the grey water footprint. Depending on the degree of pollution of water, a given quantity of freshwater is needed to assimilate the load of pollutants to acceptable standards.

The water footprint concept is multidimensional and considers all the water used according to the sources from which the water is extracted and the volumes of freshwater necessary to assimilate polluted water to ambient levels. Thus, the water footprint concept reveals water consumption volumes by source and polluted volumes by type of pollution (Hoekstra et al., 2011). Different types of water footprint assessments can be conducted to evaluate the impact of human behaviour on sustainable water use (Hoekstra et al., 2011). A water footprint can be defined in different forms as:

- **Water footprint of a consumer or group of consumers**

  Hoekstra et al. (2011) defined the water footprint of a consumer or group of consumers as the total volume of water used for the production of goods and services used by the consumer. Both freshwater consumed and the amount of water polluted during the course of production are taken into account. When a group of consumers is considered, one simply sums the water footprints of the individual consumers. The water footprints of consumers are expressed as the volume of water per unit of time, or as the volume of water per monetary unit obtained, by dividing the volume of water per unit of time by the income. Where a group of consumers is concerned, the water footprint can be expressed as the water volume per unit of time per capita. The water footprint of a consumer or group of consumers gives an understanding of the cumulative impact that these individuals have on water resources.

- **Water footprint of a geographically delineated area**

  This is defined as the total volume of water consumed and polluted within the boundaries of a delineated area. Typical areas include catchments and river basins, states, provinces, nations, or any other administrative spatial unit. The water footprint for a spatial unit is stated as the volume of water per unit of time. Calculating the water footprint for a geographically delineated area is usually part of a larger assessment of the sustainability of the water resources in the target area.

- **Water footprint of a business**

  The water footprint of a business refers to the sum of the water footprints of the business outputs. This business water footprint can then be further divided into the direct (operational) and indirect (supply chain) water footprints. This can also be defined as the total volume of water used, both directly and indirectly, in the business operations. The direct water footprint is the total volume of water used and polluted in a business's own operations, while the indirect water footprint is the total volume of water used and polluted in order to obtain the inputs required for the business's operations. A business's water footprint aims to assess a specific business's impact on water resources. Often, a business's water footprint is largely "imported" from elsewhere in the form of water intensive inputs produced in other catchments.

- **Water footprint of a product**

  The water footprint of a product refers to the volume of freshwater used to produce the product and is evaluated along the complete value chain of the product. All the steps along the complete value chain of the specific product are considered. Product water footprints are often calculated to enable comparisons between products, often on the basis of volume of water per caloric unit, with the aim of determining the sustainability of water resources.

Water footprint evaluation is also well grounded from the Life Cycle Assessment (LCA) perspective. The life cycle assessment (LCA) is extensively accepted and applied in environmental management as a tool for measuring various environmental impacts (Berger and Finkbeiner, 2010). Water footprint assessment in an LCA approach focuses on the environmental impacts associated with water use. Water footprint assessment in LCA does not consider the economic and social impacts. All stages of the life cycle of the product under investigation are considered, starting at raw material acquisition through to the disposal of the final product. An LCA assessment consists of four phases which are included to ensure the completeness of the assessment. These are:

1. Definition of the goal and scope of the assessment
2. Water footprint inventory analysis
3. Water footprint impact assessment
4. Interpretation of the results

A water footprint assessment using an LCA approach can be done independently (stand-alone) or factored into a wider environmental assessment. In the LCA, the origins of water sources are not considered, as they are in the Water Footprint Network (WFN) approach. LCA does not directly account for green water use. However, Ridoutt and Pfister (2010) argued that because the use of green water is directly related to the occupation of land, it is accounted for elsewhere in a complete LCA. Hence, Berger and Finkbeiner (2010) argue that green water is particularly essential in crops and livestock production, and as such, failing to account for it does not give an accurate measure of the true water used, particularly in the agricultural sector. Although the LCA accounts for blue water, however, the deterioration of water quality is accounted for through other impact assessments such as freshwater ecotoxicity or eutrophication (Jefferies et al., 2012).

ISO 14046 serves as a guideline as to what to include in a comprehensive water footprint assessment. The aim of this International Standard is to ensure a form of consistency between the different methodologies. This was done by standardising the terminologies used in the calculation and reporting of the various methods. According to ISO 14046, the term "water footprint" can only be quantified when a comprehensive impact assessment is undertaken. The ISO 14046 is based on the LCA approach and identifies potential environmental impacts that are associated with water use. It also observes changes in water quality and water use over time and across geographical dimensions (ISO/TC207, 2014).

ISO 14046:2014 does not recommend a particular methodology for the assessment of water footprint, but it does serve as a guide as to what should be considered in the calculation of a complete water footprint assessment. ISO 14046 defines a water footprint as the quantification of the potential environmental impacts related to water, and is based on the LCA approach to environmental impact. A water footprint assessment conducted according to this international standard must be compliant with ISO 14044:2006 and should therefore include the four phases of a LCA. Although both the LCA and WFN approaches can be used to evaluate the water footprints of products in South African, the guidelines of the ISO 14046 must also be kept in mind in the reporting of the water footprint indicators of South Africa. The WFN approach is employed in this study for water footprint assessment because it gives comprehensive indicators of freshwater use, as it directly accounts for blue, green and grey water utilization.

2.2.4.2 THE CONCEPT OF ECONOMIC WATER PRODUCTIVITIES

Hoekstra (2014) emphasised that the economic or efficient use of water is one of the pillars of freshwater allocation. The three pillars of freshwater allocation are environmental sustainability, economic efficiency, and the socially equitable distribution of freshwater. One of the three pillars of freshwater allocation is economic efficiency, as highlighted by Hoekstra (2014). The estimation of economic water efficiency follows after the estimation of the total water footprint. This concept builds on or contributes to sustainability assessments which over the past few years have centred on blue, green and grey water footprint indicators only. This concept of underlying water productivities estimations is related to water footprints. The calculation of the economic productivity of water begins with the estimation of physical water productivities. Physical water productivity is the ratio of the yield of the agricultural product to the amount of water used ('product per drop of water'). This is usually calculated for blue water withdrawal or for the summation of green and blue water footprint. Economic water productivity is stated as the product of the physical water productivity and the price of the agricultural product. Thus, the economic water productivity of an agri-food product is the value of the marginal product of the agri-food product with respect to water. The estimated value for the economic productivity of water provides an understanding of how much income is generated per m^3 of blue, green and grey water utilised. Very little research exists in recent literature regarding the evaluation of economic water productivities.

The existing literature is limited to the study of Chouchane et al. (2015) who assessed the economic water productivities for certain selected crops in Tunisia. The findings by the authors provide an indication of the income that was generated per cubic metre of green, blue, and grey water used in Tunisia. Specifically, Chouchane *et al.* (2015) found the economic water productivities of the selected crops in Tunisia to range 0.03 US$/$m^3$ (olives) to 1.08 US$/$m^3$ (tomatoes). However, it must be emphasised that the authors did not include the costs incurred in producing this range of products. This implies that economic water productivity is not the same as profit, since costs of production are not factored into the analysis of economic water productivities.

In Cyprus, Zoumides et al. (2014) conducted an economic water productivity assessment for crop production. The main focus of the authors was on quantifying water utilisation and supply for crop production. However, the authors moved a step further to estimate blue and green economic water productivities. Total water productivities were first calculated for the selected crops, after which the value was multiplied by the product prices. The total productivities were then divided by the blue and green water footprints. The yields of crops were divided into rain-fed yield, and yields from both irrigation and rainfall. Once the crop yields from rain and irrigation were obtained, they are then divided by their respective footprint indicators. Green economic water productivity is calculated by dividing yield by rainfall only by the green water footprint, whereas the yield from irrigation is also divided by the blue water footprint to derive blue economic water productivities. The results are multiplied by the prices of each crop to ascertain the economic water productivities per cubic metre of water.

The findings reported by Zoumides et al. (2014) revealed that about 80 % of agricultural gross value in Cyprus originates from irrigation farming, and out of this, only 39 % comes from rain-fed agriculture. The remaining 61 % is attained from blue water use or irrigation farming. The minimum blue water economic productivity in Cyprus was found to be 0.89 €/m^3, with a maximum of 1.15 €/m^3, from 1995 to 2009. The minimum green water economic productivity was found to be 0.22 €/m^3 and the maximum about 0.45 €/m^3 from 1995 to 2009. The above indicate that blue water productivities are higher than green water productivities in Cyprus. Such findings provide an indication of how productively Cyprus' blue and green water are being utilised.

Similarly, Central Asia has been assessed for its blue water economic productivities for the main fibre crop, cotton, and wheat and rice cereal crops. The assessment was done by Aldaya, Munoz and Hoekstra in 2010. The authors found cotton to be the highest user of blue water, followed by rice and wheat, respectively. It was found that cotton has the highest blue water economic productivity, despite the high water footprint. This finding indicates that a high water footprint does not always mean that low water productivities will be observed in terms of economic water productivities. The economic productivities of cotton, rice and wheat were found to be 0.5 US$/$m^3$, 0.18 US$/m^3 and 0.07 US$/$m^3$ respectively.

Research on the economic productivities of water is very scanty for the semi-arid and arid regions of Southern Africa. The existing literature is limited to that of Munro et al. (2014), who assessed the citrus water footprint in the Sundays River Valley. The authors did not assess total economic water productivity for citrus production, but rather water productivity at the production stage of citrus. This does not give an indication of water productivities along the entire citrus production value chain.

A sector-specific assessment of water use for irrigation farming and the forestry sector has been conducted by Crafford et al. (2004). The authors focused on the direct and indirect benefits associated with water utilisation for irrigation in the agricultural and forestry sector. This research was conducted for established forestry, sugarcane production under irrigation, and some subtropical fruits produced in the Crocodile River Catchment Area. Economic, social and environmental impacts were estimated for each of the production sectors mentioned above. The environmental aspect of this research was examined using the LCA methodology.

It was revealed that the minimum value added to a cubic metre of water was 1.8 ZAR/m^3 with a maximum of 2.6 ZAR/m^3 for established forest in terms of direct economic impact. For sugarcane and subtropical fruit, the authors found 1.3 ZAR/m^3 for sugarcane, while that for the subtropical fruit was found to range between 3.2 ZAR/m^3 and 8.7 ZAR/m^3. Indirectly, it was found that about 19.9 ZAR/m^3 to 32.1 ZAR/m^3 value is added to each cubic metre of water utilised in the forest sector, whereas about 9.9 ZAR/m^3 was found for sugarcane production and the value for subtropical fruit was found to be between 3.2 ZAR/m^3 and 8.9 ZAR/m^3. Regarding the environmental aspect, the authors concentrated on water utilisation impacts in the various sectors on water quality and biodiversity, as well as the health effects of these production activities on humans (Crafford et al., 2004). These authors did not look at the actual water productivities, since their approach did not consider the estimations of water footprints from which economic productivities could be derived, given the yield and prices of products obtained from the irrigated sugarcane, subtropical fruit and forestry products.

The above discussions reveal that little has been done in terms of how economical South Africa's water use has been. Thus, the economic productivities of water in South Africa have not being thoroughly assessed in order to provide vital economic indications of water use, even though the country is water scarce. More importantly, the little research on value addition and economic water productivities has focussed on crops only, with little or no emphasis being placed on the dairy value chain, and on the livestock industry in general. Hence, there is the need for an economic evaluation of water productivities in the dairy industry. In order to contribute to the assessment of economic water productivities, there is the need to discuss the methods that are used in estimating a water footprint and economic water productivities. Therefore, the next section provides detailed discussion on the methods applied in a water footprint and economic water productivities assessment.

2.2.5 METHODS OF ASSESSING WATER FOOTPRINT AND ECONOMIC WATER PRODUCTIVITY

2.2.5.1 METHODS OF ASSESSING WATER FOOTPRINT

The relevance of water sustainability and the crucial need to protect the restricted available freshwater have prompted various authors to come up with different water footprint calculation methods. The existing methods of assessing water footprint include:

a. Consumptive water-use based volumetric water footprint

This method is recognised by the Water Footprint Network. It was originally developed by Hoekstra (2003) and endorsed by the Water Footprint Network (WFN). Under this method, the assessment of a water footprint is categorised into three distinct sources of the water, namely blue, green, and grey water. Figure 2.2 below describes the components of a water footprint as described in terms of the consumptive water-use based volumetric water footprint method. A shown in Figure 2.2, the total water footprint is categorised into three, with the aim of identifying the origin of the water. Surface and groundwater are clearly separated. Rainfall that does not become runoff but for degradation of water quality are distinctly separated. This implies that the water footprint concept takes into account the blue, green and grey components of a water footprint, as well as indirect water usage. As shown in Figure 2.2, the return flows are excluded from water footprint evaluations.

- **Blue water footprint**

This component of a water footprint comprises all the surface and groundwater utilised in a product's life cycle (Hoekstra et al., 2011). The blue water footprint is an indicator of fresh surface or groundwater consumed. Blue water consumptive uses include the quantity of water evaporated and the quantity that goes into the product, water lost to different catchments (including water transfers), and water abstracted during periods of limited supply and returned in times of excess supply. However, evaporation has been found to be the most significant component of blue water consumption, and hence consumptive use is often linked to evaporation.

However, the other components should not be excluded in assessing blue water footprint (Hoekstra et al., 2011). It must be emphasised that the consumptive use does not suggest that the water disappears from the hydrological cycle; rather, it suggests that the water is not immediately available for alternative use. This is expressed empirically as:

$$WF_{proc,blue} = \text{blue water evapotranspiration} + \text{blue water incorporation} + \text{loss return flow} \quad (2.1)$$

- **Green water footprint**

This consists of all the rainwater that is evapotranspired or goes into the product. It can also be described as rainwater kept in the soil and which is only available for vegetation transpiration. Hoekstra et al. (2011) defined this as the total amount of rainwater utilised in a production cycle. The green water footprint for agricultural and forestry production is very relevant. Empirically, it is expressed as:

$$WF_{proc,green} = \text{green water evapotranspiration} + \text{green water incorporation} \qquad (2.2)$$

In the context of agriculture, models that are suitable for estimating evapotranspiration of crops, based on soil, crop and climate data, can be used to assess green water consumption.

- **Grey water footprint**

This is defined as the amount of freshwater needed to reduce water pollutants to acceptable standards (Hoekstra *et al.*, 2011). Thus, polluted water requires large quantities of freshwater to "dilute" loads of contaminants to acceptable standards. The volumetric-based grey water footprint does not include an indication of the extent of damage caused by the pollutants to the environment, but this is simply a method to include the amount of water required to reduce the pollution to acceptable norms. This is also expressed empirically as:

$$WF_{proc,grey} = \frac{L}{c_{max} - c_{nat}} \qquad (2.3)$$

The "*L*" in the calculation is the pollutant load (in mass/mass) that is discharged into the water body. This load is divided by the difference between the acceptable water quality standard for that pollutant (the maximum acceptable concentration c_{max} (in mass/mass) and the natural concentration in the receiving water body, c_{nat} (in mass/mass)).

The total water footprint is obtained by summing the different types of water footprints. This is expressed as:

$$WF_{Proc} = WF_{proc,blue} + WF_{proc,green} + WF_{proc,grey} \qquad (2.4)$$

Two alternative approaches could be employed in examining the total water use along a product cycle. The two approaches are the chain-summation approach and the stepwise accumulative approach (Hoekstra et al., 2011). The first approach is employed in a production process with a single output. Such cases rarely exist in practice, where one can simply divide the total water usage by the output. The second approach is more general and is applicable to production processes that have more than one input and several outputs.

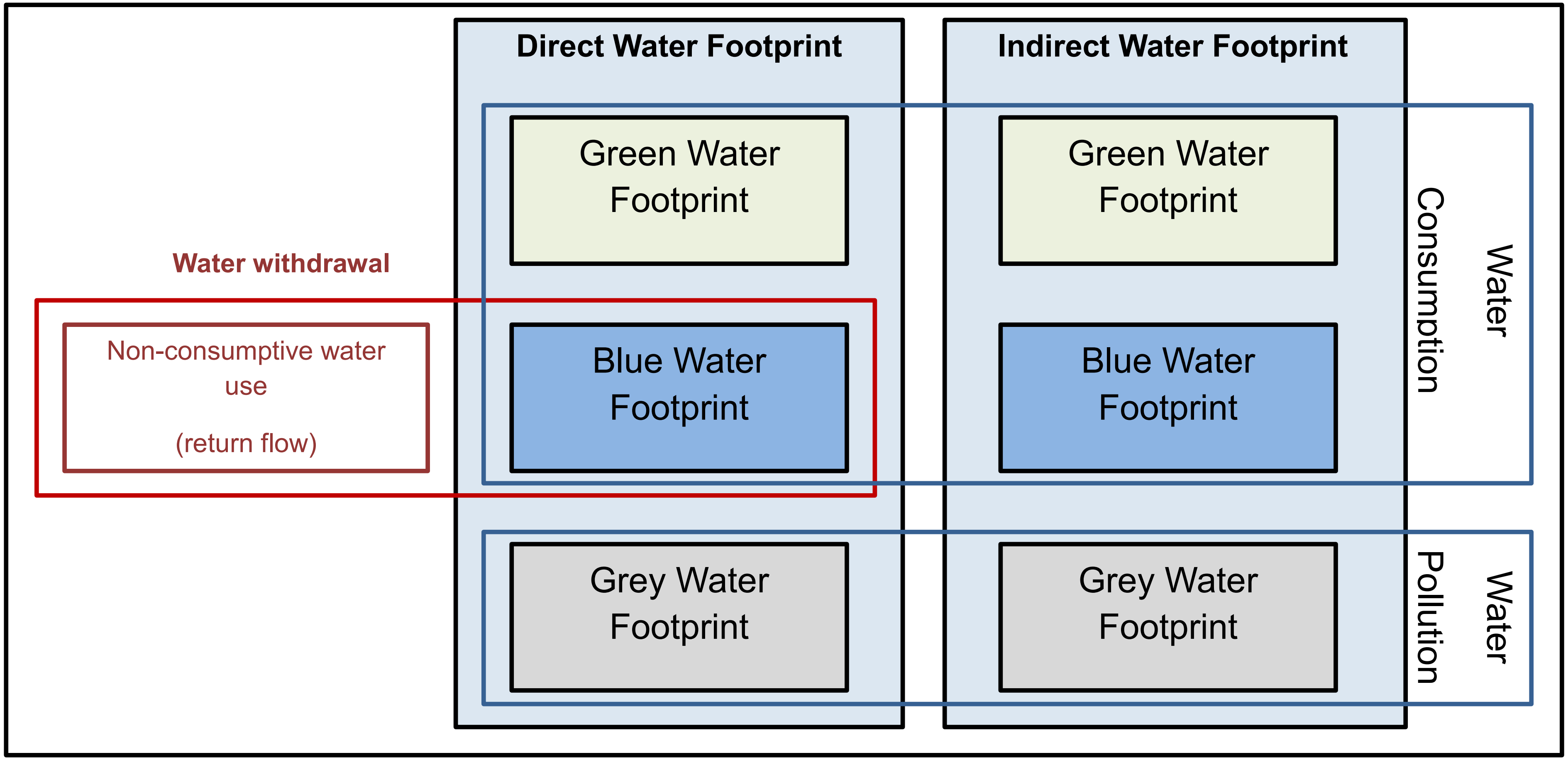

Figure 2.2: Components of a water footprint as described in consumptive water-use based volumetric water footprint method

Source: Hoekstra et al. (2011)

b. Stress-weighted water Life Cycle Assessment (LCA)

This method was suggested by Pfister et al. (2009). The distinction between the LCA method and the consumptive volumetric-based method is that the LCA reveals the effect of water usage on a specific geographical area or region (Van Der Laan et al., 2013). The basis for assessing the water footprint should be the stress-weighted water approach, as described in the LCA methodology (Pfister et al., 2009). However, the authors stated that much emphasis is placed on the quantities of water used, with little emphasis on water sources and the type of water use. The sources of water and the type of water use should be accounted for when using the LCA method to evaluate the water footprint, particularly at the inventory phase (Pfister *et al.,* 2009).

In the LCA methodology, consumptive water use is defined to consist of all the freshwater withdrawals that go into different water catchments, to be incorporated into the products or evaporated. Changes in the quality of water that returns to the original water source are described as degradative use, according to Pfister et al. (2009). This methodology attributes much importance to consumptive use and virtual water. The virtual water includes blue and green water. A further review of the LCA approach by Pfister et al. (2009) shows that only a blue virtual water footprint is accounted for. The authors argued that green water does not add to environmental flows unless it becomes blue, and hence the LCA methodology does not directly include a green water footprint. Green water is linked to land use and is only available through the use of land.

The calculation of the water quantities used in a product cycle follows the virtual water database developed by Chapagain and Hoekstra (2004). After calculating the volume of water used, the Water Stress Index (WSI) is further estimated. The WSI examines whether the freshwater withdrawal surpasses the water body's replenishment. The estimation of WSI is based on the water usage (WU) to water availability (WA) ratio (WTA), described by Van Der Laan et al. (2013). The WaterGAP2 global model is also applied (Pfister et al., 2009). The WaterGAP2 global hydrological water availability model uses data from the period 1961 to 1990. Hence, the annual average water availability is used. The application of such dataset allows for annual estimations and does not support short periods of severe water stresses. Hence, estimations of WTA are done using annual data only. A variation factor (VF) is usually included in the model to cater for monthly variations in precipitation. Pfister et al. (2009) highlighted the point that water catchment facilities (dams) decrease the change in water supply, and hence controlled catchments require a reduced variation factor (Pfister et al., 2009).

The WTAs in regulated and unregulated catchments are calculated as follows:

$$WTA_{\text{Regulated catchments}} = \sqrt{VF} \times \frac{WU}{WA} \tag{2.5}$$

$$WTA_{\text{Non-regulated catchments}} = VF \times \frac{WU}{WA} \tag{2.6}$$

$$VF = e + \sqrt{\ln(S_{month})^2 + \ln(S_{years})^2} \tag{2.7}$$

The variation factor is the overall measure of dispensation of the multiplicative standard deviation of the annual S_{Year} and monthly S_{Month} precipitation (Pfister et al., 2009). The WTA is employed in the estimation of WSI because the WSI is nonlinear in WTA. Hence, there is the need to adopt a logistic function. This helps in the attainment of continuous variables ranging between 0.01 and 1 (Pfister et al., 2009).

$$WSI = \frac{1}{1 + e^{-6.4WTA}(\frac{1}{0.01} - 1)} \tag{2.8}$$

The minimum value of WSI should be 0.01. The impact of water withdrawal at the minimum point will be marginal. The WSI value should not exceed one. A WSI value of 1 implies that there is extreme water stress (Van Der Laan et al., 2013). The LCA approach does not directly account for grey water, as does the consumptive water-use-based volumetric water footprint approach described by Hoekstra et al. (2011). Water quality is indirectly included in other impact assessments, such as freshwater toxicity or eutrophication (Ridoutt and Pfister, 2010).

c. *Adapted LCA water footprint methodology*

This methodology distinguishes Freshwater Ecosystem Impacts (FEI) from Freshwater Depletion (FD). This methodology uses several assumptions to arrive at the final impact estimates (Pfister et al., 2009). Under this methodology, the blue and green water are differentiated. The blue water under this methodology is defined as the total ground and surface water that can be abstracted. Water flows in a form of rain water or water in rivers, and groundwater reserves and water stocks are classified under this method. The authors assumed that various crops and natural vegetation have similar water requirements, and as such, they concluded that green water would not vary if crops were to be produced instead of natural vegetation. Green water is considered relevant under this methodology only when a blue water footprint is to be estimated. This implies that green water becomes irrelevant if blue water footprint calculations are not required (Milà i Canals et al., 2008).

A distinction is made concerning non-evaporative and evaporative water uses. Milà i Canals et al. (2008) described water use as non-evaporative if the water used returns to the source where it originated from and can be used for other purposes. On the other hand, the water becomes evaporative if it is exhausted and not available for immediate use by other water users (Milà i Canals et al., 2008). The contribution from this methodology has to do with the addition of a land use variable, which is argued to have a significant effect on water availability. The authors explained that some farming systems impact significantly on rainwater availability. For instance, tilled lands dry faster than lands with vegetation cover do. Thus, land with vegetation cover can contain soil water for a longer period, compared with tilled land with no vegetation cover. This methodology accounts for the impact of land use in calculating a water footprint. The contribution of land use to a water footprint is calculated by deducting the water loss from a reference land use from the water loss from a specific plot or area of land under consideration (Milà i Canals et al., 2008). The Water Stress Indicator (WSI) used under this methodology is expressed as:

$$\text{WSI} = \frac{\text{Water use}}{\text{Water Resource Available} - \text{Ecological Water Requirement}} \tag{2.9}$$

The application of this formula gives detailed information regarding water availability for other purposes, since the water required by the ecological system is accounted for (Milà i Canals et al., 2008). The water loss attributable to land use is estimated and added to blue water use. The sum of these two water sources is multiplied by the Water Stress Indicator (WSI). The value obtained is used as a classification factor. The volume of depleted freshwater is estimated by formula:

$$\text{ADP}_l = \frac{ER_l - RR_l}{(R_l^2)} \times \frac{R_{rs}^2}{(DR_{rs}^2)} \tag{2.10}$$

where *l* is the relevant water resource, *rs* refers to the reference resource, ER_l is the resource's extraction rate, RR_l is the resource's regeneration rate, R_l is the resource's ultimate reserve, R_{rs} is the reference resource's ultimate reserve, and DR_{rs} is the reference resource's deaccumulation rate.

d. Hydrological water balance method

This method builds upon the water balance method conceptualised by Hoekstra et al. (2011). This method was described by Deurer et al. (2011). What is unique about this method is that it does not focus only on consumptive water, but also accounts for the water balance (Van Der Laan et al., 2013). The description of the components of a water footprint follows Hoekstra et al. (2011). However, there is a slight difference in the estimation procedure (Deurer *et al*., 2011). Unlike Hoekstra et al. (2011), the estimated water footprints derived from the hydrological water balance method can be either positive or negative. Deurer et al. (2011) explained that in situations where the total blue water abstracted is higher than the water recharge, either through return flows or through rainfall, then a positive water footprint is attained. On the other hand, if the water recharge through return flows and rainfall exceeds the blue water abstraction, then a negative water footprint is observed. Hence, a negative water footprint gives an indication of blue water sustainability (Deurer et al., 2011). The hydrological water balance method is specified empirically to include the amount of water that flows into a catchment, the amount that flows out, and storage variations (Deurer et al., 2011). Green water under the hydrological water balance method is specified as:

$$\Delta \text{Green water} = D^{r} + ET^{r} + R^{r} - RF \qquad (2.11)$$

where ET^{r} represents evapotranspiration during rainfall season, *RF* is the effective rainfall (rainfall – quantity of water intercepted by crops), D^{r} is the drainage under rain-fed conditions, and R^{r} is the runoff during rainfall. The blue water footprint, on the other hand, is expressed as:

$$\Delta \text{Blue water} = D^{r} + D^{ir} + R^{r} + R^{ir} - IR \qquad (2.12)$$

where D^{r} denotes the drainage under rain fed conditions, D^{ir} represents the difference between drainage under rain-fed and irrigated conditions. R^{r} denotes the runoff in rain-fed settings, R^{ir} represents the difference between runoff under rain-fed and irrigated conditions, IR denotes annual amount of water utilised for irrigation. The grey water footprint calculation follows the formula described by Hoekstra et al. (2011), as specified in Equation 2.3. The total water footprint is obtained by summing all the different components estimated (Herath et al., 2013).

2.2.5.2 METHODS OF ASSESSING ECONOMIC WATER PRODUCTIVITIES

After the water footprints are calculated based on any of the methods discussed above, the economic water productivities can be estimated to give an indication of the income generated per unit of water use. In estimating the water productivities, there a distinction should be made between crop yield from rainfall and that of irrigation (Chouchane et al., 2015). Once such distinction is made, water productivities can be discussed for different water components. Blue water productivity is defined as the yield attained due to irrigation, divided by the amount of blue water utilised. This is expressed as:

$$WP_{blue} = \frac{Yt_{blue}}{ET_{blue}} \quad (2.13)$$

where Yt_{blue} is the crop yield under irrigation, and ET_{blue} is the evapotranspiration of blue water. Green water productivity, on the other hand, can be defined as the crop yield obtained from rainfall only, without irrigation, divided by the total green water used by the crop (Hoekstra, 2013). This is specified as:

$$WP_{green} = \frac{Yt_{green}}{ET_{green}} \quad (2.14)$$

where Yt_{green} is the crop yield under rain-fed conditions only, and ET_{green} denotes evapotranspiration of green water for rain-fed conditions (without irrigation). It must be emphasized that this equation will not apply to crops grown under winter rainfall climate or winter crops grown in a summer rainfall region, in both cases there probably won’t be any rainfed yield. Crop yields under rain-fed conditions only (Yt_{green}), according to Chouchane et al. (2015) and Doorenbos and Kassam (1979), can be calculated as:

$$\left(1 - \frac{Y_a}{Y_m}\right) = RF_y \left(1 - \frac{ET_a}{CWR}\right) \quad (2.15)$$

where RF_y denotes the yield response factor, the actual crop output per hectare is denoted by Y_a, and Y_m denotes maximum output attainable at the optimum water level. ET_a denotes the real crop evapotranspiration measured in millimetres per period, whereas CWR denotes crop water requirement in millimetres per period. The economic water productivity is then obtained by multiplying the estimated water productivities by the value added to the product and it is usually expressed in monetary values per kilogram (e.g. ZAR/kg).

In conclusion, the above review shows that the methods of calculating a water footprint vary from one method to the other. As discussed, the consumptive water-use-based volumetric water footprint takes into consideration all the components of water used (blue, green, and grey), with clear distinctions between the sources of water. The stress-weighted water LCA directly focuses on the blue water footprint, without accounting for a green water footprint, because the developers of this methodology believe that green water is inseparable from land use. The adapted LCA water footprint method, however, concentrates on green and blue water resources. Blue water under this methodology is categorised into groundwater, which is also referred to as fund, fossil groundwater, identified as stock and rivers or flows. The last method, which is the hydrological water balance, assesses blue, green, and grey water footprints, but on an annual basis and at local levels. This approach categorises the hydrological system into inflows, outflows and storage. Since the consumptive water-use-based volumetric water footprint takes into account, and clearly differentiates between, different water footprint components, this approach was employed to calculate the water footprint of the selected agricultural products in this research.

2.3 CARBON FOOTPRINT ASSESSMENT IN THE SOUTH AFRICAN DAIRY INDUSTRY

2.3.1 BACKGROUND

Recently, much attention has been paid to carbon emissions from various sectors of the South African economy. In September 2015, South Africa presented its Intended Nationally Determined Contribution (INDC), which focuses on reducing GHG emission levels to about 398 to 614 $MtCO_2e$ by 2025–2030 (Department of Environmental Affairs (DEA), 2015). In terms of percentage, the above reduction targets represent about 20–82% upsurge on 1990 $MtCO_2e$ levels, without land usage and its variations. Based on these projections, South Africa’s contribution towards limiting global warming is regarded as inadequate by the Department of Energy.

According to Climate Action Tracker (2015), South Africa’s inadequate rating reveals that the country’s contribution is not in support of the global fair target of reach 2°C pathway. Statistics indicate that if other countries were to adopt South Africa’s principle for global warming, then the world’s global warming would be expected to surpass 3–4°C (Climate Action Tracker, 2015). South Africa intents to lower GHG emission levels by 34 % by the year 2020, and targets reaching a 42 % reduction by 2025. However, the current contributions from the country are inconsistent with the pledge which was made in Copenhagen. This shows that the current policies in South Africa towards limiting global warming are ineffective or inefficient. Therefore, there is the need for an implementation of more stringent, effective and efficient policies in order for the country to reach its intended targets. DEA (2013) statistics indicate that there is an increasing trend in emissions in the country, based on the existing policies.

It is shown that existing emission policies have not had a significantly positive effect on emissions as was expected, and that emissions fall under business-as-usual (BAU) levels. For instance, emissions are expected to reach of 729 MtCO_2e in 2020. Statistically, this represents about a 110% rise in emissions, using the 1990 emissions as a reference point. This rise in emissions is attributed to the inefficient existing policies and projects aimed at reducing GHG emissions and global warming. Historically, South Africa is placed twelfth in the ranking of countries with the largest carbon dioxide (CO_2) emissions, and contributes to almost half of all the GHG emission in Africa (GHG National Inventory Report, 2014). Out of the total GHG emissions in the country, about 80% is attributed to carbon dioxide (CO_2). This shows that carbon emission is a major environmental issue, which requires a holistic assessment and attention in order to become more environmentally sustainable. In an attempt to deal with the increasing emission trends, the government issued the Carbon Tax Policy Paper in 2013 (GHG National Inventory Report, 2014).

This study contributes to the attainment of environmental sustainability in the country by evaluating carbon footprints of dairy products in South Africa. This is an imperative move, aimed at attaining sustainable dairy industry. This research offers insights into consistent valuation techniques that can be established to give more knowledge of current environmental impacts, applicability of different solutions, and of mitigating strategies. The next section gives an overview of GHG emissions in the dairy industry.

2.3.2 GREENHOUSE GASES EMISSIONS AND THE DAIRY INDUSTRY

Variations in climate are currently regarded as constituting the most imminent environmental issue affecting societies (Steffen et al*.,* 2007). Variability in climate poses a great threat to a sustainable environment. Recently, the livestock sector has become to be regarded as a significant contributor to climate variation. According to Rotz et al. (2013), this sector contributes about 18 % to anthropogenic GHG emissions. Gerber et al. (2010) revealed that the dairy sector contributes 4.0 % of global emissions. Analysis of the dairy sector indicates that primary dairy outputs alone account for 2.7 % of total GHG emissions, globally. A by-product of dairy industry – beef – accounts for 1.3 % of total GHG emissions, globally. Agricultural products and productions result in GHG emissions which are different from emissions from other sectors, such as transport or energy. In agriculture, the common and most important contributors are methane (CH_4) and nitrous oxide (N_2O), while agricultural land use change (LUC) also significantly contributes biogenic CO_2. The other sectors are mostly dominated by fossil carbon dioxide (CO_2) emissions (Flysjö, 2012).

Figure 2.3 below shows the global GHG emissions by sector or economic activities that lead to their production. As shown in Figure 2.3, energy supply produced 26 % of 2004 global GHG emissions (IPCC, 2007). The industry contributed 19% of global GHG emissions (IPCC, 2007). Under this sector, GHG emissions primarily arise from burning fossil fuels. Land utilisation, land utilisation variation, and forestry produced 17% of global GHG emissions (IPCC, 2007). It must be emphasised that the CO_2 that ecosystems remove from the atmosphere are not included under this sector.

Transportation is accountable for 13 % of worldwide GHG emissions. Commercial and housing also accounted for 8 % of worldwide GHG emissions. Waste and wastewater are responsible for 3 % of worldwide GHG emissions (IPCC, 2007). Agriculture produced 14 % of worldwide GHG emissions, although this does not include energy consumption for transportation on the farm and energy utilisation for input production. If all these other activities were to be included, Foley et al. (2011) opined that the agriculture sector would be more likely to account for 30–35 % of worldwide GHG emissions.

Gerber et al. *(*2010) have stated that in the dairy industry, much of the burden on the environment occurs at the production phase. In developed countries, about 80 % of GHG emissions are recorded before a dairy product reaches the farm gate. Globally, 1 kg milk at the farm gate, on the average, is associated with 2.4 kg of carbon dioxide (CO_2e) emission (Gerber et al., 2010). Carbon dioxide (CO_2e) emissions differ from one region to another.

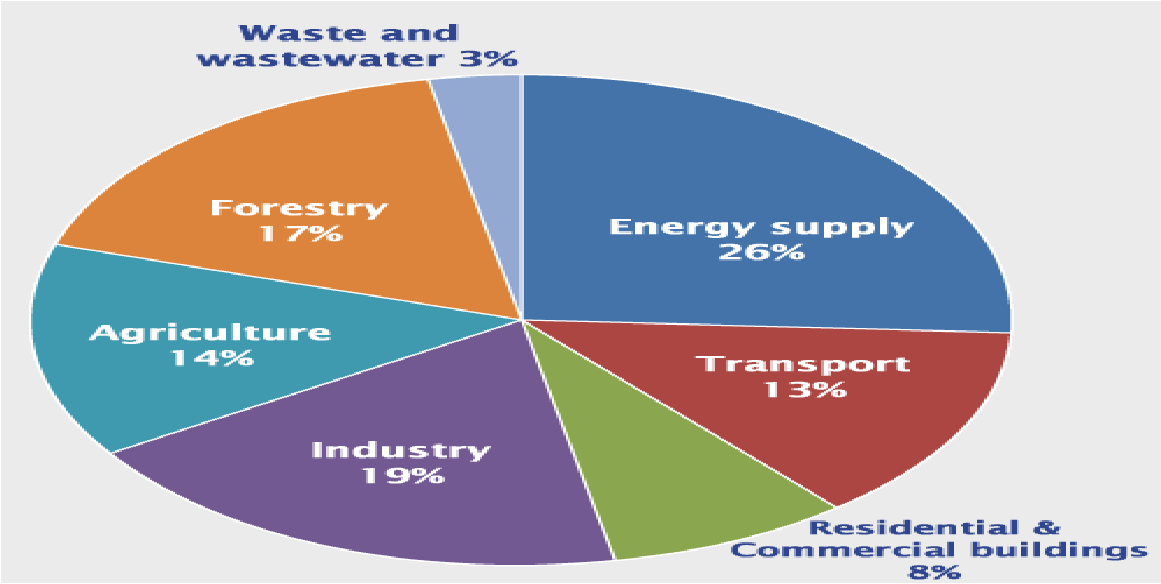

Figure 2.3: Global GHG emissions

Source: IPCC (2007)

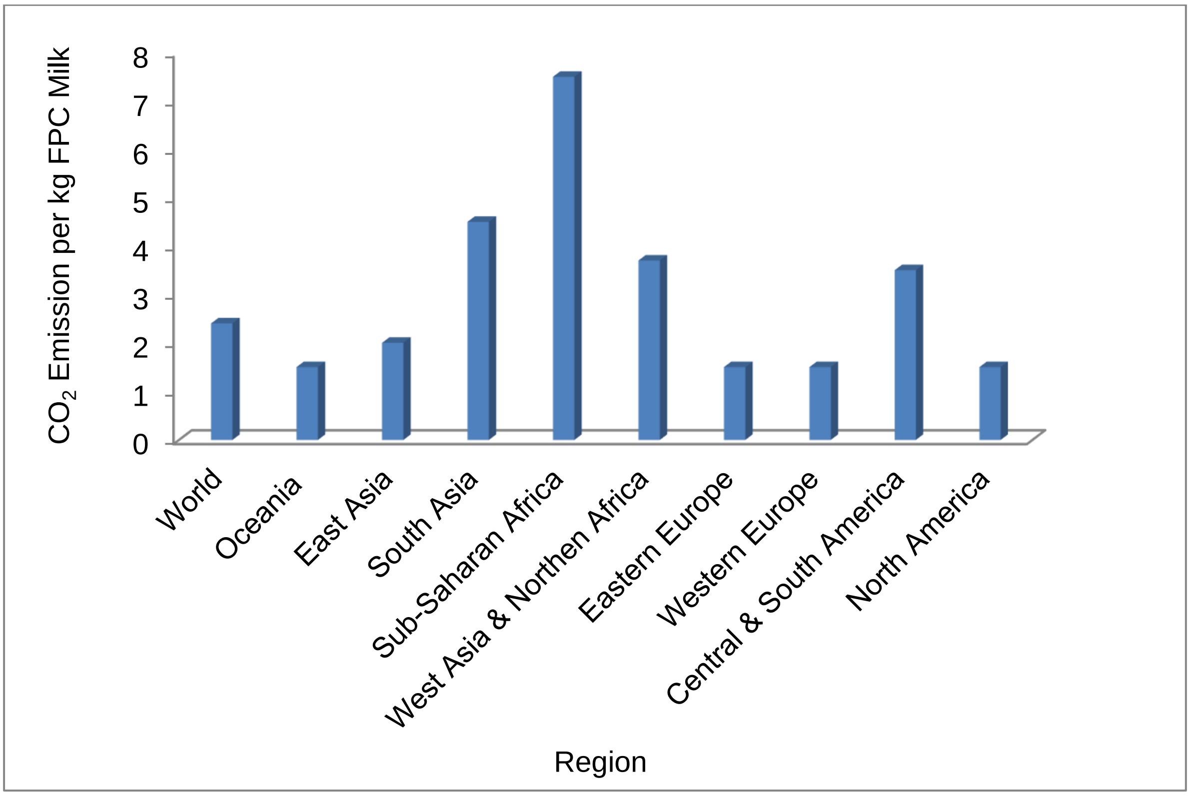

Figure 2.4: Carbon footprint (CO_2e) per kg fat and protein corrected (FPC) milk at farm gate

Source: Gerber et al. (2010)

For instance in Western Europe, Eastern Europe, Oceania and North America, carbon dioxide (CO_2e) emission is 1.5 kg per 1 kg milk. However, in sub-Saharan Africa, the CO_2e emission is 7.5 kg per kg milk, whereas that of Eastern Asia, Western Asia, Northern Africa, and Central and South America is between 2 and 4.5 kg CO_2e per kg milk. In developed countries, dairy production is regarded as a specialised production, whereas in emerging countries dairy cattle are used for multiple purposes (e.g. draught power). One of the reasons that may account for the high carbon footprint of milk in sub-Saharan Africa is the low milk yield per cow.

In conclusion, the agricultural sector, which includes the dairy industry, is a significant contributor to GHG emissions and contributes immensely to climate variation. It is worth noting that emissions from the agricultural sector are usually underestimated. Much of the emissions from the dairy industry occur at the farm gate. It is worth noting that carbon footprints of milk are very high compared to other regions of the world. This suggests that there are many practices and activities in the African dairy industry that leads to these high carbon footprint figures. Therefore, there is the need for thorough assessment of the dairy industry to identify the major emission areas and the possible mitigation strategies that can be adopted to reduce emissions. Hence, one of the objectives of this section is to identify emission areas and mitigation strategies that will be feasible in the South African context.

2.3.3 GLOBAL GHG EMISSION TRENDS AND CHALLENGES IN THE FUTURE

Globally, an overview of the future trends and challenges associated with GHG emissions has received some attention. FAO (2006) reported that GHG emissions are expected to increase. The report indicated that, apart from animal products which are known to account for large GHG emissions, the global demand for animal products remains a key challenge. It is estimated that global demand for animal products will double by 2050, in reference to baseline reports for the year 2000 (FAO, 2006). This anticipated surge in demand is significantly attributed to the increasing human population. A shift in dietary patterns towards more animal protein, particularly in developing economies, has been regarded as one of the main factors accounting for the high demand for animal products.

According to FAO (2006), the world's estimated typical per capita dairy intake was about 76 kg of fresh milk per year. However, it was observed that consumption in developed countries was higher than that of developing countries was. The statistics indicated that consumption in developing countries were about five times lower, relative to consumption in developed countries, for fresh milk equivalence per individual and annum (Flysjö, 2012). FAO (2006) predicted that by the year 2050, the world's per capita annual intake of dairy foodstuffs (excluding butter) would reach 100 kg of fresh milk equivalents. It was further indicated that developing countries would observe an increase of about 70% in milk consumption, with about 78 kg fresh milk equivalents. However, in developed countries, milk consumption is expected to range from 214 to 227 kg fresh milk equivalents.

The projected increase in food demand has been a major challenge to the World Food Program (WFP) and leaders across the globe. Meeting the increase in food demand implies that there is the need for increases in productivity. Production can increase through the extension of cultivated land areas or intensification (FAO, 2006). Unfortunately, land for agriculture or farming is restricted and subjected to pressures from other sectors of an economy. The limited land available is being competed for by various sectors such as industries, energy, and transportation, while part is required for forest conservation. This competition is likely to be intense with time (FAO, 2006). Expanding cultivated land areas has some limitations because this would be at the expense of native ecosystems. Thus, the rainforests that are being conserved will have to be turned over to agricultural or farming lands, since they are suitable for agriculture. The impact of intensification on the environment should be considered if intensification is to be adopted as a possible expansion strategy. The use of improved or high-yielding varieties can be employed as a viable option. Rockström et al. (2009) argued that agriculture presently has contributed to climate variation, damaged biodiversity, and has altered the nitrogen cycle, globally. Therefore, sustainable production methods and technologies are vital for meeting future demand, while making efficient use of the available land.

The shifting dietary pattern towards food from animal sources is regarded as one of the possible answers for meeting the increased food demand. However, animal production, according to Sonesson et al. (2010), has higher environmental impacts, compared with crop production such as vegetables. In addition, limiting food wastage has been considered as an important strategy (Sonesson et al., 2010). This suggests that expanding or intensifying production is not the only solution for meeting the increasing demand for food, but also for making sure that the limited amounts of food produced are not wasted.

2.3.4 METHODS OF ASSESSING CARBON FOOTPRINT

Over the years, several attempts have been made in the assessment of GHG emissions in various sectors of global economies. The first attempt was an assessment by IPCC in 2001. This panel analysed and categorised GHG emitted through enteric methane and manure management according to the sectors from where they are emitted. For instance, whether the emissions originated from the energy, industry, agricultural, or transport sector, among others. However, an initial sector-specific assessment of GHG emissions was conducted in the global livestock chain. This assessment by the IPCC was based on Livestock's Long Shadow Approach (FAO, 2006). Livestock's Long Shadow Approach was used in the livestock sector to calculate all emissions along the livestock food chains and this consists of all emissions reported by IPCC under various sector categories. However, the Livestock's Long Shadow Approach failed to disaggregate or compare GHG emission estimates by region or per kilogram of animal products. Based on this limitation, the LCA was developed to provide a detailed methodological assessment of different commodities, processes and production systems (Gerber et al., 2010). The next subsection discusses the Life Cycle Assessment methodology.

2.3.4.1 THE LIFE CYCLE ASSESSMENT (LCA) METHOD

Globally, the LCA approach has been accepted and used in environmental impact assessments. For instance, the LCA is extensively used in agriculture and dairy industries to evaluate the ecological effects and sustainability of agricultural activities. The method is also used to detect areas of production where emissions are intensive along the agricultural production chain. LCA is deep-rooted and clearly defined in ISO 14040 and ISO 14044. The key advantage of LCA is that it gives an all-inclusive valuation of the production cycle (ISO, 2006). The LCA analysis consists of all life cycle phases. It also includes all associated inputs and outputs, as well as the allied in-flows and out-flows from the environment.

According to Gerber et al. (2010), LCA offers an outline to generally find actual methods to minimise ecological burdens while examining the effect of changes in production process. This framework ensures that environmental problems are thoroughly identified and not transferred from a particular stage and cycle of the product to a different one. Nonetheless, there are some limitations associated with it, particularly when applied to agriculture. The first challenge is that it requires intensive data and as such, it is difficult to apply in interconnected food chains. As a result of this, researchers are forced to make assumptions which may influence the accuracy of estimates. Secondly, the procedural selections and assumptions about system limit demarcations, useful components, and distribution procedures may be biased and influence the estimates (Gerber et al., 2010).

2.3.4.2 PRINCIPLES OF LCA

The initial application of LCA approach was made in the industry section, where LCA was used to analyse industrial process chains. However, it has been employed in assessing the environmental impacts of agriculture for over 15 years. The LCA principle requires the complete examination of production structures. The system boundary, according to Gerber et al. (2010), principally hinges on the aim of the research. The functional unit is also clearly defined in terms of its quantity per a given production unit and a specified quality level. This means that the functional unit can be expressed in terms of a defined quantity, depending on the type of product being assessed. An example would be per 1 kg of a product, such as fat content or protein content.

However, LCA usage in agriculture is complex due to the multiple yields that result from agricultural production. Thus, aside the main agricultural outputs, there are other by-products or secondary products that arise from agricultural production. Therefore, there should be proper apportioning of ecological impacts to their applicable systems, in line with rule of allocation grounded on diverse principles. Flysjö (2012) revealed that LCA is an appropriate tool for situation analysis aimed at identifying the point along the value chain where ecological impacts are very severe. That is, identifying the “hot spots” in the dairy industry where the largest GHG emissions can be reduced, while making sure that potential environmental problems are not shifted to different phases along the dairy value chain, and so prevent increase in net emissions.

2.3.4.3 PHASES OF LIFE CYCLE ASSESSMENT

The ISO 14040 report revealed four phases of LCA. Figure 2.5 below shows the phases of the LCA framework, as illustrated in ISO 14040 (ISO, 2006). As shown in the figure, the first phase entails the **goal and scope definition**. Under this phase, the researcher describes the purpose of the study, the functional unit (FU), system boundaries, methods for co-product handling, data, and data quality requirements (ISO, 2006). System expansion or allocation is employed in addressing co-product handling under the first phase. A system expansion approach helps to elucidate allocation by expanding the system boundaries to contain additional functions associated with the co-products. Allocation means dividing the environmental burden between co-products, based on factors such as economic value. The second phase is the **inventory analysis.** This phase deals with the data collected and the calculations to be done. Under this phase, GHG emissions are computed per functional unit. The next phase is the **impact assessment**, where emissions are classified and multiplied by their characterisation factor. For instance, all emissions contributing to global warming are defined. The fourth phase is **interpretation**. This is a replicative process that occurs during the whole assessment process. Under this phase, identification of important issues is done, based on the results, evaluation of completeness, sensitivity check, limitations, conclusions and recommendations. Sonnemann et al. (2011) revealed that the scope and goal of a study indicates the type of LCA approach that needs to be employed. Currently, there are two well-known approaches that are used: these are Attributional Life Cycle Analysis (ALCA) and Consequential Life Cycle Analysis (CLCA). Whichever is applicable depends on the goal and scope of a study. The ISO 14040 and 14044 (ISO, 2006) reports indicate that there are no clear-cut distinctions between the two LCA approaches. However, ALCA is known to assign elementary flows and possible ecological impacts to a given product system, based on the history of the product. On the other hand, CLCA examines the ecological impacts of possible variations between different product systems (ISO, 2006).

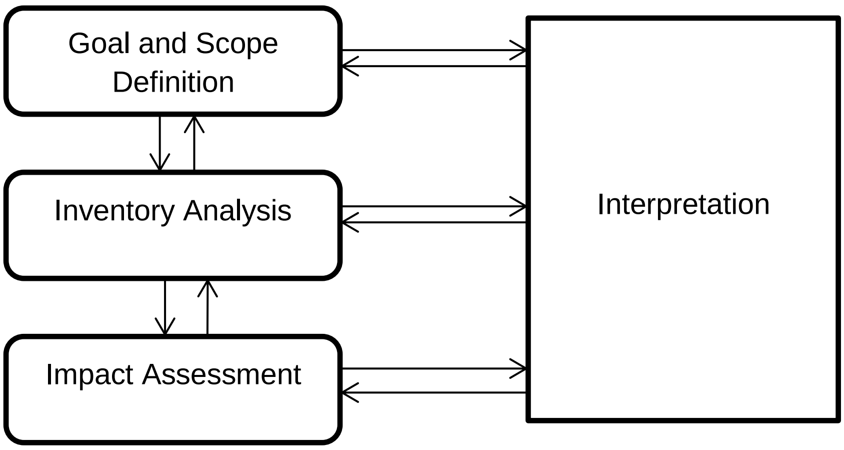

Figure 2.5: Phases of Life Cycle Assessment

Source: ISO 14040 (ISO, 2006)

Attributional Life Cycle Analysis (ALCA) is usually referred to as ‘accounting LCA’. This is because ALCA offers an understanding of the share of universal challenges that are linked to a product (Sonnemann et al., 2011). ALCA allows for the aggregation of results by adding all emissions arising from various sectors in a particular region or country to arrive at the total emission. ALCA records the physical flows of a system, but fails to take into account the impacts arising from variations in demand for the product. This means that whether an increase in demand results in more emissions or not, is not accounted for under this approach. The ALCA approach considers all upstream and downstream procedures that are really linked to the produce under study. The data required for an ALCA approach comprise the actual providers' data or average data. Most studies have applied the allocation to apportion ecological impacts among co-products from several productivity processes, as occurs in agriculture. Nonetheless, some studies have applied system expansion, notwithstanding it being often linked with the CLCA approach. ALCA is mostly applied in situations where the researcher wants to assign ecological impacts to diverse areas, such as agriculture, energy, transport, and food sectors. Furthermore, ALCA is suitable for identification of 'hot spots' and their degrees in various life cycle stages. ALCA is regarded as an easier approach to implement, relative to CLCA.

On the other hand, consequential LCA (CLCA) is often regarded by researchers as "change-oriented LCA". Unlike ALCA, the CLCA approach was established by economists, since it captures marketing aspects of the analysis. According to Sonnemann et al. (2011), CLCA deals with the impacts that occur on the environment as a result of change in demand for products that cause environmental problems in production. This approach preferably comprises only the processes influenced by a decision. The CLCA data employed characterise actual suppliers, so long as the data is not altered. Under CLCA, multi-product output is handled by applying system expansion while including more functions associated with the co-products. The products displayed under system expansion are usually indeterminate and this usually influences the final result. Hence, the underlying assumptions must be clearly spelt out when conducting analysis. However, CLCA is suitable for analysing future approaches. Nevertheless, Ekvall et al. (2005) opined that both ALCA and CLCA are applicable in decision-making and learning purposes. For instance, Ekvall and Andrae (2006) and Thomassen et al. (2008) applied both attributional and consequential approaches for a single product to prove the feasibility of applying both approaches. The authors argued that consequential LCA is effective in evaluating ecological impacts of separate choices or rules, whereas attributional LCA is mainly adopted to elude links with systems that has large environmental impacts. Hence, both purposes are considered to be appropriate. Further findings from authors such as Sanden and Karlstrom (2007) have revealed that both attributional and consequential LCA are appropriate for modelling future, present or current systems.

The attributional approach is employed here because this study seeks to evaluate the environmental burden of the existing and current South African dairy industry, and to assign impacts to different areas. The primary aim of this section is to assess the carbon footprint of milk in the South Africa dairy sector by means of LCA using consistent calculation methods, modelling approaches and data. Unlike previous LCA studies which are either global in scope or focused on developed countries, the present study is country-specific. As a result, specific data pertaining to South Africa was used. The functional unit for this research is 1 kg of energy in corrected milk at the farm gate. The system boundary in this research is limited to the South African dairy farm gate. Inputs of dairy production and raw materials used, as well as all major GHG emissions, are considered. Milk is the central product from the dairy farms. Manure from the animals is used in fertilising grazing lands and fodder production at the farms. Therefore, no allocation is required.

2.3.4.4 GUIDELINES FOR LCA APPLICATION IN CARBON FOOTPRINT ASSESSMENT

Over the past few years, researchers have applied LCA to evaluate the sustainability indicators in the livestock sector, particularly in developed countries (Galli et al., 2012; Ridoutt et al., 2014; Rotz et al., 2013). However, these studies differ substantially in their application of LCA, in terms of level of detail, system boundaries definition, emission factors employed, allocation techniques, and functional units. Various assumptions have been outlined for estimating a carbon footprint under the LCA methodology. These assumptions were made to attain more comparable results and to establish harmonisation in the calculation methods. The existing guidelines developed for evaluating a product carbon footprint include ISO 14067 (ISO, 2012), BS EN ISO 14044 (ISO, 2006), GHG Protocol's Product Life Cycle Accounting and Reporting Standard (World Business Council and World Resource Institute for Sustainable Development, 2011), the International Reference Life Cycle Data System (ILCD) handbook which was compiled by the European Commission, Joint Research Institute and Institute for Environment and Sustainability in 2010, and PAS2050 described by the British Standard Institute (BSI, 2011). The PAS2050 guidelines require the assessment to be relevant, complete, consistent, accurate and transparent. In the dairy industry, there are three main guidelines provided by the International Dairy Federation (2010), namely the IDF guide to standard LCA methodology employed in the dairy subdivision; Procedures for carbon footprint calculation for dairy foodstuffs by Carbon Trust (2010); and Product Category Rules (PCR) for processed liquid milk, published by the Swedish Environmental Management Council in 2010.

2.3.4.5 SOURCES OF GHG EMISSIONS

The sources of emission in the dairy industry need to be harmonised in a holistic way because dairy–cattle production systems yield multiple outputs: eatable foodstuffs, such as beef and milk, and non-edible products and services like draught power, leather, manure and capital. One of the key aspects that needs particular attention is the functional unit. Globally, the functional units used to report GHG emissions are kg of carbon dioxide equivalents (CO_2–eq.) per kg of FPCM, and carcass weight, at the farm gate (Gerber et al., 2010). According to Gerber et al. (2010), milk is converted to FPCM with 4.0 % fat and 3.3 % protein through the application of the formula below:

$$\text{FPCM} = \text{Raw milk (kg)} \times (0.337 + 0.116 \times \text{Fat content (\%)} + 0.06 \times \text{Protein content(\%)}) \qquad (2.15)$$

When analysing the carbon footprint of milk, it is imperative to consider milk consumed fresh and the quantity of milk that is transported and processed through the product cycle after the product leaves the farm gate. GHG emissions in the dairy industry are associated with the processing and transportation of dairy products (e.g. cheese or milk powder) and are estimated in kg of CO_2 equivalent per kilogram of FPCM equivalent, when reported at the farm gate. The system boundaries in the dairy industry comprise the whole milk production chain, from feed production through to the final processing of milk and meat, not excluding transportation to retail markets. The dairy system boundary is categorised into two sub-systems:

1. **From cradle to farm-gate**. This sub-system comprises all upstream processes in livestock production, up to the point where the animals or products leave the farm. These include producing grass, feed crops, crop residues, by-products, and concentrates. The above-mentioned processes will lead to:

    - Production of nitrogen fertiliser (CO_2);
    - Direct and indirect emissions (N_2O) arising from manure and chemical fertiliser application to crops;
    - Direct and indirect emissions (N_2O) arising from deposition of manure and urine on pasture crops;

- Emission of CO_2 from energy used for fertilisation, transportation of agrochemicals, field operations, drying, and processing of feed crops and fodder;
- Processing of crops into by-products and concentrates;
- Conveyance of livestock feed from the production site to the feeding site;
- Variations in carbon stocks resulting from land use change (IPCC, 2006);
- Loss of nitrogen (N) associated with changes in carbon stocks;
- CH_4 production through enteric fermentation by ruminants; and
- Direct and indirect emissions of CH_4 and N_2O from manure storage.

2. **Farm-gate to retail**. This sub-system entails:
   - The transport of milk and animals to dairies and slaughterhouses;
   - Processing of raw milk into commodities such as cooled milk, yoghurt, cheese, butter, and milk powder;
   - Production of packaging; and
   - Transport to the retail distributor.

Figure 2.6 below shows the system boundaries that are considered in assessing GHG emissions in the dairy sector. As shown in the figure, the calculation of GHG emissions requires the description of the livestock production system.

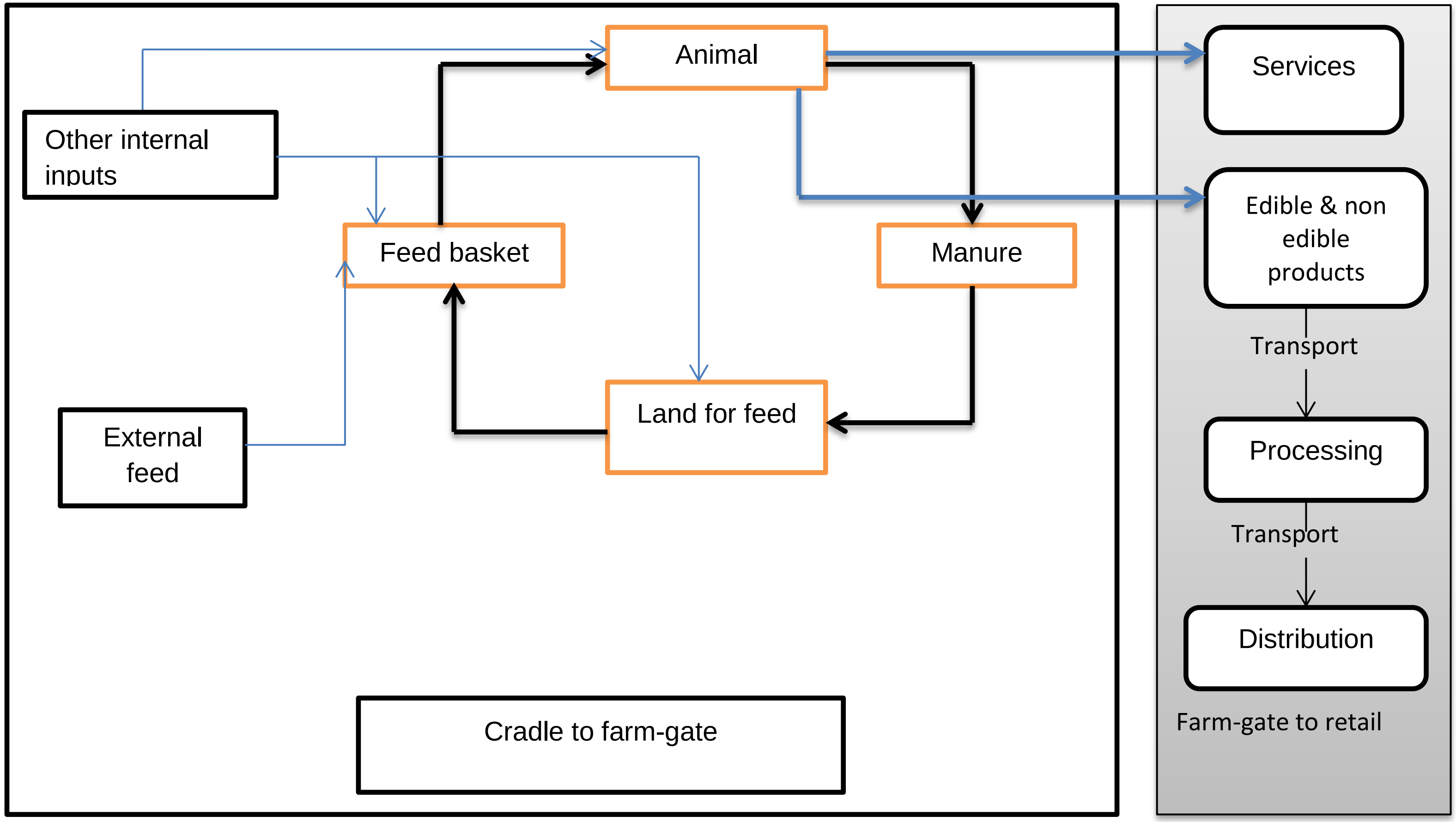

Figure 2.6: System boundary in the dairy sector

Source: Adopted from Gerber et al. (2010)

2.4 CONSUMERS' PREFERENCES, WILLINGNESS TO PAY, AND WELFARE EFFECTS OF WATER AND CARBON FOOTPRINT SUSTAINABILITY INFORMATION

2.4.1 BACKGROUND

In recent years, the assessment of consumers' preferences for sustainable food products has been gaining particular attention, especially in developed countries (Grebitus et al., 2015). Researchers are interested in knowing how environmentally sustainable attributes and information will change the sustainability behaviour of consumers and producers (Grebitus et al., 2015). The interest in environmental sustainability attributes is triggered by the association between the production and consumption of agricultural food products and the effects of these activities on ecosystems (IPCC, 2007).

Carbon and water footprint indicators have significant effects on consumers' preferences, behaviour and welfare (Grebitus et al., 2015; Hoekstra et al., 2011). An understanding of consumers' behaviour towards environmental sustainability attributes provides relevant insights for framing sustainability policies and generating consciousness about activities that are not sustainable. This insight contributes to the minimisation of the growing stress on the environment. Furthermore, an understanding of consumers' sustainability behaviour helps in finding probable markets for produce from ecologically sustainable or environmental friendly production systems. Similarly, Hynes et al. (2012) stated that improvement and changes in water quality attributes exert significant welfare effects on water users.

Despite the relevance of understanding consumers' preferences, willingness to pay, and welfare effects, existing studies of environmental sustainability assessments in South Africa have ignored the impact of water and carbon footprint sustainability attributes on consumers' behaviour and welfare. Therefore, the current knowledge is insufficient to understand how South African consumers would react to changes in water and carbon sustainability attributes and policy changes. The lack of information on consumers' behaviour towards water and carbon sustainability attributes has led to the lack of a connection and understanding between consumption activities and environmental pressures on freshwater and the earth's atmosphere in South Africa. Based on this, the present study seeks to assess South African consumers' heterogeneous preferences, willingness to pay, and welfare effects arising from water and carbon footprint information. Prior to assessment of consumers' preferences, it is imperative to first assess consumers' awareness of environmental sustainability attributes. Therefore, the next section discusses consumers' awareness of environmental sustainability attributes.

2.4.2 CONSUMERS' AWARENESS OF ENVIRONMENTAL SUSTAINABILITY ATTRIBUTES

Generally, producers are required to inform or update consumers on the constituents of their products offered for sale. This is because the consumer has the right to know about the product he or she is purchasing. The process of allowing the consumer to be aware of the product that he or she is buying is termed product awareness (Khurana, 2007). Consumer awareness in terms of marketing ensures that consumers are knowledgeable about the different types of products, product qualities or characteristics, point of sales, product prices, and available sales promotion. The rationale behind the creation of consumer awareness started in England after the Second World War. More emphasis was placed on the right of consumers to be aware of the attributes or characteristics of food products in the United States of America in 1962, where consumer's rights to information on products were formally declared. The declarations were initially made on four basic consumer rights, namely choice, information, safety, and awareness (Khurana, 2007). Keller (2003) has noted that product awareness could be formed through labels or brands, and that such information is of particular importance to consumers, since purchasing decisions often made with a short time and under time pressure. This implies that for a consumer to know the quality status of a product, the product label or brand awareness acts as a signal to consumers.

Recently, environmentalists and conservation scientists have proposed that food products should be labelled according to how much water is used to produce them, as well as the carbon emitted to the earth's atmosphere (Grebitus et al., 2015; Van Oel and Hoekstra, 2012). The call for such footprint labels and information is attributable to the current water scarcity situation and global warming. Bougherara and Combris (2009) found that the impact of a product and its production process on the environment is an important factor which influences consumers' decisions to buy a product. The authors highlighted the point that the consumers' awareness of the impact arising from the production of the product and the product itself is the main influencer of consumers' buying decisions.

Consumers' awareness of the quantity and source of water that goes into the growing, manufacturing and processing of food products, as well as concerns over GHG emissions, has resulted in water and carbon footprint sustainability assessments being made in recent years. The creation of awareness and the promotion of the concept of water and carbon footprints in the context of consumers' studies has placed focus on including items of sustainability information on product labels, with the goal of drawing the attention of consumers to how drastically we are draining our most precious resource, and to how we can sustain it for future generations.

Although the use of footprint label information is gaining prominence, there is no consensus on how best to measure and label footprint indicators on products so as to ensure that the public understands its full impact (Noga and Wolbring, 2013), as well as on the precise quantification of the footprint indicators or attribute changes on the welfare of consumers. Most people have no idea how much fresh water they are consuming, nor of the carbon emitted during the production of what they are consuming. This suggests that producers and manufacturers could create awareness by adding water and carbon footprint labelling information to gain competitive advantage and earn a premium for their products.

The method for conveying water and carbon sustainability information to consumers is very relevant to sustainable product marketing. This is because global anxieties about climate variation and the wide-ranging standing of the environment have augmented the expectations of consumers that food products have sustainability credentials and these are expected to be verified by consumers in time to come, as awareness heightens. There are significant and pressures are increasing in key export and local markets for disclosure of information on GHG intensity, carbon footprints, and recently, the water footprint of products. Product labelling has been identified as a common method for communicating the product attributes to consumers that may influence their choices. The increased consumer consciousness and awareness of sustainable food products have created heterogeneity among consumers, globally (Bougherara and Combris, 2009). The various segments of consumers for sustainable food markets are influenced by both public and private motivations towards creating a sustainable environment.

Within the agri-food market, existing studies on carbon labelling of products are limited to those of Vandenbergh, Dietz and Stern (2011). The findings from these studies highlighted the role of carbon labelling in maintaining a green economy. A similar study was done in Germany by Grebitus et al. (2015) to assess consumers' stated preferences for carbon and water footprint labelled products. The findings from the authors revealed that an assessment of environmentally sustainable attributes provides an understanding of consumers' choices and identifies potential markets for environmentally sustainable food products. Insights from such findings indicate that awareness creation through water and carbon footprint labelling will act as an effective instrument for changing consumers' behaviour and transforming markets. This, moreover, supports the interests in the growing realisation that creating awareness through label designs and information should be informed by research that focuses on the primary end-user – the consumer.

Presently, many international and domestic research studies into food product labels have, to date, established that the design of food labels or mode of creating awareness of a product is crucial in its success in the market. Meanwhile, existing products on the market today do not have environmental sustainability attributes. However, recent concerns over the environment and fresh water scarcity have prompted concerns for including key information that consumers seek to rely on in purchasing. Carbon and water footprint labelling can be very successful in driving market changes. This requires wider consumer education and retailer training to ensure that new labels are widely understood and used by consumers (Ottman, 2011).

It must be emphasised that the concept of consumers' awareness and use of product labelling to convey information about product quality is well well-known and rooted in economic theory (Nelson, 1970; Darby and Karni, 1973). The perfect information is usually attained through awareness creation through product labelling. The supply aspect of marketing sustainable products is very intricate. The motivations for businesses and producers to provide product labels with credence characteristics impacts positively on consumers. Once these attributes are provided, it becomes a search characteristic. Producers with a profitability objective will only adopt sustainability labelling if the extra income attained exceeds the cost incurred in producing the labelling design (Cohen and Vandenbergh, 2012; Vandenbergh et al., 2011). The above discussions reveal that consumers' awareness has different implications for their preferences, willingness to pay and, product competitiveness. Hence, the next section discusses consumers' preferences and willingness to pay for environmentally sustainable characteristics.

2.4.3 CONSUMERS' PREFERENCES AND WILLINGNESS TO PAY FOR SUSTAINABILITY ATTRIBUTES

Prior to the discussion of consumers' preferences for environmentally sustainable attributes or products, it is very important to explain the assumptions, rationale and relevance of studying consumers' preferences (Centre for International Economics (CIE), 2001). The CIE (2001) conceptually defined consumers' preferences as a bundle of propositions that centres on the choices of consumers that gives rise to diverse changes in consumers' pleasure, values, and utilities. The underlying rationale behind consumers' preferences is to attain the ideal choice. Preferences by individuals or segments of consumers provide the room for consumers to rate or rank different goods and services, based on their expected or revealed utilities.

It must be emphasised that consumers' preferences for products are not only reliant on their prices or the incomes of the consumers (Castello, 2003). This means that a consumer's ability to purchase a product does not reveal his or her choice. For instance, a consumer may have a preference for sustainable food products, but his or her income can only allow the purchase of conventional or unsustainable products. There are three important assumptions which are considered when analysing consumers' preferences. The first is completeness. This assumption applies when a consumer is indifferent between two products in terms of which one to choose. For instance, if a consumer is faced with beef and lamb, every consumer has his or her preference for one of the two meat choices. The assumption of completeness requires that the consumer should be able to weigh his options between beef and lamb.

The next assumption is known as transitivity (CIE, 2001). This assumption establishes a relationship between a set of products. For example, if a consumer prefers sustainable product A to sustainable product B, and also prefers sustainable product B to product C, the assumption requires the consumer to prefer sustainable product A to product C. The third assumption relating to a consumers' preference is centred on non-satiation. This assumption indicates that more of a product is continually accepted, as long as it does not have negative implications on the consumer's capacity to consume new products.

In economic terms, the assessment of consumers' preferences or choices is very relevant because it establishes the strong relationships between product preferences and consumers' demand for such products. It helps to understand what consumers prefer and are willing to spend their income on. This in turn will help producers to determine consumers' demands and what characteristics of products to strive for in order to meet the demand of consumers. Once the consumers' preferences are revealed, the next step is to evaluate in monetary terms the amount that a consumer is willing to offer for an increase in utility or the amount that he or she is willing to accept for a reduction in utility. This estimation approach is referred as willingness to pay (WTP). Conceptually, willingness to pay is defined as the maximum amount that the consumer is willing to contribute to compensate for the increase in his or her utility following the introduction of new products or improvements in a product's attributes (Tait et al., 2011).

Based on this, the assessing of consumers' preferences for existing and new products has become an important task for researchers and practitioners in governmental, non-governmental and private organisations (Castelló, 2003). This is because entrepreneurs are concerned about what the preferences of the people are, marketing departments are interested in knowing which products consumers' prefer and are willing to pay for, and generally, governments are keen to know what members of the public think about health, environment and welfare policies. This suggests that the assessment of consumers' preferences has diverse implications, such as in the design and implementation of social policies, testing the acceptance of newly introduced products on the market, and the demographic targeting of consumers based on preference categories.

Recent literature on consumers' preferences for food products in the agricultural sector has seen some changes in consumer and retailer demands, particularly in some niche markets for sustainable food products (Grebitus et al., 2015). The changes in consumers' choices and preferences are shifting towards environmentally sustainable agri-food products because of consumers' conscious awareness of the environmental effects associated with agricultural production and the fact that food production is the major user of the global limited water resources (Van Oel and Hoekstra, 2012).

In New Zealand, Tait et al. (2011) revealed that consumers' concerns about variability in the climate and the state of their environment have influenced consumers' preferences for food products with sustainability attributes and characteristics that are visible to the consumers. The authors emphasised that the medium for communicating sustainability attributes to consumers is through product labelling. The shift in preferences for sustainability attributes has resulted in increasing pressures on producers, exporters and companies to indicate their carbon footprint information on products. It was worth nothing that the way in which the sustainability information is conveyed to consumers is a critical issue of policy concerns in New Zealand. The trend in preferences for sustainability products and information has also created significant changes in most value chains in New Zealand's major industries.

Consumers' attitudes and preferences for environmentally sustainable attributes have been evaluated for Japan and the United Kingdom (UK) (Tait et al., 2011). It was found that the labelling of environmentally sustainable products is the common method for passing information of sustainability attributes to consumers and that this influences their choices for fruits. Interestingly, the authors found that the format of labelling the sustainable product plays a significant role in catering to consumers' preferences. However, the authors found variations in preferences for the different labelling formats and in how much consumers are willing to pay for the sustainability attributes. It must be emphasised that a discrete choice experimental survey was employed by the authors to assess the preferences for the sustainability attributes in Japan and the UK.

In Canada, consumers' preferences and choices regarding ground beef labelled with environmentally sustainable footprint information were assessed by Grebitus et al. (2013). The authors found that preferences for environmental footprint indicators hinge on the consumers' human values, besides traditional socio-economic characteristics. The authors concluded that certain human ethics have a predictive influence on choices and readiness to pay for products with environmentally sustainable footprint indicators or attributes. Additionally, consumers' behaviour towards environmentally sustainable attributes has been found to be linked to human attitudes towards environmental quality and the economic motivation for sustaining the environment (Grebitus et al., 2016). Similarly, Roeser (2012) studied consumers' preferences for footprint-labelled products from the viewpoint of emotional engagement by consumers and found that consumers who are passionate about the changing climate have positive preferences and motivation to buy footprint-labelled products, all things being equal. This implies that preferences and willingness to pay for environmentally sustainable or footprint-labelled products are more related to the ethics, standards and attitudes of the individual consumers, and this differs from country to country.

Early research on preferences for environmentally friendly products by Kempton (1991) revealed that Americans prefer, and are ready to pay for, environmentally friendly goods and services, with the intention of sustaining the environment for future generations. On the other hand, Hersch and Viscusi (2006) related preferences for environmentally sustainable products to how risky the consumers' see the implications of climate change over a period of time. It was found that individuals who are not in favour of environmental sustainability have their own personal interests and are not looking at environmental sustainability from a social welfare point of view. They are interested in the benefits that they will accumulate from the unsustainable environmental conditions for their own parochial interests. However, the authors opined that this attitude of the advocates of non-environmentally sustainable product declines with time. The authors further found that the age of consumers also has significant impact on preferences for environmentally sustainable products, and that younger people are more concerned about the future and are more willing to pay in order to sustain the environment for the future

In Germany, an interesting study on consumers' stated preferences for carbon and water footprint labelled potatoes was conducted by Grebitus et al. (2015). The authors applied choice experimental survey data in their research and found that heterogeneity in preferences exists for potatoes without carbon and water footprint labels. The authors found that accounting for the value systems of consumers significantly explains German consumers' preferences and choice of water and carbon footprint labelled products. However, it was revealed that the consumers' generalised trust and beliefs do not significantly influence consumers' preferences for footprint-labelled food products in Germany. Gulev (2012) and Grebitus et al. (2015) found that consumers with strong social orientation have higher preferences for potatoes labelled for lower footprints, compared with consumers with their own personal orientations. The authors concluded with a hypothesis that consumers with social orientation have a better congruency for footprint-labelled products that are more sustainable. Among the socio-demographic factors considered in their study, only the age of respondents was found to have significant standard deviation estimate, suggesting that the age of respondents plays a vital role in explaining consumers' choices for footprint-labelled food products in Germany. The policy implications that emanated from this research were that consumers' heterogeneity matters to some extent in terms of labelling food products with carbon and water footprint information.

The above discussions suggest that, for environmental sustainability policymakers to communicate effectively in terms of the merits and demerits of environmentally sustainable attributes through footprint labelling, it is very important to consider heterogeneity in preferences among consumers. They should consider identifying the various segments of consumers and designing labelling formats that will educate consumers about footprint indicators. It is clear from the discussions that most of the consumer studies on preferences and willingness to pay for footprint labelling and environmentally sustainable attributes are European based, with little or none from Africa, particularly South Africa. Although it has been found that heterogeneity in preferences exists for footprint labelling and environmentally sustainable attributes, this does not necessarily imply that the findings in Europe can be said to be in harmonisation with heterogeneity in African regions. Hence, there is a need to assess individual or class-specific choices and willingness to pay for footprint labelling and environmentally sustainable attributes in Africa, with heterogeneity of preferences in mind. In order to obtain efficient findings, as well as the identification of the various consumer segments which are interested in footprint labelling and environmentally sustainable attributes, there is the need to review existing methods of evaluating preferences and willingness to pay for product attributes. Therefore, the next section provides a detailed review of methods for estimating consumers' preferences and willingness to pay.

2.4.4 METHODS OF ESTIMATING CONSUMERS' PREFERENCES AND WILLINGNESS TO PAY FOR ENVIRONMENTALLY SUSTAINABILITY ATTRIBUTES

Methods for estimating consumers' preferences and willingness to pay for product attributes date back to McFadden's (1974) standard statistical framework for explaining consumer behaviour and choices. This framework is modelled as a random utility model, as proposed by McFadden (1974).

The random utility model assumes that consumers are rational, preferring products that give them the highest utility (Olynk, Tonsor and Wolf, 2010). More precisely, a rational consumer chooses from a number of product alternatives, preferring the one that offers the highest utility level on any given choice scenario. Similarly, Lancaster also proposed an attribute methodology, known as Lancaster's characteristic methodology, in 1966. This characteristic methodology postulated that an individual consumer's utility is attained directly from a distinct set of characteristics or attributes of products, and indirectly from consumed goods (McFadden, 1974). The methodology explains that, for a given overall utility of a product's alternative, it is possible to decompose and apportion utilities to each of the constituent attributes of the product. Hence, the attributes of a product alternative can represent the arguments of the utility function.

The CIE (2001) categorised methods for assessing consumers' preferences and willingness to pay into two broad contexts, namely the revealed preference and stated preference approaches. The revealed preference approach is applicable in preference and willingness to pay studies when there is existing data on the product or service of study from past behaviour of consumers. On the other hand, if there is no existing data on the product or subject of study, then the stated preference approach is applicable. For instance, in the case of preferences and willingness to pay for carbon and water footprint information in South Africa where there is no existing data, the stated preference approach is the ideal method to apply. The differences between the two approaches are based on the origin and methods of data collection. The revealed preference approach uses data from past behaviour of consumers, whereas stated preference data points are solicited through surveys (Castelló, 2003). A thorough review of methods by the CIE (2001) shows the stated preferences approach becomes very advantageous in situations where the existing data, based on previous behaviour, is not in consonance with the objective function, and more importantly, when historical data is not available.

Thus, the stated preference approach becomes very relevant for assessing preferences and willingness to pay for new products or the introduction of new product attributes to the market (CIE, 2001). The conceptual framework of the stated preference approach for evaluating consumers' preferences and WTP is shown in Figure 2.7 below. Figure 2.7 shows that the stated preference approach is categorised into two broad valuation methods. These include a contingent valuation (CV) method and a multi-attribute valuation (MAV) method.

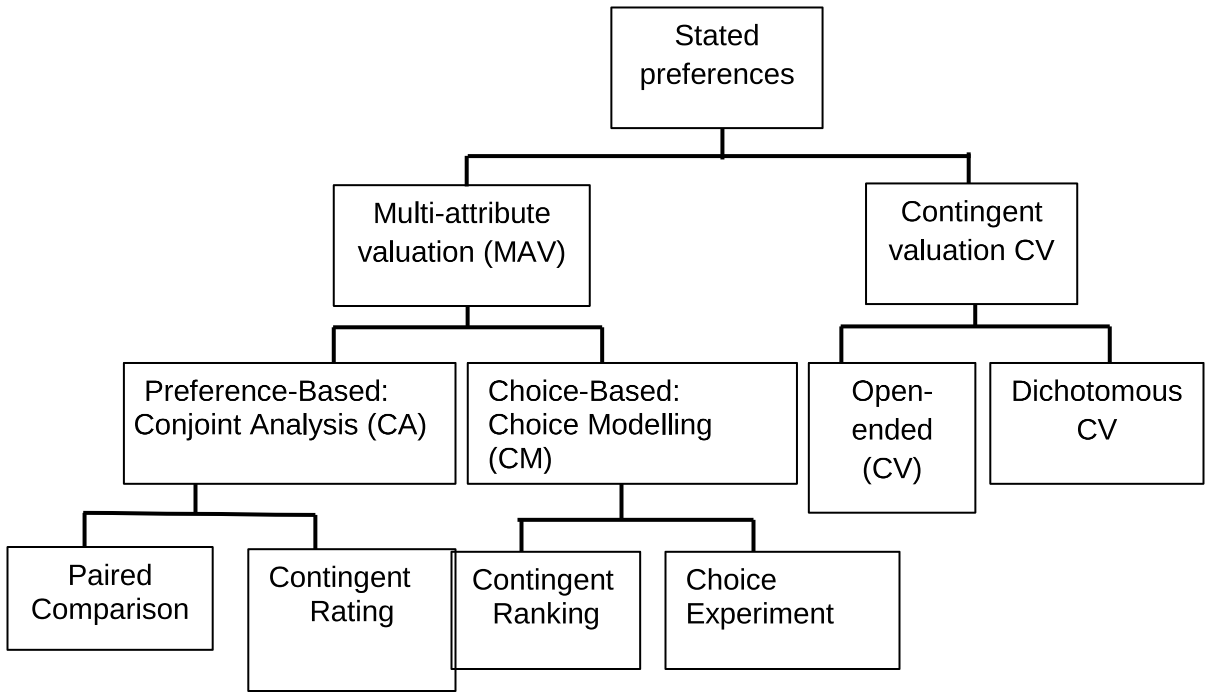

Figure 2.7: The family of stated preference methods

Source: CIE, 2003

2.4.4.1 CONTINGENT VALUATION METHOD

As indicated in Figure 2.7, the contingent valuation technique is categorised into open-ended and dichotomous choices. This method, in general, uses a designed survey instrument for a hypothetical market where the product under study can be traded. The name of this technique was based on the point that the value estimates are conditional on an imaginary scenario that is offered to people for valuing. A contingent market is identified and describes the product to be investigated, its context, and the manner in which the product will be funded. In the questionnaire design, respondents sampled for the survey are asked to state the maximum amount of money they are ready to pay for, or are willing to accept as a compensation for, a proposed change in utility level of a product (Hanley et al., 2001).

The dichotomous choice approach for contingent valuation allows consumers to select their preferences from close-ended product options with their stated prices. However, the open-ended contingent valuation method allows the respondent to give his or her willingness to pay an amount. This method has been criticised in recent years because it has been found to be vulnerable to biases. The CIE (2001) revealed that consumers find it hard to respond to open-ended statements in situations where they are not familiar with the product that they are being asked to value. It was further opined that if open-ended questions are used for soliciting consumers' willingness to pay for new and non-market products, it becomes difficult for consumers since they are not used to the product. However, consumers may have preferences for the new product but they lack knowledge on how much to offer for that product, given the space of time within which the consumer makes his or her purchasing decision (CIE, 2001).

Based on these limitations, most recent contingent valuation studies have resorted to the dichotomous method of elicitation (Hanley et al., 2001). The dichotomous method uses binary questions. Under this method, the survey respondents are presented with the product and asked to answer "yes" or "no". This form of question typifies the random utility function. Empirically, such data is estimated with binary logit models with a maximum likelihood estimation procedure. Nonetheless, Hanley et al. (2001) have hinted that the estimated willingness to pay amounts derived from dichotomous responses may be higher than that in open-ended elicitation is, probably due to "yes saying" by respondents. The open-ended contingent valuation data is usually estimated with hedonic pricing, Tobit and regression models. Besides these limitations, the CIE (2001) further highlighted the point that the contingent valuation method is applicable to only one product or attribute at a time, and that multiple attributes cannot be given to respondents simultaneously for appraisal. Therefore, it is considered as a poor evaluation method, as consumers find it difficult to provide accurate valuation estimates when presented with hypothetical products. Another potential weakness of this method is that some sampled survey respondents may tend to act advantageously, mostly when dealing with public goods or services. The above discussion shows that both methods of contingent valuation have some limitations. Hence, recent attention has been shifted to stated preference multi-attribute valuation (MAV) methods.

2.4.4.2 THE MULTI-ATTRIBUTE VALUATION (MAV) METHODS

The multi-attribute valuation (MAV) method, as shown in Figure 2.7 above, is categorised into preference-based conjoint analysis and choice-based modelling (Hall et al., 2002). The fundamental variation between the CV method and the MAV method is that the contingent valuation method considers one product attribute at a time, while the multi-attribute based method can analyse more than one product attribute concurrently (Hall et al., 2002). It must be emphasised that if the aim of the research is to examine a valuation estimate for a single product attribute, then adoption of contingent valuation does not become a limitation. However, it is problematic when it is applied to multiple product attribute evaluations. In practice, the contingent valuation method is linked to policy comparison, whereas preference-based conjoint and choice modelling is known for market analysis of product attributes, where new products and attributes are very relevant for product development and niche marketing.

Generally, the stated preference multi-attribute valuation method focuses on modelling consumers' or users' preferences for products or services. Under this method, the product being considered is described by its attributes, as measured at different levels (Castelló, 2003). The preference-based conjoint analysis allows respondents or consumers to rate or rank each of the alternative products presented to him or her, based on the product's attributes. The preference-based choice approach makes provision for the consumer to select one product option from among several product options, defined by their attributes and levels with their associated prices. The preference-based conjoint analysis technique asks consumers to assess a number of proposed or real products, which are described according to their attributes. The preference-based choice technique allows consumers to assess sequences of contending goods or products and to choose one from a defined choice set with varied product attributes and levels. This shows that the choice-based preference technique typifies the normal purchasing or shopping tasks performed by consumers every day. Thus, the act of buying products from competing shops and from different product brands mirrors the choice-based preference technique. The preference-based conjoint analysis technique only requires the consumer or respondent to rate or rank the product, without making a commitment to select a particular option. Hence, most researchers prefer to use the choice-based preference technique, rather than a preference-based technique (Castelló, 2003; CIE, 2001). Price variables are included in the design of the choice sets or product options, and this allows the researcher to indirectly estimate the willingness to pay amounts for the product attributes being studied.

Bateman et al. (2002), upon a review of both contingent valuation and multi-attribute approaches, concluded that the contingent valuation method can be used for multiple attributes by designing separate alternative product options for the different attributes. However, this approach is very costly and time consuming. The multi-attribute approach, on the other hand, is advantageous over contingent valuation because it covers more than one attribute at a time and is less costly to undertake. Multiple attributes are easier to evaluate with models that can predict willingness to pay amounts and pricing models. The multi-attribute choice experiments help to minimise multicollinearity problems in estimations since the choice designs adopts orthogonal or efficiency approaches, such as D-efficiency, and fractional designs. The multi-attribute approaches are also easy to answer, from the respondents' point of view (Bateman et al., 2002).

Empirically, multi-attribute choice data has been previously estimated with a conditional logit model. However, it was later found to impose homogenous preferences on all respondents, which in reality is not the case because some consumers are heterogeneous in their preferences (Birol et al., 2009). However, this shortcoming can be adequately represented by including interaction variables. Therefore, recent studies have adopted the latent class of logit and mixed logit models. The latent class model accounts for heterogeneity by a discrete distribution over unobserved endogenous classes of consumers (Birol et al., 2009). Membership of a specific class depends significantly on the respondents' observable socio-economic or attitudinal factors. The mixed logit model accounts for consumers' unobserved heterogeneity and allows model parameters to vary randomly over individual consumers. This model assumes that each consumer represents a segment (Hensher and Greene, 2003). The latent class model is an upgrade of the mixed logit model, where the random coefficient is discretely distributed, and there are finite numbers of classes, compared with the mixed logit model. This study will adopt the latent class model to capture underlying heterogeneity among consumers for sustainability attributes. Additionally, the mixed logit model will be used to capture individual consumers' heterogeneous preferences. The identification of the individual and specific consumer segments for sustainability attributes helps in designing recommended targeted sustainability policies towards improving the welfare of consumers belonging to a particular segment and individuals over a period of time. Hence, the next section discusses consumers' welfare measures and how to estimate welfare measures arising from changes in policies or attributes of products.

2.4.5 THE CONCEPT AND METHODS OF ESTIMATING CONSUMERS' WELFARE MEASURES

Estimations of consumers' welfare gains or losses arising from new food safety, quality and sustainability attribute changes are based on the concept welfare estimation. The concept of consumers' welfare estimations, according to Hanemann (1984), expresses the overall impact of introducing different goods or changes in product attributes on the welfare of buyers as the change in a consumer's expenditure function, before and after the introduction of new goods. This is estimated at the observed utility levels after the new goods or products are introduced. The introduction of new attributes to livestock products in the livestock industry have resulted in a number of studies being done, aimed at evaluating consumers' choices and WTP for changes in product attributes. Lusk and Norwood (2005) modelled beef quality heterogeneity. Cicia and Colantuoni (2010) assessed traceability attributes using meta-analysis. The impacts of food safety on beef consumption across countries have been analysed by Schroeder et al. (2007) and Schumacher et al. (2012). It is clear from the growing body of literature that little or no research has focused on preferences and welfare estimates for water or carbon footprint sustainability attributes of livestock products. However, water and carbon footprint sustainability information has been gaining prominence in recent years as a result of increasing awareness of the water scarcity and climate variation.

Nonetheless, few studies have assessed consumers' welfare or compensating surplus estimates arising from changes in water quality and recreational policy changes. For instance, Hynes et al. (2012) evaluated multiple changes in water quality attributes and their impacts on the welfare of water users, using choice experiments. Birol et al. (2009) assessed the welfare implications of the optimal management of wetlands. The authors quantified the welfare effects that would arise from risks associated with flooding, as well as water recreation and the conservation of biodiversity. The only research that has considered water and carbon footprint sustainability attributes was conducted Grebitus et al. (2015) in Germany on potatoes. The authors found that consumers are heterogeneous in their preferences and concluded that consumes with strong social orientation have higher preferences for potatoes labelled for lower footprints, as compared with consumers with their own personal orientation. However, the welfare implications or the impacts of consumers' preferences for footprint labels were not assessed. This shows that welfare evaluations of water and carbon footprint policy changes have received little attention. Hence, knowledge on consumer welfare (compensating surplus) estimates emanating from water and carbon footprint policy changes are non-existent or insufficient to guide food and environmental sustainability policymakers regarding the segments of consumers “who gain” or “lose” due to the sustainability policy changes. Meanwhile, Birol et al. (2009) and Hanemann (1984) revealed that once the individual consumers’ or users’ preferences for the new policy changes are revealed, their compensating surplus estimates can be computed because the consumers’ preferences are in line with utility maximisation and demand theory.

The choice experimental approach has been the most recently applied method for evaluating changes in quality and sustainability attributes. This method has been prominent because it gives room for the researcher to calculate preferences, willingness to pay values, and compensating surplus estimates arising from changes in attributes, policies and improvements in sustainability attributes from the view point of sustainable water and environmental management. For example, Eggert and Olsson (2009) applied a multi-attribute choice experiment to value multiple water quality attributes in the marine sector. Similarly, Kosenius (2010) used a choice experiment to assess heterogeneity in preferences for multiple water quality attributes in Finland. An evaluation of the non-use welfares of marine conservation regions was also done by McVittie and Moran (2010), using the choice experiment. The choice experiment method used by these authors allowed them to account for heterogeneity in consumers’ or users’ preferences. Hence, the choice experiment is used in this research to assess preferences and welfare estimates arising from consumers’ choice of water and carbon footprint sustainability attributes.

2.5 CHAPTER CONCLUSIONS

This section provides a summary and conclusions of the relevant literature that reviewed the global and South African dairy industry, the assessment of the water footprint and economic water productivity of dairy products, carbon footprint assessment in the dairy industry, and consumers’ preferences and welfare measurements. Based on the review of the global dairy industry, it is concluded that dairy farming has been an integral part of agricultural production for decades. Global milk production varies from one continent to another, from country to country, and also differs from one production system to another. The industry not only contributes primarily to the supply of milk and other dairy products, but is also a significant contributor to the global meat supply. The industry contributes significantly to the global protein needs of people. It must be emphasised that the dairy industry has shifted from small-scale subsistence farming to large-scale commercial production, with substantial increases in global milk production and numbers of dairy cows. Africa's milk production has improved significantly over the years. However, the production is affected mainly by variations in climatic conditions. This provides the rationale for this research to propose strategies and recommendations for improving the dairy industry by reducing the negative impacts of climate change, while increasing milk yields and performance of dairy cows. In South Africa, it is concluded that the dairy industry plays a significant role in economic development, job creation, and the social and welfare improvement of people working in the industry, and in the country at large. Despite the significant contribution from the industry, it is uses significant amounts of water, particularly for feeding livestock.

The review of the water footprint and economic water productivity of dairy products reveals that water footprint assessment is gaining prominence and has become a major issue of policy concern to governments, organisations, policymakers, water users and water managers. This is because water is a scarce resource and a large proportion of the world's population faces difficulties in getting fresh water. It is concluded that food production is the major user of fresh water resources. South Africa is among the most arid countries in the world and agriculture is the highest user of the available water resources. Water footprint assessments have received some attention in South Africa, but the economic aspects of water footprints have received little attention. Few researchers have linked the economic aspect of water to water footprint indicators South Africa. The existing knowledge is insufficient to effectively guide South African policy and decision makers, water users and managers in formulating appropriate policies to guide freshwater use and for water users to be economically efficient in water use. The review of the concepts of water footprints reveal that the Global Water Footprint Standard of the Water Footprint Network, described by Hoekstra et al. (2011), gives an all-inclusive indicator of freshwater use, relative to the Life Cycle Assessment (LCA).

The estimation of economic water efficiency builds upon the estimation of a total water footprint. The estimation of economic water productivities follows certain steps; the first stage involves the estimation of physical water productivities, and finally the economic water productivities are estimated. Research on the economic productivities of water is very scanty from the viewpoint of the semi-arid and arid regions of Southern Africa. Hence, there is the need for an assessment of economic water productivities to be undertaken. Available methods of estimating water footprints include the consumptive water-use-based volumetric water footprint, stress-weighted water Life Cycle Assessment (LCA), adapted LCA water footprint methodology, and the hydrological water balance method. The consumptive water-use based volumetric water footprint, as accepted by the Water Footprint Network, accounts for blue, green, and grey water footprints, with clear distinctions being made between the sources of water, and hence will be used in this study.

The review of literature on carbon emissions shows that South Africa's contribution towards minimising global warming is inadequate. It is concluded that current emission policies in South Africa are not sufficient for significantly reducing carbon emission to the expected business-as-usual (BAU) levels. The agriculture sector, in general, is revealed to account for about 30–35 % of global GHG emissions. The livestock sector has substantial impacts on GHG emissions. The dairy sector alone contributes 4.0 % of global emissions. Pressure is increasingly mounting on the environment, with GHG emissions expected to increase. The increase in demand for animal products is attributed to the increase in the world's population and shifts in consumers' dietary patterns. Therefore, considering the importance of the dairy sector, the global climate crisis and food challenges, it is imperative to conduct a life cycle assessment of the diary sector. The LCA approach has been widely employed in assessing carbon footprints.

The review of consumers' preferences, WTP, and welfare effects of water and carbon footprint sustainability information shows that it is very relevant to know how environmentally sustainable attributes and information will change consumers; and producers; sustainability behaviour, as well as the welfare implications of their changed behaviour. Despite the relevance of understanding consumers' preferences, willingness to pay, and welfare effects, the review of literature has revealed that existing research on environmental sustainability assessments have ignored South Africa. Hence, present knowledge is inadequate to understand how South African consumers would react to changes in water and carbon footprint sustainability attributes and policy changes. The review further shows that consumers' awareness of carbon and water footprint information plays a significant role in shaping consumers' behaviour. It is also concluded that heterogeneity in preferences exists among consumers for sustainable product attributes, and as such, sustainability studies should adopt methods that account for heterogeneous preferences.

The review of the methods for assessing consumers' preferences and WTP for product attributes emanates from McFadden's (1974) standard statistical framework and Lancaster's (1966) characteristic methodology for explaining consumer behaviour and choices. The methods for assessing consumers' preferences and WTP for sustainability attributes can be categorised into revealed and stated preferences approaches. The stated preference approach will be used in this study because no data currently exists on preferences and WTP for water and carbon footprint sustainability attributes in South Africa. The review of the methods for estimating consumers' preferences and welfare estimates reveals that a choice experiment is appropriate when dealing with multiple sustainability attributes or policy changes. Hence, in this study, the choice experiment was used to assess preferences and welfare estimates arising from consumers' choice of water and carbon footprint sustainability attributes.

CHAPTER 3

ASSESSMENT OF WATER FOOTPRINT AND ECONOMIC WATER PRODUCTIVITY OF DAIRY PRODUCTS AND FEED PRODUCTS

This chapter deals with the assessment of water footprint and economic water productivity of dairy products and feed products in order to determine the water use efficiency in the dairy industry of South Africa. The chapter is written in two articles. The first article evaluates water footprint and economic water productivities of dairy products in South Africa. The second article evaluates the economic water productivities along the dairy value chain in South Africa: Implications for sustainable and economically efficient water-use policies in the dairy industry.

3.1 ARTICLE ONE: EVALUATION OF WATER FOOTPRINT AND ECONOMIC WATER PRODUCTIVITIES OF DAIRY PRODUCTS IN SOUTH AFRICA

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ABSTRACT

Assessment of water footprint sustainability indicators and economic water productivities is regarded as a cornerstone of the world's sustainability goal and the reduction of the fresh water scarcity risk. These assessments are gaining much prominence because about four billion people face severe water scarcity, globally. Attaining sustainable and economically efficient water use goals requires a thorough assessment of all the existing sectors that use water. This paper examined the water footprint and economic water productivities of dairy products in South Africa for the periods 1996–2005 and 2006–2013 using the water footprint network assessment methodology. The study found the total water footprints of all the selected dairy products in South Africa to be higher than the global averages are. During the period of 1996 to 2005, South African dairy producers utilized more green water in their dairy production. The production of butter and cheese products, whether grated or not grated, powdered or not powdered, blue-veined and cheese of all kinds had the highest total water footprints among all the dairy products in South Africa. Dairy production under a sole grazing system has high water footprints and low economic water productivities, relative to mixed production systems, for the period 2006–2013. With blue water becoming very scarce in South Africa, it is time for dairy livestock producers to shift their production to a system that is highly productive and has low water footprints. The water footprints of most of the dairy products for period 2006–2013 have reduced by varying amounts, relative to 1996–2005, which shows that water users along the dairy industry chains are managing water cautiously. The findings have revealed dairy products that have high economic water productivities, and suggest that profit maximising and environmentally sustainable dairy producers and water users should integrate both blue water sustainability and economic water productivity indicators in their production decisions.

Key words: Blue water sustainability; Dairy products; Dairy production systems; Water footprint indicator

1. INTRODUCTION

In recent years, ecological and environmental sustainability assessments have been gaining much prominence, globally. The global water scarcity phenomenon has become a major issue of distress to governments, policy-makers, water users and water managers as well as private and non-governmental organisations and professional bodies interested in environmental and sustainability issues. It is estimated that about four billion people across the globe face severe water scarcity (Mekonnen and Hoekstra, 2016). An assessment of water sustainability indicators across various sectors of the global economy identified that, the greatest share of the world's freshwater is utilized in food production (IWMI, 2007). About 86 % of all the freshwater resources in the world are consumed in food production (IWMI, 2007). This implies that the relative importance of water to food production and human survival cannot be overlooked. As a result of that, researchers and policy makers in recent years are interested in the study of sustainable and economical water utilization in the food sector.

Water footprint assessment is one of the ways of assessing water utilization in the food sector. The water footprint assessment gives an account of the quantity of fresh water utilized in the production of a particular food commodity (Hoekstra et al., 2011). Accounting for green (rainwater), blue (surface and groundwater) and grey (related to assimilating water pollutant) water consumption along the whole product value chain. Sustainability assessment of how water is utilized for food production reveals how producers along the food production chain behave with regards to the blue water available to them; as to whether they are using the available water resources sustainably or not. An important pillar of fresh water allocation is economic water productivity, which quantifies the value obtained by producers per unit of water used in producing a particular product (Hoekstra, 2014). The economic water productivities are calculated after the estimation of physical water productivities.

Water footprint sustainability assessments of livestock production systems and products have received some attention in recent years in countries such as Ireland (Murphy et al., 2013), Australia (Ridoutt et al., 2014) and China (Huang et al., 2014). Regarding dairy products, water footprint of assessments of milk and milk products have received much attention in developed countries such as Germany (Drastig et al., 2010), Argentina (Manazza and Iglesias, 2012), New Zealand (Zonderland-Thomassen et al., 2014) and in India (Amarasinghe et al., 2010). Animals and animal products' water footprints across the globe have also been explored based on global averages (Mekonnen and Hoekstra, 2012). These assessments employed different methods such as the water footprint assessment methodology (Drastig et al., 2010; Mekonnen and Hoekstra, 2012), and life cycle assessment methodology including direct and virtual water consumption (Manazza and Iglesias, 2012; Murphy et al., 2013; Huang et al., 2014; Ridoutt et al., 2014; Zonderland-Thomassen et al., 2014). Most of these studies have focused on developed countries (Drastig et al., 2010; Huang et al., 2014; Murphy et al., 2013; Ridoutt et al., 2014; Zonderland-Thomassen et al., 2014), with little emphasis placed on water-scarce African countries including South Africa.

Existing studies that focus on assessing water utilization in the agricultural sector in South Africa are limited to the work of Jordaan and Grové (2012) who assessed the cumulative value added to water along the value chain of small-scale farmer produced raisin and vegetables in order to determine the point along the value chain where most value is added to water. Scheepers and Jordaan (2016) recently examined the blue and green water utilization for producing lucerne, used as feed for dairy cows. Owusu-Sekyere et al. (2016) recently quantified water utilization for milk production and processing in South Africa. However, this study focused only on milk with 4% fat and 3.3% protein. At the national level, information on water footprints of some dairy products was available from work of Mekonnen and Hoekstra (2012). However, these studies are limited to the quantification of water footprint indicators only, without accounting for economic water productivities, which is a strong pillar of fresh water allocation.

Nonetheless, some authors have assessed economic water productivities of products in the food sector. For instance, in Tunisia, assessments of some key crops were done to ascertain how productive the country is, in terms of water and land utilization (Chouchane et al., 2015) Schyns and Hoekstra (2014) conducted similar studies for some predominant crops produced in Morocco. Mekonnen and Hoekstra (2014) further assessed water conservation through trade in Kenya. Zoumides et al. (2014) conducted an economic water productivity assessment for crop production in Cyprus. All these studies focused on economic water productivities of crops, but with no similar studies being done on livestock products.

This study aims to assess the water footprint and economic water productivity of primary and derived dairy products for different production systems and periods in South Africa. This contributes to the limited knowledge on economic water productivities in the livestock sector and, to the best of our knowledge, this will be the first step taken towards assessing economic water productivities for dairy products in the dairy industry, particularly in Africa. Findings from this study can potentially assist water and environmental sustainability policy makers to understand whether, how and why consumers, water users and dairy producers along the dairy value chain might shift their consumption and production patterns to more sustainable and economically efficient ones. Insights from this study can further contribute to the current debate on the economic dimension of water footprint assessment.

2. MATERIALS AND METHODS

2.1. THE STUDY AREA

The study was conducted in South Africa. South Africa is one of the driest areas in the world and is ranked 30th in terms of freshwater water scarcity (Department of Water Affairs, 2013). The mean rainfall of the country is about 450 mm (DWA, 2013). According to DAFF (2012), approximately 80% of South Africa's agricultural land is suitable for livestock farming. The main source of water supply in the country is surface water (DWA, 2013). Ground water is widely used in rural and arid areas. A significant volume of water originates from return flows from major urban and industrial developments to streams. South Africa irrigates 1.5% of its total landmass to produce 30% of the total crops produced (DWA, 2013). Backeberg and Reinders (2009) recounted that irrigated agriculture in South Africa utilizes about 40% of the utilizable runoff while agricultural production in general use more than 60% of the available water (DWA, 2013). In the dairy industry sector, large quantities of water are utilized for feed production. About 98% of all the water used along the dairy value chain in South Africa goes into feed production (Owusu-Sekyere et al., 2016).

The South African dairy industry is handled by Milk South Africa (Milk SA) and South African Milk Processors' Organisation (SAMPRO). These bodies consist of dairy farmers, producers and processors, who produce different dairy products for the local and international market. Dairy producers in South Africa do not import composite animal feeds (DAFF, 2015). However, some quantities of feed ingredients such as soya oilcake, yellow maize and fish meal are imported. It must be emphasised that there was no import of fish meal over the past ten years in the dairy industry (DAFF, 2015). There are three main systems of feeding dairy cows. These include: (i) Semi-intensive farm-based ration obtained from available crops, pastures and crop residues with minimal rations purchased. (ii) An intensive, zero-grazing dairy system using a total mixed ration. (iii) A traditional, extensive or dual-purpose system (Milk SA, 2014). About 56% of dairy cows in South Africa rely on pasture, 38% rely on total mixed ration (TMR) and 6% rely on mixed or dual purpose system (Ercole, 2013; Milk SA, 2014).

Table 3.1 presents production differences between the grazing (pasture) and mixed ration systems of feeding dairy cows for 300 days lactation period. This survey was done as part of a scheme towards dairy cattle improvement in the South African dairy industry. Average milk yield for total mixed ration is higher that grazing system, with a significant mean difference of 1463 kilograms of milk per cow for 300 days lactation period. In terms of fat content, the survey revealed that the butter fat content per kilogram for the mixed system is significantly higher than that of the grazing system. This is indicated by the significant mean difference of 65 at 5% level. Additionally, the protein content of mixed system of feeding dairy cows is higher than that of the grazing system, as shown by the significantly positive mean difference of 53.

Table 3.1: Mean production differences between grazing and mixed systems of dairy feeding

System	Milk (kg)	Butter fat (kg)	Protein (kg)	Butter fat (%)	Protein (%)
Mixed	7411 (1489)	310(61)	256(50)	4.26(0.36)	3.48(0.21)
Grazing	5949(1285)	245(50)	203(42)	4.23(0.33)	3.46(0.22)
Mean difference	1463***	65**	53**	0.04	0.02

Source: Dairy Cattle Improvement Scheme (Milk SA)
Values in brackets are standard deviations
** indicates significant mean difference at 95% confidence interval

2.2. DATA SOURCES AND DESCRIPTION

The paper used secondary data from 1996–2013. Table 3.2 provides an overview of the data inputs, sources and duration. Mekonnen and Hoekstra (2012) provided data on water footprints of derived products from animals for different countries for the periods of 1996-2005. It must be emphasized that the data reported by these authors are weighted averages estimated at the global level for the stated period. The data pertaining to South Africa were extracted for the selected dairy products from grazing and mixed systems, for the stated period. The volumes of blue, green and grey water utilization in the dairy industry for the periods of 2006-2013 were obtained from the South African Milk Processors' Organisation (SAMPRO) and Milk South Africa (Milk SA). Milk SA was established in 2002 to oversee the South African dairy industry. These organisations consist of dairy producers and processors, who produce different dairy products for the local and international market.

Data on producer prices of daily products and production quantities were obtained from SAMPRO and FAOSTAT (FAO, 2015). Part of the data on feed production and water usage for feed crops used in the dairy industry were attained from the work of Van Rensburg et al. (2012). Data on crop water use, irrigation, evapotranspiration, drainage and rainfall for different catchment areas and irrigation schemes for feed and forage crops production were obtained from Van Rensburg et al. (2012). This information was utilized in the estimation of the feed and forage crops' water footprints. Data on feeding (composition and quantities) were obtained from commercial dairy producers and processors who have electronic feed calculation systems with good recordkeeping. This electronic feed calculation system keeps records of feed ration, moisture content, dry matter, the nutritional content of feed inputs and the complete ration for the lactating cows. The data obtained from different producers and production areas for the period of 2006-2013 were aggregated and used in the calculations of blue, green and grey water footprints of the primary and derived products.

Table 3.2: Data inputs and sources

Input variable	Source	Period
Water footprints of derived dairy products	Mekonnen and Hoekstra (2010, 2012)	1996-2005
Water utilization in the dairy industry	SAMPRO and Milk SA	2006-2013
Crop water use, irrigation & evapotranspiration	Van Rensburg et al. (2012); SAMPRO and Milk SA	2006-2013
Drainage and rainfall	Van Rensburg et al. (2012)	2006-2013
Feeding (composition and quantities)	SAMPRO and Milk SA	2006-2013
Yields for different systems	SAMPRO and Milk SA	2006-2013
Product values (producer prices)	FAOSTAT (FAO, 2015), SAMPRO and Milk SA	2006-2013

2.3. METHODOLOGICAL AND EMPIRICAL FRAMEWORK

In the calculations of the water footprints, the paper adopted the terminologies and empirical procedures outlined by Hoekstra et al. (2011). The methodology outlined by these authors for quantifying water footprint has been adopted by researchers in recent years to distinctly quantify the proportion of the total water footprint that is blue, green or grey in a particular product value chain. Conceptually, the surface and groundwater utilized for producing any of the selected dairy products is quantified as the blue water footprint of that product. The rainwater utilized for producing any of the selected dairy products is also quantified as the green water footprint of that dairy product. Hoekstra et al. (2011) iterated that the green water footprint excludes the rainwater that runs off. The quantified amount of water used to fine-tune the water quality to its acceptable standard becomes the grey water footprint. Grey water footprint deals with water contamination.

The stepwise accumulative procedure was applied in our quantifications of water footprints of the dairy products since the focus was on a variety of dairy products (Hoekstra et al., 2011). The empirical specification employed by Chapagain and Hoekstra (2004) to calculate live animals' water footprints was employed to quantify the water footprint of live animals. The quantification of the service water footprint in our analysis was based on the procedure set out by Hoekstra et al. (2011). In calculating the water footprint of various feed crops and dairy products, the estimation procedures employed by Mekonnen and Hoekstra (2012) were followed. Additionally, the water footprint estimates of dairy products reported by Mekonnen and Hoekstra (2012) for the period of 1996-2005 were utilized and compared with our estimates for 2006-2013 because we applied the same models, parameters, assumptions and guidelines used by the authors. Also, the dairy products and production systems considered in our study and that of Mekonnen and Hoekstra (2012) are the same. The proportion of imported feed ingredients that were incorporated into rations formulated for dairy animals was approximated to be about 1.5 %. Hence, the weighted average water footprint based on the relative volumes of local production and imports were taken in the calculation of the water footprint of animal feed ingredients (Mekonnen and Hoekstra, 2012). For the different field and forage crops, their blue water footprints were calculated using the formula specified in equation (3.1.1):

$$WF_{proc,blue} = \frac{CWU_{blue}}{Y} \qquad (3.1.1)$$

where $WF_{proc,blue}$ represents the blue water footprint of a particular feed crop, CWU_{blue} denotes the blue component in feed crops water use and Y is the feed crop yield (Hoekstra et al., 2011). The green water footprint is estimated in a similar manner as the blue water footprint. The green water used for feed crop production and natural vegetation for pastoral grazing was calculated as specified in equation (3.1.2):

$$WF_{proc,green} = \frac{CWU_{green}}{Y} \qquad (3.1.2)$$

where $WF_{proc,green}$ represents the green water footprint of a particular feed crop, CWU_{green} denotes the green component in feed crops water use. The crop water use component of equations (3.1.1) and (3.1.2) is defined as the sum of the daily evapotranspiration over the complete growing period of the feed crops (Hoekstra et al., 2011) and empirically denoted as equation (3.1.3):

$$CWU_{blue,green} = 10 \times \sum_{d=1}^{lgp} ET_{blue,green} \quad (3.1.3)$$

$ET_{blue,green}$ represents the blue and green water evapotranspiration. The water depths are changed from millimetres to volumes per area by using the factor 10. The summation is done over the complete length of the growing period from day one to harvest (Hoekstra et al., 2011). The grey water footprints of the feed crops are calculated by taking the chemical application rate for the field per hectare (AR, kg/ha) and multiplied by the leaching-run-off fraction (α). The product is divided by the difference between the maximum acceptable concentration (c_{max}, kg/m^3) and the natural concentration of the pollutant considered (c_{nat}, kg/m^3). The result is then divided by the crop yield (Y, tonne/ha). This is expressed empirically in equation (3.1.4):

$$WF_{proc,grey} = \frac{(\alpha \times AR)/(c_{max} - c_{nat})}{Y} \quad (3.1.4)$$

It is worth noting that the fresh water used in cleaning the processing facilities was recycled and later used for cleaning the cattle runs and the floor of the dairy parlour. The dairy processing water thus becomes grey water in the effluent pond and was accounted for according to the grey water methodology. The grey water emanating from the faeces and urine of the lactating cows was estimated with the use of an effluent sample analysis, and the volume measured as the flow into the effluent pond. In line with the stepwise accumulative procedure, the water footprint of the main product Υ is assumed to be produced from x inputs or feed crops. Let x inputs be numbered from i=1…. x. Assuming that x inputs are used to produce y dairy products, let the different dairy output products be represented as Υ =1….y. The dairy products' (Υ) water footprints are represented as:

$$WF_{prod}[\Upsilon] = \left(WF_{proc}[\Upsilon] + \sum_{i=1}^{x} \frac{WF_{prod}[i]}{f_{\Upsilon}[\Upsilon, i]} \right) * f_{v}[\Upsilon] \quad (3.1.5)$$

where $WF_{prod}[\Upsilon]$ denotes total water utilized in order to produce Υ . The water footprint of input *i* is represented by $WF_{prod}[i]$. $WF_{proc}[\Upsilon]$ is the processing water that was used to process *x* inputs to *y* output products. The product and value fractions are denoted by $f_p[\Upsilon, i]$ and $f_v[\Upsilon]$, respectively. Details regarding the product and value fraction are outlined in Hoekstra et al. (2011). After calculating the dairy products' footprints for different production regions, weighted averages were calculated in order to determine total, blue, green and grey water footprints at the national level. The calculation of the weighted averages follows the formula specified in equation (3.1.6):

$$WWF = \frac{\sum_{l=1}^{n} x_l \times w_l}{\sum_{l=1}^{n} w_l} \qquad (3.1.6)$$

where the weighted average water footprint is denoted by WWF. x_l is the water footprint value of a given dairy product from production region l and w_l represents the weight assigned to the given dairy product from production region l. The weights were assigned in line with the contribution of the different regions to total dairy output. Given that $WF_{prod}[\Upsilon]$ is measured in cubic m^3/tonne, the physical water productivity (*PWP*) of a particular dairy output product Υ measured in kg/ m^3 and expressed in (equation 3.1.7):

$$PWP = \frac{1}{WF_{prod}[\Upsilon]} * 1000 \qquad (3.1.7)$$

After calculating the physical water productivity, economic water productivities are further calculated. The economic water productivity for a particular dairy output product is then attained by multiplying the physical water productivity by that particular dairy product's value per kilogram. The producer prices are expressed in price per kilogram of the output product Υ. We denote the price of Υ by Υ_{Price}. We express the economic water productivity (*EWP*) in equation (3.1.8):

$$EWP = PWP * \Upsilon_{Price} \qquad (3.1.8)$$

The monetary value attained from every cubic meter of water used in producing any of the dairy products then becomes the economic water productivity of that product (Chouchane et al., 2015). Economic water productivities were estimated for all the dairy products considered in the study. The water footprints and water productivities of the selected products were separated for grazing and mixed systems of raising dairy cows in the study area because water utilization (Mekonnen and Hoekstra, 2012) and milk yields from these production systems differ (Scholtz et al., 2014).

3. RESULTS AND DISCUSSIONS

3.1. THE WATER FOOTPRINTS OF SOUTH AFRICAN DAIRY PRODUCTS VERSUS THE GLOBAL AVERAGES FROM THE YEAR 1996-2005

The water footprints of South African dairy products were compared the global averages for the period 1996–2005 to understand the water use pattern and how dairy producers are behaving in terms of water utilization (Table 3.3). The findings point out that the average blue water footprints for all the dairy products in South Africa are lower than the global average blue water footprints are. This implies that in terms of blue water usage, water users in the South African dairy industry are performing better, compared with the global blue water footprint indicators. Regarding green water utilization, the 1996-2005 estimates by Mekonnen and Hoekstra (2010) show that South Africa's green water footprints are higher than the global average green water footprints for the dairy products considered, suggesting that green water use along the dairy industry chain in South Africa is higher, compared with other parts of the world. However, the grey water footprints for the dairy products in South Africa are lower than the global estimates for the same dairy products.

Although South Africa's blue and grey water footprints were revealed to be lower, the 1996-2005 estimates indicate that the overall water footprints for the selected dairy products in South Africa are higher than the global average total water footprints are. The high total water footprint indicators for dairy products in South Africa are attributable to the higher green water footprints. This further indicates that the highest proportion of water utilized along the dairy chain in South Africa during the 1996-2005 periods was accumulated from the farm level, since green water was not utilized at the processing and marketing stage of the dairy value chain. This is supported by Owusu-Sekyere et al. (2016) who iterated that the largest proportion of water used along the dairy value chain in South Africa is green water. The high green water footprints for South Africa could be attributed to low milk yield associated with sole grazing system of dairy production under which relies on rainfall for field and forage crops production for feeding livestock (Scholtz et al., 2014). The low milk output could be explained by the low yield of rain-fed field and forage crops largely used dairy producers in South Africa, compared to the global average. For both South Africa and the world, the highest total water footprint was found to be associated with the production of butter. This is followed by the various cheese products, whether as grated or not grated, powdered or not powdered, blue-veined and cheese of all kinds. The high water footprints of all these products are as a result of the conversion factors (product/value fractions) used (Mekonnen and Hoekstra, 2012).

Table 3.3: The average blue, green and grey water footprint of dairy products for the period 1996-2005

Product description	South Africa (m^3/tonne)				Global average (m^3/tonne)			
	Blue WF	Green WF	Grey WF	Total WF	Blue WF	Green WF	Grey WF	Total WF
Milk not concentrated and unsweetened not exceeding 1% fat	41	1019	40	1100	86	863	72	1021
Milk not concentrated & unsweetened exceeding1% not exceeding 6% fat	42	1053	41	1136	88	891	75	1056
Milk and cream not concentrated and unsweetened exceeding 6% fat	76	1896	74	2046	159	1605	134	1898
Milk powder not exceeding 1.5% fat	190	4739	185	5114	398	4011	336	4745
Milk and cream powder unsweetened exceeding 1.5% fat	190	4739	185	5114	398	4011	336	4745
Milk and cream powder sweetened exceeding 1.5% fat	200	4739	185	5124	408	4011	336	4755
Milk and cream unsweetened,	62	1576	63	1701	132	1334	112	1578
Milk and cream sweetened	81	1896	74	2051	164	1605	134	1903
Yogurt concentrated , unsweetened	48	1185	46	1279	99	1003	84	1186
Buttermilk, curdled milk & cream	64	1597	62	1723	134	1352	113	1599
Whey whether or not concentrated or sweetened	26	646	25	697	54	547	46	647
Products consisting of natural milk constituents sweetened	48	1185	46	1279	99	1003	84	1186
Butter	223	5546	217	5986	465	4695	393	5553
Cheese, fresh unfermented, and curd	128	3174	124	3426	266	2687	225	3178
Cheese, grated or powdered, of all kinds	218	5038	197	5453	439	4264	357	5060
Cheese processed, not grated or powdered	218	5038	197	5453	439	4264	357	5060
Cheese, blue-veined	218	5038	197	5453	439	4264	357	5060
Cheese (others)	218	5038	197	5453	439	4264	357	5060

Mekonnen and Hoekstra (2010)

The lowest water footprints among all the dairy products were associated with the production of whey and non-concentrated and unsweetened milk not exceeding one per cent fat, respectively. The next product with low water footprint was non-concentrated and unsweetened milk and cream with more than 6 % fat. Comparing the water footprint estimates of South Africa for the period of 1996-2005 to other African countries where water footprint is gaining much prominence, the estimates show that the water footprints of butter and the assorted cheese products in South Africa are about 31 and 8 % lower than that of Tunisia and Kenya, respectively for the same time period (Mekonnen and Hoekstra, 2010). Similarly, the water footprint of whey and milk (non-concentrated and unsweetened) not exceeding one per cent fat in South Africa are about 64, 31 and 8 % lower than that of Morocco, Tunisia and Kenya, respectively for the same time period (1996-2005) (Mekonnen and Hoekstra, 2010b). Given that the South African estimates are higher than the global averages, but lower than these African countries, there is therefore the need for South Africa to have its country-specific benchmarks based on the country's available freshwater resources and for which the water footprints of products in that country can be related to. This benchmark will help South Africa by serving as a reference and assist in establishing water footprint reduction targets. This is in agreement with recent findings by Zhuo et al. (2016) in China.

3.2. WATER FOOTPRINTS OF DAIRY PRODUCTS UNDER DIFFERENT DAIRY PRODUCTION SYSTEMS IN SOUTH AFRICA FOR THE PERIOD 2006-2013

The average water footprints of the selected dairy products were estimated for sole grazing (extensive) and mixed systems (intensive and extensive) of production and the estimates are provided in Table 3.4. The estimates indicate that the blue water footprints for the selected dairy products produced under sole grazing system, is higher than the blue water footprints under the mixed production system, with the exception of whey (whether or not concentrated or sweetened), which had the same blue water footprints under the two production systems. This concurs with the findings of Srairi et al. (2009) in an assessment of water productivities for dairy and meat cows kept in irrigation scheme in Morocco. The authors found that significant variability in milk and meat outputs placed substantial influence on water productivities. Given the blue water scarcity situation in South Africa, it is vital for dairy livestock producers to decide whether to keep dairy animals solely on grazing or under the extensive system of production.

Regarding green water use, the results show that green water footprints for the grazing system are higher than that of mixed production system for all the dairy products. In terms of total water footprints, the results suggest that the total water footprints of all the dairy products produced under the grazing system alone are higher than the total water footprints of the same products produced under mixed production systems. The high green water footprints under the grazing or extensive system of production are as a result of the preponderance of indirect water usage for forage production. This might also be attributed to low milk yield associated with the extensive system of raising dairy cattle in South Africa (Scholtz et al., 2014). The low milk yield from this system can be attributed to poor pasture and forage output, mainly due to erratic rainfall.

MacDonald et al. (2007) opined that low milk yield from cows kept on grazing system can be attributed to the inability of cows to eat sufficient metabolizable energy for high production owing to feed intake constraints. Low milk yield affects water footprints estimates in the sense that lower yield from a particular production system directly increases the water footprint values of that particular system (Bosire et al., 2015). The high water footprints may also be attributed to low feed conversion efficiencies of animals kept on grazing system (Bosire et al., 2015). Therefore there is the need for dairy livestock producers to review their pastures and rangelands management strategies to increase feed availability and quality. This will increase dairy output, which in turn will reduce water footprints. For both grazing and mixed production systems, dairy livestock producers should breed animals with better growth rates and milk yield per cow, with the aim of enhancing feed conversion efficiency. This will reduce water footprints and enhance water productivities.

In terms of individual dairy products, the results reveal that the highest total water footprints are associated with butter for both grazing and mixed systems of production. Cheese products, whether grated or not grated, powdered or not powdered, blue-veined and cheese of all kinds recorded the next highest water footprints for both systems of production. Also, products such as milk powder with fat content not above 1.5%, milk and cream powder (unsweetened) exceeding 1.5% fat were found to have the third-highest total water footprints for both grazing and mixed systems of production. The high water footprints of these products raise major concerns for sustainability policy-makers. Producers of these products should consider an investment in technologies that minimize water usage and increase dairy product outputs, especially for butter and cheese processing. Another alternate will be the importation of such products with high water footprints from countries with enough water resources and where the same products are produced with minimal water usage. The results reveal that whey (whether or not concentrated or sweetened) has the lowest water footprints under both systems of production. Yoghurt (concentrated and unsweetened) and other dairy products containing some milk components (sweetened) were among the dairy products with low water footprints for both grazing and mixed systems of production.

Table 3.4: The average blue, green and grey water footprint of dairy products for different production systems in South Africa (2006-2013)

Product description	Grazing system (m^3/tonne)				Mixed system (m^3/tonne)			
	Blue WF	Green WF	Grey WF	Total WF	Blue WF	Green WF	Grey WF	Total WF
Milk not concentrated and unsweetened not exceeding 1% fat	69	1289	40	1398	68	1180	39	1287
Milk not concentrated & unsweetened exceeding1% not exceeding 6% fat	70	1263	41	1374	69	1185	41	1295
Milk and cream not concentrated and unsweetened exceeding 6% fat	75	1914	74	2063	68	1583	73	1724
Milk powder not exceeding 1.5% fat	187	4784	185	5156	171	3369	183	3723
Milk and cream powder unsweetened exceeding 1.5% fat	187	4784	185	5156	171	3369	183	3723
Milk and cream powder sweetened exceeding 1.5% fat	197	4784	185	5166	181	3369	183	3733
Milk and cream unsweetened	62	1591	62	1715	57	1383	61	1501
Milk and cream sweetened	80	1914	74	2068	73	1583	73	1729
Yogurt concentrated , unsweetened	47	1196	46	1289	43	1137	46	1226
Buttermilk, curdled milk & cream	63	1612	62	1737	58	1396	62	1516
Whey whether or not concentrated or sweetened	25	625	25	675	25	599	23	647
Products consisting of natural milk constituents sweetened	47	1196	46	1289	43	1137	46	1226
Butter	219	5599	217	6035	200	3876	214	4290
Cheese, fresh unfermented, and curd	125	3204	124	3453	115	2386	123	2624
Cheese, grated or powdered, of all kinds	215	5086	197	5498	198	3557	195	3950
Cheese processed, not grated or powdered	215	5086	197	5498	198	3557	195	3950
Cheese, blue-veined	215	5086	197	5498	198	3557	195	3950
Cheese (others)	215	5086	197	5498	198	3557	195	3950

3.3. THE WATER PRODUCTIVITIES (PHYSICAL AND ECONOMIC) OF THE SELECTED DAIRY PRODUCTS IN SOUTH AFRICA

Table 3.5 presents the water productivities of the dairy products for different production systems in South Africa. The water productivities were expressed in physical and economic terms. For both systems of production, the results show that whey, yogurt (concentrated and unsweetened), milk (unsweetened and unconcentrated) with fat content greater than 1 % but not higher than 6 % fat and milk (unsweetened and unconcentrated) with fat content higher than 1 % have physical water productivities, respectively. However, it is worth noting that expressing water productivities in the physical context does not provide much insight when water utilization is assessed from an economic viewpoint (Pereira et al., 2009). Hence, it was imperative to focus on economic water productivities. Additionally, profit maximising firms are more interested in maximising the value attained from the quantity of water utilized in their production, in lieu of focusing on physical water productivities (Molden et al., 2010). This is because blue water is directly associated with production cost and as such; firms aim at gaining more value to cover the cost of water and other production inputs.

Under the grazing system of production, the results show that higher economic water productivities are associated with milk and cream (unsweetened) and whey, as 0.74 and 0.59 US dollars are attained per every cubic metre of water used to produce one kilogram of these dairy products, respectively. This is followed by yogurt (concentrated and unsweetened) and buttermilk (curdled milk and cream), respectively. Milk (unsweetened) and cream powder with fat content exceeding 1.5 %, milk and cream (sweetened), milk and cream powder (sweetened) with fat contents higher than 1.5 % and milk powder with fat content not above 1.5 % have the lowest economic water productivities, respectively. Under the mixed system of production, the results show that milk and cream (unsweetened), and whey have high economic water productivities, respectively. This is followed by cheese (fresh unfermented and curd), buttermilk (curdled milk and cream) and yoghurt (concentrated and unsweetened), respectively.

On the other hand, milk and cream powder (unsweetened) with a fat content higher than 1.5 % has the lowest economic water productivity of 0.13 US$/m3. This is followed by milk and cream (sweetened) and milk and cream (unconcentrated and unsweetened) with a fat content higher than 6 %, respectively. In general, the results show that economic water productivities for all the dairy products under the mixed system of production are higher than those of the grazing systems are. The difference in economic water productivities is the result of the difference in water use or footprints for the two systems. The higher water footprints observed for the grazing system resulted in low physical water productivities and hence the low economic water productivities. This provides the justification for stakeholders in the dairy sector to consider which system is economically efficient in terms of water use.

Table 3.5: Physical and economic water productivities for different production systems in South Africa (2006-2013)

Product description	Grazing system			Mixed system		
	Total WF (m^3/tonne)	Physical Water productivity (kg/m^3)	Economic water productivity (US$/ m^3)	Total WF (m^3/tonne)	Physical Water productivity (kg/m^3)	Economic water productivity (US$/ m^3)
Milk not concentrated and unsweetened not exceeding 1% fat	1398	0.72	0.21	1287	0.78	0.23
Milk not concentrated & unsweetened exceeding 1% not exceeding 6% fat	1374	0.73	0.22	1295	0.77	0.23
Milk and cream not concentrated and unsweetened exceeding 6% fat	2063	0.48	0.15	1724	0.58	0.17
Milk powder not exceeding 1.5% fat	5156	0.19	0.14	3723	0.27	0.20
Milk and cream powder unsweetened exceeding 1.5% fat	5156	0.19	0.10	3723	0.27	0.13
Milk and cream powder sweetened exceeding 1.5% fat	5166	0.19	0.13	3733	0.27	0.18
Milk and cream unsweetened	1715	0.58	0.74	1501	0.66	0.85
Milk and cream sweetened	2068	0.48	0.13	1729	0.58	0.15
Yogurt concentrated , unsweetened	1289	0.78	0.42	1226	0.82	0.44
Buttermilk, curdled milk & cream	1737	0.58	0.39	1516	0.66	0.45
Whey	675	1.48	0.59	647	1.55	0.62
Butter	6035	0.17	0.19	4290	0.23	0.30
Cheese, fresh unfermented, and curd	3453	0.29	0.38	2624	0.38	0.51
Cheese, grated or powdered, of all kinds	5498	0.18	0.25	3950	0.25	0.34
Cheese processed, not grated or powdered	5498	0.18	0.23	3950	0.25	0.32
Cheese, blue-veined	5498	0.18	0.31	3950	0.25	0.43
Cheese (other)	5498	0.18	0.25	3950	0.25	0.34

The contributions of different provinces to total dairy production in South Africa are presented in Figure 3.1. The Western Cape province is the highest contributor to the total dairy production for the 2012/2013 production season. The Eastern Cape and KwaZulu-Natal provinces are the second-highest contributors to the total dairy production of the country, with 24 % contributions each. Thirteen per cent of the country's dairy products come from the Free State province, with the North West and Mpumalanga provinces contributing 5 % and 4 %, respectively to the total dairy production of the country. The remaining provinces contribute 3 % to the total dairy production. The high contributions from the Western and Eastern Cape provinces, as well as KwaZulu-Natal province, are probably attributable to the favourable climate and good pasture regimes for livestock production.

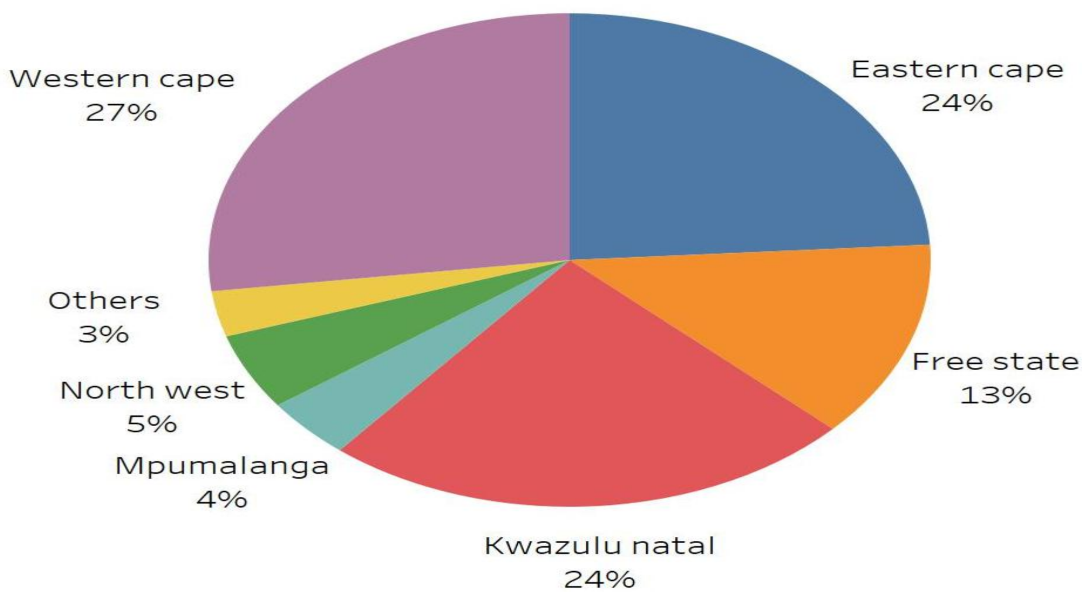

Figure 3.1: The contributions of dairy products from the various provinces in South Africa

Source: DAFF (2012)

3.4. THE WATER USE BEHAVIOUR IN DAIRY PRODUCTION BETWEEN 1996-2005 AND 2006-2013

Table 3.6 presents the estimates of average water footprints of the dairy products calculated for the periods 1996–2005 and 2006–2013 in South Africa. The 1996–2005 estimates by Mekonnen and Hoekstra (2010) were compared to our 2006–2013 estimates because the same models, parameters, assumptions and guidelines as outlined in the water footprint assessment manual were employed in both estimations. Also, the analyses for the two time periods were conducted for the same dairy products and production systems and as such the estimates are comparable. This comparison is critically important to understand the degree of sustainability with which freshwater is used in the dairy industry in recent years. This will accurately and effectively inform water managers and water users towards the sustainable use of freshwater in dairy production.

Comparing the water footprint of the dairy products between the periods of 1996–2005 and 2006–2013, it was revealed that the production of milk (unconcentrated and unsweetened) with fat content not higher than 1% recorded the highest increase in water usage. This is followed by the same product with fat content exceeding 1% but not higher than 6%. The implication from these findings is that the water usage in the production of these dairy products has increased. This can be ascribed to our qualitative information which revealed that some of these unsweetened and unconcentrated milk products are produced by dairy producers who are not processors and as such their capacity to recycle blue water is limited compare with the other products which are mainly produced by dairy processing companies with good water recycling systems in recent years. The production of the remaining dairy products saw significant improvements in terms of water saving, comparing the water footprints between the two periods. For instance, the highest reduction in water usage was associated with the production of butter. Similarly, there were somehow moderate reductions in water use for the production of cheese products, which were found to be among the dairy products with high water consumption.

Between the periods of 1996–2005 and 2006–2013, the production of dairy products such as milk powder with fat content not above 1.5%, unsweetened milk and cream powder with fat content higher than 1.5%, as well as milk and cream powder (sweetened) with above 1.5% fat content, saw reductions in water usage of about 13%. The remaining dairy products also recorded some reductions in water use between the two periods, which is a good indication that water users in the dairy industry recognise the need for water management and saving strategies to sustain their business and the environment in the long run. The reductions in water footprints for the dairy products vary from product to product. This provides the rationale for awareness creation and campaigns on sustainable water management aimed at imparting water-saving attitudes among South Africans because our findings indicate that water use behaviour in the dairy industry has improved since actors along the dairy value chain have become conscious of the water scarcity situation in the country.

The study is not without limitations; firstly, our analysis focused only on dairy production under the grazing and mixed production system due to unavailability of data for other production systems such as the intensive, zero-grazing and traditional dual-purpose dairy system. Secondly, the study focused only on dairy outputs without considering meat output. Thirdly, we acknowledge the lack of consistency in input variables and data sources. For instance, the data extracted from Mekonnen and Hoekstra (2012) are averages of a global assessment and as such using it in the context of a national assessment has pros and cons. Facilitating consistent, reliable and frequent livestock surveys at provincial and national levels in South Africa would be essential to safeguard precision of future studies that focus on productivities and efficient use of resources in different livestock production systems. Similar studies should be conducted for dairy production under the systems not considered in this study when data is available. Future research in South Africa should consider the development of country-specific water footprint benchmarks for different product categories and production systems to serve as a reference and assist in establishing water footprint reduction targets. Additionally, future studies should consider water footprints and economic water productivities for different meat production systems in South Africa.

Table 3.6: Comparison of the average water footprints of the dairy products for the periods 1996-2005 and 2006-2013 in South Africa

Product description	Water footprint in m^3/tonne (2006-2013)[b]	Water footprint in m^3/tonne (1996-2005)[a]	Mean difference (m^3/tonne)[b]	Percentage change [b]
Milk not concentrated and unsweetened not exceeding 1% fat	1343	1100	243	22
Milk not concentrated & unsweetened exceeding1% not exceeding 6% fat	1335	1136	199	17
Milk and cream not concentrated and unsweetened exceeding 6% fat	1894	2046	-153	-7
Milk powder not exceeding 1.5% fat	4440	5114	-675	-13
Milk and cream powder unsweetened exceeding 1.5% fat	4440	5114	-675	-13
Milk and cream powder sweetened exceeding 1.5% fat	4450	5124	-675	-13
Milk and cream unsweetened	1608	1701	-93	-5
Milk and cream sweetened	1899	2051	-153	-7
Yogurt concentrated , unsweetened	1258	1279	-22	-2
Buttermilk, curdled milk & cream	1627	1723	-97	-6
Whey whether or not concentrated or sweetened	661	697	-36	-5
Products consisting of natural milk constituents sweetened	1258	1279	-22	-2
Butter	5163	5986	-824	-14
Cheese, fresh unfermented, and curd	3039	3426	-388	-11
Cheese, grated or powdered, of all kinds	4724	5453	-729	-13
Cheese processed, not grated or powdered	4724	5453	-729	-13
Cheese, blue-veined	4724	5453	-729	-13
Cheese (Other)	4724	5453	-729	-13

a. Mekonnen and Hoekstra (2010)

b. Field survey

4. CONCLUSIONS

Generally, it is concluded that South Africa's total water footprints for the dairy products considered in this study are higher than the estimate global average total water footprints in the period 1996–2005. Nonetheless, it can be concluded that South Africa's average blue water footprints for all the dairy products considered are lower than the global average blue water footprints in the period 1996–2005. Additionally, it can be concluded that during the period of 1996-2005, South African dairy producers were utilizing more green water in their dairy production. We suggest that current dairy producers should make efficient use of green water. Regarding the dairy products, the study conclude that butter and cheese products (whether grated or not grated, powdered or not powdered, blue-veined) and cheese of all kinds had the highest total water footprints in South Africa for both periods. In the 2006–2013 period, the study concludes that the total water footprints for all the dairy products produced solely under grazing systems are higher than the total water footprints of the same products produced under the mixed production systems. The study also concludes that blue water footprints under the grazing system are higher, relative to the blue water footprints under the mixed production system. It is also concluded that the water footprints for most of the dairy products in the period of 2006–2013 have reduced compared with the 1996–2005 estimates. Regarding water productivities, it is concluded that the economic water productivities for all the dairy products under the mixed system of production are higher than those of the grazing systems are. Among the dairy products, the study concludes that dairy products such as milk and cream (unsweetened), whey, cheese (fresh unfermented and curd), buttermilk (curdled milk and cream) and yoghurt (concentrated and unsweetened) had the highest economic water productivities, respectively. Milk and cream powder (unsweetened) with fat content above 1.5%, milk and cream (sweetened) and milk and cream (unconcentrated and unsweetened) with a fat content higher than 6% had the lowest economic water productivity. Given that there are low blue water footprints and high economic water productivities in the mixed production system, this system appears to be a better alternative, relative to the sole grazing system. Farm management options to boost water productivities under the various systems of livestock production include increasing dairy output, improving feed conversion efficiency of cows, animal health improvement, investment in water saving technologies and adoption of pasture management practices that increase forage availability and quality. Additionally, forage and pasture management practices that circumvent land degradation to reduce the quantity of water needed for field and forage crops.

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3.2 ARTICLE TWO: ECONOMIC WATER PRODUCTIVITIES ALONG THE DAIRY VALUE CHAIN IN SOUTH AFRICA: IMPLICATIONS FOR SUSTAINABLE AND ECONOMICALLY EFFICIENT WATER-USE POLICIES IN THE DAIRY INDUSTRY

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ABSTRACT

The global water scarcity situation is a major issue of concern to sustainable development and requires detailed assessment of water footprints and water productivities in all sectors of the economy. This paper has analysed economic water productivities along the dairy value chain in South Africa. The findings reveal that the value added to milk and water as it moves along the value chain varies from stage to stage; with the highest value being attained at the processing level, followed by the retail and farm gate levels, respectively. Milk production in South Africa is economically efficient in terms of water use. Feed production accounts for about 98.02 % of the total water footprint of milk with 3.3 % protein and 4 % fat. Feed production is economically efficient in terms of cost and water use. Value addition to milk and economic productivity of water are influenced by packaging design. Not all economically water productive feed products are significant contributors to milk yield. Future ecological footprint assessments should take into account the value added to output products and economic water productivities along the products' value chain, rather than relying only on water footprint estimates.

Keywords: Economic water productivity; dairy industry; water efficiency; water footprint; water policies; value addition

1. INTRODUCTION

The global water scarcity phenomenon has become a major issue of concern to governments, organisations, policy-makers, water-users and water managers. A significant proportion (two-thirds) of the world's population faces difficulties in getting freshwater (Mekonnen and Hoekstra, 2016). The pressure on freshwater resources arises as a result of population growth, climate change, pollution of existing water resources, urbanisation, among other things (Jefferies et al., 2012). In many parts of the word, quantities of water supply do not meet the quantity demanded by the various sectors of the economies. Food production has been identified as the major user of the available scarce water resources; accounting for about 86 % of all global water use (IWMI, 2007). However, given the fact that food production is vital for human survival and the essential role that water plays in food production, there is the need to design strategies and methods to make efficient use of water in all sectors, particularly in agriculture which uses most of the world's water.

Based on this, two internationally accepted concepts of water footprint have been developed; the water footprint concept as described by Hoekstra et al. (2011) and the Life Cycle Assessment (LCA) as described in the ISO standards. The water footprint (WF) approach introduced by Hoekstra (2003) is gaining prominence because it gives a comprehensive assessment of freshwater use, and quantifies and maps water consumption and pollution in relation to production or consumption. The concept of water footprint in the Life Cycle Assessment approach (LCA) has also been applied in many studies (Ridoutt et al., 2014; Zonderland-Thomassen et al., 2014).

Various authors have assessed water footprints of products in the agricultural sector. Ridoutt et al. (2014) and Zonderland-Thomassen et al. (2014) assessed the water footprint of beef cattle and sheep production systems in Australia and New Zealand, respectively. In China, water availability footprint of milk and milk products from large-scale farms has been assessed by Huang et al. (2014). Matlock et al. (2012) examined the potential water use, water stress, and eutrophication impacts from US dairy activities. Environmental impacts associated with freshwater consumption along the life cycle of animal products was analysed by De Boer et al. (2013) in the Netherlands. Amarasinghe et al. (2010) assessed water footprints of milk production in India. Water footprint analyses of milk production in Germany and Argentina have been examined by Drastig et al. (2010) and Manazza and Iglesias (2012), respectively.

The growing body of literature is limited to quantification of water footprint indicators and, to some extent, the environmental impact. The economic aspect of water footprint indicators has received little attention, particularly in the semi-arid and arid regions of southern Africa. Meanwhile, Hoekstra et al. (2011), and Pérez-Urdiales and García-Valiñas (2016) indicated that economic water efficiency and water-efficient technologies are very important to ecologically sustainable environmental policies. Existing studies on economic water productivities are limited to that of Chouchane et al. (2015) who assessed the economic water and land productivities related to crop production for irrigated and rain-fed agriculture in Tunisia. Similar assessments have been done for case studies in Morocco and Kenya (Mekonnen and Hoekstra, 2014; Schyns and Hoekstra, 2014). Zoumides et al. (2014) also included economic water productivity when assessing the water footprint of crop production and supply utilisation in Cyprus. It is clear that the focus has been on economic water productivities of crops, with no similar research being done in the livestock sector. To the best of our knowledge, no known study has evaluated the economic productivity of water along the dairy value chain. Therefore, current knowledge is insufficient to understand whether, how and why water users and managers along the dairy value chain might shift to more sustainable and economically efficient production patterns.

The present paper contributes to filling this gap in knowledge by assessing the economic water productivity along the dairy value chain in South Africa. We estimated economic water productivity for milk and important feed crops because evidence shows that a significant proportion of water usage in the dairy sector goes into feed production. This will be the first step towards an assessment of economic water productivities for feed crops and dairy products, particularly in Africa. The economic water productivity is the value of the marginal product of the agri-food product with respect to water (Chouchane et al., 2015; Molden, 2007; Playan and Matoes, 2006). The economic productivity gives an indication of the income that is generated per cubic metre of water used. The economic water productivity is calculated in two steps. First, the physical water productivity (in kg/m^3 of water) is calculated by dividing the yield (kg) by the water footprints (m^3) of the product. In the second step, the economic productivities (US$/$m^3$ of water) of the product are calculated by multiplying the physical water productivity (kg/m^3) of each product by their monetary value (US$//kg).

2. METHODOLOGY

2.1. CONCEPTUAL AND EMPIRICAL FRAMEWORK

The concept of the Global Water Footprint Standard of the Water Footprint Network was employed in this study. The water footprint network approach adopted gives a distinction between green, blue and grey water used along the value chain (Berger and Finkbeiner, 2010; Hoekstra et al., 2011). The calculations of blue, green and grey water footprints of the feed crops and milk followed the terminologies and procedures set out in The Water Footprint Assessment Manual (Hoekstra et al., 2011). The blue water footprint ($WF_{proc,blue}$, m^3/tonne) is estimated as the blue component in crop water use (CWU_{blue},m^3/ha), divided by the crop yield (Y, tonne/ha) in relation to the feed crops. This is specified as:

$$WF_{proc,blue} = \frac{CWU_{blue}}{Y} \quad \text{(volume / mass)} \tag{3.2.1}$$

The green water footprint (WF_{green}, m^3/tonne) is calculated in a similar manner as the blue water footprint. The green water used for feed crop production and natural vegetation for pastoral grazing constitute the total green water footprint considered along dairy value chain because we found that no green water is used at the processing and retailing stages of the dairy value chain. The final calculated green water footprint is an indicator of the total amount of rainwater that was evapotranspired by the crop and incorporated into the crop.

$$WF_{proc,green} = \frac{CWU_{green}}{Y} \quad \text{(volume / mass)} \tag{3.2.2}$$

The crop water use component of equations (1) and (2) is defined as the sum of the daily evapotranspiration (ET, mm/day) over the complete growing period of the feed crop (Hoekstra et al., 2011). This is expressed as:

$$CWU_{blue,green} = 10 \times \sum_{d=1}^{lgp} ET_{blue,green} \text{(volume / area)} \tag{3.2.3}$$

The blue and green water evapotranspiration is denoted by $ET_{blue,\ green}$. The water depths are converted from millimetres to volumes per area (m^3/ha) by using the factor 10. Summation is done over the complete length of the growing period (lgp) from day one to harvest (Hoekstra et al., 2011). Grey water footprints ($WF_{proc,grey}$, m^3/tonne) of the feed crops are estimated by taking the chemical application rate for the field per hectare (AR, kg/ha) and multiplied by the leaching-run-off fraction (α). The product is divided by the difference between the maximum acceptable concentration (c_{max}, kg/m^3) and the natural concentration of the pollutant considered (c_{nat}, kg/m^3). The result is then divided by the crop yield (Y, tonne/ha). This is expressed empirically as:

$$WF_{proc,grey} = \frac{(\alpha \times AR) / (c_{max} - c_{nat})}{Y} \quad \text{[volume / mass]} \tag{3.2.4}$$

In the study area, fresh water used in cleaning the processing facilities was recycled and later used for cleaning the cattle runs and the floor of the dairy parlour. The dairy processing water thus becomes grey water in the effluent pond and was accounted for according to the grey water methodology. The grey water emanating from the faeces and urine of the lactating cows was estimated with the use of an effluent sample analysis, and the volume measured as the flow into the effluent pond. After estimating the blue, green and grey water footprints, they were summed up to obtain the total water footprint.

After calculating the water footprint of the feed crops, we calculated the marginal water productivities for the feed crops. In estimating the water productivities for the feed crops, a distinction was made between crop yield from rainfall and that of irrigation. Once such distinction is made, water productivities can be discussed in terms of green and blue water. The blue water productivity is described as the incremental yield attained due to irrigation divided by the blue water footprint or the volume of blue water consumed (Hoekstra, 2013). This is expressed as:

$$WP_{blue} = \frac{Yt_{blue}}{ET_{blue}} \tag{3.2.5}$$

where Yt_{blue} is the crop yield under irrigation, and ET_{blue} is the evapotranspiration of blue water. Green water productivity, on the other hand, can be defined as the crop yield obtained from rainfall only, without irrigation, divided by the total green water used by the crop (Hoekstra, 2013). This is specified as:

$$WP_{green} = \frac{Yt_{green}}{ET_{green}} \tag{3.2.6}$$

where Yt_{green} is the crop yield under rain fed conditions only, and ET_{green} is the evapotranspiration of green water that would have occurred without irrigation. Crop yield under rain fed conditions only (Yt_{green}), according to Chouchane et al. (2015) and Doorenbos and Kassam (1979) can be calculated as:

$$\left(1 - \frac{Y_a}{Y_m}\right) = RF_y\left(1 - \frac{ET_a}{CWR}\right) \tag{3.2.7}$$

where RF_y is a yield response factor, Y_a is the actual crop yield in kg per hectare, and Y_m is the maximum yield attainable at optimum water level. ET_a denotes the actual crop evapotranspiration measured in millimetres per period, whereas CWR is the crop water requirement in millimetres per period. The total water productivity then becomes the sum of blue and green water productivities for the feed crops:

$$\text{Total WP} = WP_{green} + WP_{blue} \qquad (3.2.8)$$

Regarding the primary product (milk), the chain-summation approach was used to estimate the water footprint since our focus was only on milk and not a variety of derived dairy products (Hoekstra et al., 2011). The water footprint of milk consists of direct and indirect water footprints (Mekonnen and Hoekstra, 2010a). The water footprint for the output product (processed milk with 3.3 % and 4 % fat) is denoted by $WF[\Upsilon]$. The output product (Υ) is produced from *x* inputs. Let *x* inputs be numbered from *i=1…. x*. Assuming that *x* inputs are used to produce only Υ dairy product. The output product's (Υ) water footprint is represented as:

$$WF_{prod}[\Upsilon] = \frac{\sum_{i=1}^{x} WF_{proc}[i]}{P[\Upsilon]} \quad (m^3 / \text{tonne}) \qquad (3.2.9)$$

where $WF_{prod}[\Upsilon]$ denotes the total water utilized in order to produce Υ. The water footprint of input *i* is represented by $WF_{prod}[i]$ and $P[\Upsilon]$ is the production quantity of product Υ. Given that $WF_{prod}[\Upsilon]$ is measured in m^3 per tonne; the physical water productivity (*PWP*) of the output product Υ is expressed in kilograms per cubic metre (kg/m^3) and specified as:

$$PWP(kg / m^3) = \frac{1}{WF_{prod}[\Upsilon](m^3 / \text{tonne})} * 1000 \qquad (3.2.10)$$

After calculating the physical water productivity, the economic water productivity for the output product Υ is then attained by multiplying the physical water productivity by the monetary value added to Υ per kilogram. Various authors in recent literature have used producer prices as a proxy for value added in estimating economic water productivities due to difficulties in getting data for estimating value added to the products investigated (Chouchane et al., 2015; Schyns and Hoekstra, 2014; Zoumides et al., 2014). However, this paper adds some novelty in our economic water productivity estimates by moving a step further to calculate the value added to milk along the dairy value chain as well as some important feed products for our productivity estimates. As the main product moves along the value chain, value is added at each stage. Hence, we estimated the value added to milk at the farm gate, processing or wholesale and retail levels in order to ascertain the point along the dairy value chain where most value is added. The value added to the out product (Υ) was estimated by deducting the cost per kilogram of Υ from the sales revenue obtained from selling one kilogram of Υ at each stage of the value chain (Crafford et al., 2004). Thus, the value added to the output product (Υ) is the total revenue from the product minus the cost of all intermediate inputs employed in the production of Υ. We denote the value added to Υ at a particular stage of the value chain as $\mathrm{VAD}_{ivc}[\Upsilon]$ and expressed empirically as:

$$\mathrm{VAD}_{ivc}[\Upsilon] = \mathrm{Re}_{ivc}(\Upsilon) - \mathrm{Co}_{ivc}(\Upsilon) \qquad \mathrm{ZAR/kg} \tag{3.2.11}$$

where $\mathrm{Re}_{ivc}(\Upsilon)$ is the sales revenue obtained from selling one kilogram of Υ at each stage of the value chain and $\mathrm{Co}_{ivc}(\Upsilon)$ is the cost of all intermediate inputs employed to produce a kilogram of Υ. $\mathrm{Co}_{ivc}(\Upsilon)$ consists of the cost of water usage, capital, land, labour, feed, taxes, veterinary, transport, packaging, fuel, repairs and maintenance, etc. The total value added ($\mathrm{TVAD}[\Upsilon]_{vc}$) along the complete value chain was calculated by summing the value added at each stage of the value chain. This is specified as:

$$\mathrm{TVAD}_{vc}[\Upsilon] = \sum_{i=1}^{3} \mathrm{VAD}_{ivc} \qquad \mathrm{ZAR/kg} \tag{3.2.12}$$

The value added to water as the product moves along the value chain can be expressed as the ratio of the value added to the output product (Υ) at each stage of the value chain over the quantity of water utilized at the respective stages (Crafford et al., 2004). Given the value added to the output product (Υ) along the value chain, marginal contribution from water $\mathrm{MVAD[water]}$ is specified as:

$$\mathrm{MVAD[water]}_{vc} = \frac{\mathrm{VAD}_{ivc}}{\mathrm{WU}_{ivc}} \tag{3.2.13}$$

VAD_{ivc} denotes value added to the product at *i* stage of the value chain and WU_{ivc} is the quantity of water used at *i* stage of the value chain. We then expressed the economic water productivity as:

$$EWP(ZAR/m^3) = PWP(kg/m^3) * VAD(ZAR/kg) \quad (3.2.14)$$

The economic water productivity (EWP) is expressed in ZAR[1]/m^3. The procedure for estimating the physical and economic water productivities for the output product was applied to estimate the physical and economic water productivities for the feed crops.

2.2. DATA

Both primary and secondary data pertaining to the South African dairy sector were used. Primary data on cost and revenue expenditures on feed products and raw milk were obtained from dairy agribusiness companies who form part of the South African Milk Processors' Organisation (SAMPRO), and Milk South Africa (Milk SA). Milk SA was established in 2002 to oversee the South African dairy industry. These organisations consist of dairy producers and processors, who produce different dairy products for the local and international market. These companies consist of both commercial dairy and processing plants where milk is processed and bottled. Data on price consisted of producer, wholesale and retail prices. Secondary data on feed production, inputs cost, water usage for feed crops and servicing water used in the dairy industry were attained from SAMPRO, Milk SA and Van Rensburg et al. (2012). Van Rensburg et al. (2012) assessed water utilization for important field and forage crops.

The dairy producers considered have feed calculation systems with electronic recordkeeping and as such accurate data on feed composition and the quantities fed to animals were available. The data obtained were aggregated and average values were used in further calculations. The electronic feed calculator records information on quantities of the various feed products and ingredients in feed ration, moisture content, dry matter, nutritional values of the inputs and the

[1] Average exchange rate for December, 2015: US$1; ZAR 15.05

complete ration for the lactating cows. Data obtained from these sources were used to calculate the volumes of blue, green and grey water utilized in milk production. Our estimated water footprints for feed crops such as maize, soy and sun flower were compared to the estimates obtained by Mekonnen and Hoekstra (2010a) for South Africa. Secondary data on prices of feed crops were obtained from Bureau of Food and Agricultural Policy and Southern Africa (BFAP).

3. RESULTS AND DISCUSSION

3.1. WATER FOOTPRINT, MARGINAL AND ECONOMIC WATER PRODUCTIVITIES OF FEED PRODUCTS

Table 3.7 presents the water footprints of key feed products included in a balance ration formulated for dairy cows. We estimated blue, green and grey water footprints for these feed stuffs in order to ascertain which of them uses more water. The results show that high protein concentrates (HPC) and yellow maize meal had the highest total water footprints, while oats silage had the lowest. Among all the feed crops, lucerne hay and maize silage had the highest blue water footprints. In terms of green water, high protein concentrate and yellow maize meal had the highest footprints, respectively. In all instances, the grey water footprint was lower than both blue and green water footprints, with the exception of yellow maize meal and sun flower cake. Additionally, maize meal and lucerne hay recorded the highest grey water footprints.

Table 3.7: Water footprint of main feed products in a complete ration for dairy cows

Feed products	Blue WF (m^3/year)	Green WF (m^3/year)	Grey WF (m^3/year)	Total WF (m^3/year)
Lucerne hay	217942	263165	99682	580788
Oats Silage	103587	23397	9965	136948
Sorghum Silage	122421	107529	18031	247981
Maize Silage	188961	179215	28872	397047
Yellow maize meal	0	2256175	195969	2452143
HPC	74643	2512770	47560	2634972
Soybean cake	53400	1662502	8797	1724698
Sun flower cake	21207	850268	38800	910274

HPC: High Protein Concentrate

Prior to the estimation of economic water productivities of the feed products, their dry matter contribution and marginal water productivities were calculated for a balance ration providing an average of 26.32 kilogram of dry matter per day for dairy cows and the results are presented in Table 3.8. It must be emphasised that water productivities were estimated for the main feed stuffs and ingredients. Out of the 26.32 kilogram of dry matter (DM) supplied, 28.42 % representing 7.48 kg was provided by yellow maize meal. High protein concentrate (HPC) contributed 18.47 % (4.86 kg) to the total dry matter. Lucerne hay and maize silage contributed 16.03 % and 14.78 %, respectively to the dry matter. Sorghum and oat silage also contributed 9.80 % and 3.99 % of the total daily dry matter, respectively. This result implies that yellow maize meal, high protein concentrate and lucerne hay are very important contributors to dry matter for dairy cows, not excluding the other feed stuffs. In order to arrive at meaningful conclusions, the study estimated the marginal contribution of the individual feed products to the total milk output. The total average milk yield per year for the dairy farms considered for this study was 13197 tonnes. The results reveal that yellow maize meal is the highest contributor to yearly milk yield.

Table 3.8: Dry matter contribution and marginal water productivities of main animal feed products in a complete ration for dairy cows

Feed products	Total WF (m^3/year)	Kilogram of dry matter per day	Percentage contribution to milk output[2]	Actual contribution to yearly milk output (tonnes)	Marginal water productivities (kg/m^3)
Lucerne hay	580788	4.22	16.04	2117	3.64
Oats Silage	136948	1.05	3.99	527	3.84
Sorghum Silage	247981	2.58	9.80	1293	5.22
Maize Silage	397047	3.89	14.78	1950	4.91
Maize meal	2452143	7.48	28.42	3750	1.53
HPC	2634972	4.86	18.47	2437	0.93
Other ingredients	1409485	2.24	8.50	1122	0.80
Total	7859363	26.32	100	13197	20.87

Similarly, we found that high protein concentrate and lucerne hay are the second- and third-highest contributors to the yearly milk yield, respectively. Maize silage contributed 14.78 % of the total yearly milk output, with the lowest contribution coming from oat silage. Soybean and sun flower cakes are incorporated into HPC and not fed to the animals separately, so we did not estimate separate contributions to dry matter for these feed ingredients. After estimating the

[2] Average dry matter to milk yield ratio for South Africa : 1kg DM: 3.8 output (Mekonnen and Hoekstra (2010b)

contribution to yield from the individual feed crops, water productivities of the feed products were estimated by dividing their contribution to yield by their respective water footprints.

The results are presented in the last column of Table 3.8. The findings show that feed products such as sorghum silage, maize silage, and oats silage and lucerne hay have high marginal water productivities. However, expressing water productivities in physical terms is not sufficient to meaningfully explain the economic benefits of water-use. Hence, we estimated economic water productivities which give insight to the economic benefits of water usage in the feed production sector. The results are presented in Table 3.9. The value added to the feed crops and ingredients were estimated for economic and policy purposes. In terms of value addition, the results show that more value is added to high protein concentrate and yellow maize meal, as ZAR 6.91 and ZAR 4.39 are attained from these feed products, respectively. This is followed by lucerne hay, sorghum and maize silages, respectively. The least value added is associated with oats silage. The results generally suggest that the production of all the feed products considered is economically efficient since the monetary value attained from them is positive. However, the value added varies from product to product.

The results in Table 3.9 further revealed that sorghum silage and lucerne hay are the top two feed products which have high economic water productivities; as every cubic metre of water used in producing sorghum silage and lucerne hay results in ZAR 8.72 and ZAR 6.82, respectively. This is followed by yellow maize meal and high protein concentrate (HPC); as every cubic metre of water used in their production yields about ZAR 6.71 and ZAR 6.43, respectively. Maize silage had the least economic water productivities. The above results provide vital information for livestock feed producers and water users along the dairy value chain as to which feed crops or products are economically efficient to produce in terms of water use and profitability. Notwithstanding this, the contribution to dry matter and milk yield should be taken into consideration in order to attain higher proceeds. For instance, the total economic water productivity estimates and contributions to milk output indicate that feed products such as yellow maize meal, high protein concentrate and lucerne hay are very economical in terms of water and have high contributions to milk yield. Hence, profit-maximising dairy farmers and feed manufacturers with sustainable and efficient water-use objectives can focus more on such feed products which are good contributors to milk yield and have high economic water productivities.

Despite the high economic water productivity of sorghum silage, our findings indicate that its contribution to milk yield is low, relative to feed products such as maize meal, HPC and lucerne hay. This implies that not all economically active feed products are significant contributors to milk output. Similarly, maize silage has low economic water productivity and somewhat low contribution to milk output. Therefore, dairy farmers can replace it with feed products such as triticale silage which is known to have high contribution to milk output and economic water productivities (Cosentino et al., 2015).

Table 3.9: Value addition and economic water productivity of main feed products

Feed products	Marginal water productivities (kg/m^3)	Value added (ZAR/ kg)	Economic water productivities (ZAR/m^3)
Lucerne hay	3.64	ZAR 1.88	6.84
Oats Silage	3.84	ZAR 1.37	5.22
Sorghum Silage	5.22	ZAR 1.67	8.72
Maize Silage	4.91	ZAR 1.66	3.25
Yellow maize meal	1.53	ZAR 4.39	6.71
HPC	0.93	ZAR 6.91	6.43

Average exchange rate for December, 2015: US$1; ZAR 15.05

3.2. WATER FOOTPRINT AND PHYSICAL WATER PRODUCTIVITY OF MILK PRODUCED AND PROCESSED IN SOUTH AFRICA

Table 3.10 presents the water footprint and physical water productivities of milk produced and processed in South Africa. The results show that the total yearly water footprint for producing 13196.58 tonnes of milk with 3.3 per cent protein and 4 per cent fat is 1024.95 cubic meters per tonne. Based on this figure, we estimated the physical water productivity of milk along the complete dairy value chain to be 0.98 kilograms per cubic meter. Precisely, green water footprint constitutes 862.20 cubic meters per tonne whereas blue and grey water footprints constitute 96.99 and 65.76 cubic meters per tonne, respectively. This suggests that green water (84.12%) forms the largest constituent of the total water footprint of milk, followed by blue water (9.46%) and grey water (6.42%) footprints, respectively. In terms of physical water productivities, the results indicate that 10.31 kilograms of milk is attained from every cubic meter of blue water used, whereas 1.56 kilogram of milk is obtained from every cubic meter of green water utilized.

The results further show that about 80.92 % of the total yearly water footprint in the dairy industry in South Africa is attributed to feeding lactating cows only, whereas 17.10 % is utilised for feeding non-lactating cows. This indicates that about 98.02 % of the total water footprints along the dairy value chain go into feeding of animals. This concurs with the findings of Mekonnen and Hoekstra (2010b) who opined that more than 95 % of the water footprints of animal products relates to water used for feed production. The remaining amount constitutes the water consumed by the live animals and servicing water used at the processing stage.

Table 3.10: Water footprint and physical water productivity of milk in South Africa

Parameters	Yield (tonne/year)	Blue WF (m^3/year)	Green WF (m^3/year)	Grey WF (m^3/year)	Total WF (m^3/year)
Drinking water					
Lactating cows		31153			31153
Non-lactating animals		15557			15557
Feed production water					
Lactating cows		707553	5342213	400040	6449806
Non-lactating animals			1362837		1362837
Total yearly water usage		754262	6705050	400040	7812643
Yearly Milk Production	7777				
Total yearly production WF		97 m^3/tonne	862 m^3/tonne	51 m^3/tonne	1011 m^3/tonne
Service water					
Service		-	-	188961	188961
Yearly milk processed	13197				
Total yearly servicing water		0 m^3/tonne	0 m^3/tonne	14 m^3/tonne	14 m^3/tonne
Total water footprint		97m^3/tonne	862 m^3/tonne	66 m^3/tonne	1025 m^3/tonne
Physical water productivity		10.31 kg/m^3	1.56 kg/m^3	15.21 kg/m^3	0.98 kg/m^3

3.3. VALUE ADDITIONS AND ECONOMIC WATER PRODUCTIVITIES OF MILK AT DIFFERENT STAGES AND FOR DIFFERENT PACKAGING DESIGNS

For dairy producers with profit maximization and water sustainability objectives, the value generated from their production inputs and economic water productivities are very important to their production decisions. For instance, inputs such as blue water use is directly associated with production costs and may be limiting dairy production (Chouchane et al., 2015). This implies that particular attention should be paid to activities that result in higher value addition and economic water productivities, while focusing on making rational and efficient use of water in order to be economically productive along the dairy value chain. Hence, we have estimated the value added to milk as it moves along the dairy value chain in order to determine the point along the dairy value chain where most value is added. Given the value added along the value chain, we conducted sensitivity analysis for economic water productivities of milk at different stages of the value chain and for different packaging sizes. We considered one litre and three litres packaging sizes with different sales revenue per kilogram. The results are presented in Table 3.11. The results show that a total value of ZAR 12.11 is added to a kilogram of milk when packaged in 1litre bottle, relative to ZAR 9.04 per kilogram of milk when packaged in 3 litres bottle. This implies that more value is attained when milk is packaged in smaller sizes.

Along the value chain, our results show that more value is added to milk at the processing or whole sale level irrespective of the packaging size, as indicated by the amounts of ZAR 5.84 and ZAR 4.01 per kilogram of milk for one and three litres packages, respectively and relative to the other stages along the value chain. The second highest value is added at the retail level where ZAR 4.70 and ZAR 3.46 per kilogram of milk were added to one litre and three litres packaging sizes, respectively. At the farm gate level, we found that an amount of ZAR 1.57 each was added to milk for both packaging sizes considered. It worth noting that the value added to milk at the retail level for one litre packaging size is higher than the value added to the three litres packaging size at the processing or wholesale level. Generally, the results indicate that milk production is economically efficient since the revenue attained at each stage of the value chain exceeds the cost incurred.

Regarding economic productivity of water, the results show that the economic water productivity of milk packaged in one litre bottle is ZAR 11.88 per cubic meter, whereas that of the three litres package is ZAR 8.87 per cubic meter. This means that every cubic metre of water used to produce one kilogram of milk with 3.3 per cent protein and 4 per cent fat, yields ZAR 11.88 and ZAR 8.87, when packaged in one litre and three litres respectively. The implication from this finding is that milk production in South Africa is economically efficient in terms of water usage since the value attained from every cubic meter of water used exceeds its cost.

At the production stage where larger proportion of water is used, our results indicate that every cubic meter of water utilized results in ZAR 1.55. Water use is highly economical at the processing stage; as every cubic meter of water used in the production of a kilogram of milk with 3.3 per cent protein and 4 per cent fat, resulted in ZAR 5.72 and ZAR 3.93, respectively for one litre and three litres packaging sizes. At the retail level, every cubic meter of water utilized yielded ZAR 4.61 and ZAR 3.39, when milk is packaged in one litre and three litres respectively. The above results indicate that water use along the dairy value chain is very productive at the processing and retail levels. The type of packaging sizes used for selling the dairy product has a bearing on the value addition and economic water productivity estimates.

Table 3.11: Value additions to milk as it moves along the value chain and economic water productivities of milk at different stages and different packaging sizes

Stage of value chain	Value addition (ZAR/ kg)		Economic water productivity (ZAR/m^3)	
	1 Litre packaging	3 Litres packaging	1 Litre packaging	3 Litres packaging
Farm gate	1.57	1.57	1.55	1.55
Processing/whole sale	5.84	4.01	5.72	3.93
Retail	4.70	3.46	4.61	3.39
Total	12.11	9.04	11.88	8.87
Total physical water productivity (farm gate)				0.99 kg/m^3
Total physical water productivity (wholesale and retail levels)				0.98 kg/m^3

1litre of milk =1.033 kilogram

Average exchange rate for December, 2015: US$1; ZAR 15.05

4. CONCLUSIONS

The current global water scarcity situation and the pressure on governments, organisations, policy-makers, water-users and water managers to develop sustainable and economically efficient water-use policies require rigorous assessment of water footprints and water productivities in all sectors of the economy that use water. Water footprint assessment in the agriculture and food sectors has emerged as a vital sustainability indicator. The present paper has contributed to earlier water footprint studies in South Africa and Africa as a whole by adding the economic aspect of water use along the dairy value chain. The study focused on the economic productivity of water along the dairy value chain, starting from feed production to the final product.

The findings have important economic and efficient water use implications for actors along the dairy value chain. In terms of water use, the study concludes that the highest proportion of water utilized along the dairy value chain goes into feed production. Different feed products have different water footprints. This suggests the need for water footprint assessment of different feed products to identify the ones that are higher users of the existing scarce water resources. Given the blue water scarcity situation in South Africa, our findings suggest that feed products such as lucerne hay, maize silage and sorghum silage are higher consumers of blue water resources. However, judging these products based on their water footprint estimates alone will be biased. Hence, the study's findings have highlighted the contributions of the feed products to milk output. Yellow maize meal, high protein concentrate and lucerne hay are the top three feed products with high contribution to milk output, respectively. Hence, dairy livestock producers should pay particular attention to these feed products when formulating ration for dairy cows, with the aim of attaining high milk yield, which in turn will lead to low water footprints, high value addition and economic water productivities.

Although feed production uses the highest proportion of water along the dairy value chain, our assessment of value addition and economic water productivities of the feed products proves that the production of the feed products are economically efficient in terms of cost and water use. The economic implication of this finding is that the revenue attained from producing the feed crops and the value added to water along the dairy value exceeds the cost incurred. Hence, the study concludes that dairy livestock farmers or producers are economically efficient in their production. The findings further provide vital information for livestock feed producers and marketers on the feed products which are more profitable, as our results indicate that the value added to the feed products vary from product to product. High economic values are associated with high protein concentrate, yellow maize meal, lucerne hay, and sorghum and maize silages, respectively.

Of further importance from our study is the findings which point to the fact that not all economically water productive feed products are significant contributors to milk yield. Feed products such as yellow maize meal, high protein concentrate and lucerne hay appear to be very economical in terms of water and have high contribution to milk yield, with positive value addition. Maize silage has low economic water productivity and somewhat low contribution to milk yield and as such we suggest that dairy farmers can substitute it with a better option such as triticale silage which is known to have high contribution to milk yield and economically productive in terms of water use. This provide the rationale for profit-maximising dairy farmers with sustainable and efficient water use objectives to reconsider their dairy livestock feed formulation by incorporating more of the feed products with good contribution to milk output and economic water productivities.

The study further concludes that the value added to milk as it moves along the value chain varies from stage to stage, with the highest value added at the processing level, followed by retail level and the farm gate, respectively. Albeit, the study's estimates suggest that milk production at each stage along the value chain is economically efficient in terms of cost and water use. From marketing point of view, the findings suggest that more value is added to milk and water when packaged in smaller sizes. This connote that the type of packaging design used at the processing level of the dairy value chain has an influence on value addition and economic water productivity estimates. It is generally recommend that future research on estimations of ecological footprints and economic productivities of ecological indicators such as water should not focus only on quantifying the footprint indicators. Rather, researchers should take into account economic water productivities and the monetary value added to the product along its value chain since it gives meaningful economic implications. In order to be sustainable and economically productive in water use, all water users and managers along the dairy value chain can rely on such context-specific and concrete research outcomes to reduce the pressure of animal feed production on fresh water use in the livestock sector, while maintaining milk yield and profitability. The findings provide detailed insights into profitability and economically productive water-use in the dairy industry. We suggest that policy makers, water users and managers along the dairy value chain should not rely on water footprint estimates alone to judge the industry.

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CHAPTER 4

ASSESSMENT OF CARBON FOOTPRINT ALONG THE DAIRY VALUE CHAIN IN SOUTH AFRICA

This chapter presents an assessment of the carbon footprint (from cradle to farm gate) for milk produced and processed in South Africa in order to raise awareness about GHG emission and to design strategies to reduce carbon emission in the dairy industry. This is presented in an article entitled "Assessment of Carbon Footprint Milk along the Dairy Value Chain of South Africa".

4.1 ARTICLE THREE: ASSESSMENT OF CARBON FOOTPRINT ALONG THE DAIRY VALUE CHAIN IN SOUTH AFRICA (UNPUBLISHED)

ABSTRACT

Globally, the quest to meet the increasing food demand without stressing the environment remains a major challenge to governments and policy makers. Addressing this challenge requires a thorough assessment of the food production sector to identify the major emission areas and the possible mitigation strategies that could be adopted to reduce emissions. South Africa is rated as the 12th country in the world with largest carbon dioxide (CO_2) emissions and contributes to almost half of all the GHG emission in Africa. Therefore, this study has examined the carbon footprint of milk, as well as the parameters that account for the largest impact on the carbon footprint of milk produced, under the total mixed ration (TMR) feeding system in South Africa. The study employed the lifecycle assessment (LCA) methodology for GHG emissions. The total carbon footprint of milk with 4 % fat and 3.3 % proteins produced and processed in South Africa was 2.72 kg CO_2e per kg. Methane accounted for 57.9 % of the total carbon footprint, followed by nitrous oxide (31.6%) and carbon dioxide (10.5%), respectively, in South Africa. About 98.73 % of the methane emissions emanated from enteric fermentation. More than half of the direct nitrous oxide emitted came from excreta and manure management. Fertiliser production and application alone accounted for about 78 % of the total carbon dioxide emitted along the milk product chain. By reasonably varying one parameter, holding all the others constant, the total carbon footprint can considerably increase by 17.28 %. The key parameters that need much attention in the estimation of GHG emissions are the emission factor used for methane emitted through enteric fermentation, and the emission factor for direct nitrous oxide emission and dry matter intake. In order to attain more accurate and consistent carbon footprint estimates at national and regional levels in the future, it is imperative to expand our knowledge on the key practices, activities and parameters that affect key contributors to carbon footprints, such as methane and nitrous oxide, not excluding carbon dioxide. Hence, the establishment of country- and regional-specific emission factors to be used as benchmarks for calculating carbon footprints at local levels and across industries will be a feasible strategy. Finally, carbon footprint assessment is an expedient tool for evaluating the possible impact of food production and products to climate variation, especially in developing countries.

Keywords: Carbon footprint; GHG emission; Life cycle assessment (LCA); Milk production; South Africa

1. INTRODUCTION

Globally, climate change is considered as being the most imminent environmental threat to sustainable development. Variability in climate poses great threats to sustainable environment (Steffen et al., 2007). In recent years, governments and policymakers have given much attention to the contribution of the agricultural sector to climate change. The increased attention is the result of the threat that the agricultural sector poses to the environment, particularly GHG emissions, and water and land resources (Ridoutt et al., 2014). The IPCC (2007) indicated that the agricultural sector accounts for 14 % of global GHG emissions. The agricultural activities that have resulted in the 14% contribution include management of soils, livestock and production, and biomass burning. It is worth noting that agriculture's share of 14% does not include diesel consumption by tractors, transportation of feed, production of fertilisers, land use and clearing for agriculture. Therefore, Foley et al. (2011) opined that the agriculture sector is more likely to account for 30–35% of global GHG emissions, assuming that all these contributions were added to the agricultural sector.

An overview of the future trends and challenges associated with GHG emissions from the agricultural sector reveals that GHG emissions are expected to increase (FAO, 2006). The expected increase is a result of the increase in demand for food products due to increases in the human population and changes in consumption patterns. For instance, it is estimated that the global demand for animal products will double by the year 2050, in reference to baseline reports for the year 2000 (FAO, 2006). The expected increase in demand for animal products is significantly attributed to the increasing human population. A shift in dietary pattern towards more animal protein, particularly in developing economies, has been regarded as being one of the main factors accounting for the high demand for animal products. It is predicted that the world's per capita annual intake of dairy products (excluding butter) will reach 100 kg fresh milk equivalents by the year 2050 (FAO, 2006). Developing countries will observe an increase of about 70 % in milk consumption, with about 78 kg fresh milk equivalents. However, in developed countries, milk consumption is expected to range from 214 to 227 kg fresh milk equivalents. This renders the livestock sector one of the critical sectors that need particular attention in order to reduce anticipated environmental impacts related to GHG emissions. Meeting the increase in food demand without stressing the environment is a major challenge for governments and policymakers. Addressing this challenge requires a thorough assessment of the food production sector to identify the major emission areas and the possible mitigation strategies that could be adopted to reduce emissions.

South Africa is rated as the 12th country in the world with largest carbon dioxide (CO_2) emissions and contributes to almost half of all the GHG emission in Africa (Carbon Tax Policy Paper, 2013). This shows that carbon emission is a major environmental issue that needs to be tackled from a holistic point of view in order to be more environmentally sustainable. In an endeavour to deal with the increasing emission trends, the government issued the Carbon Tax Policy Paper in 2013 that aims at reducing greenhouse gas emissions and facilitating the transition to a green economy. The South African government presented its INDC in September, 2015. The INDC policy focuses on GHG emission reduction to about 398 to 614 $MtCO_2e$ for the period 2025–2030 (DEA, 2015). In order to meet this target, carbon footprint assessment is gaining much prominence. Institutions, industries and researchers are interested in assessing the carbon footprints of food products.

The present Article assesses the carbon footprint of, and the parameters that contribute the largest impact on, milk produced and processed in South Africa. The livestock sector contributes about 18 % of anthropogenic GHG emissions (Rotz et al., 2013). Gerber et al. (2010) revealed that the dairy sector contributes 4.0 % of global GHG emissions. Existing literature indicates that about 80 % of GHG emissions occur before the dairy product reaches the farm gate (Gerber et al., 2010). This means that much of the environmental impacts occur during the production phase. The global carbon footprint of 1 kg of milk at the farm gate is 2.4 kg of carbon dioxide (CO2e). This includes emissions for transport and processing (Gerber et al., 2010). However, carbon footprints differ from one region to another. For instance, in Western Europe, Eastern Europe, Oceania, and North America, the carbon dioxide (CO_2e) emission is 1.5 kg per 1 kg of milk. In sub-Saharan Africa, CO_2e emission is 7.5 kg per kg milk, whereas in Eastern Asia, Western Asia, Northern Africa, and Central and South America, the emissions range between 2 and 4.5 kg CO_2e per kg of milk (Gerber et al., 2010). The differences in carbon footprints for the different regions provide the rationale for conducting country-specific carbon footprint estimates. Therefore, this study evaluates the carbon footprints of milk and other dairy products, using South African case studies or data. The study will provide insights into the factors that influence the carbon footprint of milk production. We focus on the carbon footprint of milk produced under the mixed production (intensive and extensive) system of dairy cattle production in South Africa.

2. *MATERIALS AND METHODS*

2.1. THEORETICAL FRAMEWORK

This study employed the Life Cycle Assessment (LCA) approach. The LCA is applied in environmental impact assessments in dairy industries to assess the environmental impacts and sustainability of dairy production (Gerber et al., 2010; Ridoutt et al., 2014). The LCA approach allows the researcher to detect areas of production along the production chain where emissions are higher. LCA is a well-rooted in ISO standards 14040 and 14044 (ISO, 2006a; ISO, 2006b). The key advantage of this approach is that it offers a holistic assessment of production processes, in terms of resource utilisation, and of environmental impacts, while it also considers multiple parameters (ISO, 2006b). The LCA analysis entails all phases of the product life cycle such as extraction of raw materials, production, transportation, usage, and waste management. It also accounts for all associated inputs and outputs, as well as the allied in-flows and out-flows from the environment. The Attributional Life Cycle Analysis (ALCA) approach was followed because it allows for the aggregation of results by adding all emissions arising from various activities to arrive at the total emission (Sonnemann et al., 2011). Furthermore, the Attributional Life Cycle Analysis (ALCA) was suitable for our study because we are interested in identifying hot spots.

Greenhouse gases are emitted at different stages along the dairy production chain. For example, there is methane emission arising from enteric fermentation, excreta on fields, and manure management. There are direct and indirect emissions of nitrous oxide, principally through chemical fertiliser application and manure management. Carbon dioxide (CO_2) is emitted primarily through the burning of fossil energy for supplying motive power in farm machinery such as tractors for pasture and forage production, in milk processing plants, and in other farm implements, as well as in construction. The formulas for calculating methane emission from enteric fermentation, excreta on field, and manure management are outlined in the IPCC (2007) guidelines. Furthermore, the estimation of direct and indirect nitrous oxide followed the procedures and formulas in the IPCC (2007) report.

2.2. FUNCTIONAL UNIT

The functional unit is 1 kilogram of milk (4 % fat and 3.3 % proteins) produced at the farm gate, as well as by products such as dry cows and surplus calves in South Africa. The milk is corrected for fat and protein content. GHG emissions were not allocated between milk, dry cows and calves because the main aim of this study is to understand how individual parameters contribute to the carbon footprint of milk in South Africa.

2.3. SYSTEM BOUNDARY

The South African dairy farm gate was considered as the system boundary. The study takes into account the GHG emissions related to all the inputs and outputs along the milk value chain. The sources of production and raw materials used for the production of the inputs were traced. It must be emphasised that the small emissions associated with activities such as pesticide production, veterinary drugs and disinfectants were not accounted for in this study (Flysjö et al., 2011). The study factored in capital goods related to energy and transportation in the milk production chain (Frischknecht et al., 2007). Additionally, GHG emissions related to land usage and its changes were excluded, because our data was scant and also because there is much debate as to which method is appropriate for integrating land usage and changes in land use (Flysjö et al., 2011). In order to address seasonal variations, we solicited data for a year.

2.4. DATA SOURCES AND DESCRIPTION

Data points on the characteristics of the dairy farms, such as herd size, number of lactating cows, dry cows, heifers and bulls, lactating and non-lactating periods, milk output and weight of animals, were obtained from selected dairy agribusiness companies in South Africa. The agribusiness companies are made up of dairy farmers and processors that belong to the South African Milk Processors' Organisation (SAMPRO). These dairy agribusinesses produce diverse dairy products for the South African market and export some of their products outside the country (Milk SA, 2014). Data on grazing, roughages, grains and feed concentrates was obtained from the selected dairy agribusinesses companies. The selected dairy agribusinesses companies have installed electronic feed calculation systems that keep records of feed intake, water intake, dry matter intake, feed conversion efficiency, ration composition, quantities of feed products fed on a daily basis, and milk output per lactating cows kept under intensive systems. In line with Clark et al. (2003) and Du Toit et al. (2013), the dry matter intake by animals grazing on pastures was expressed as the quantity of feed acquired, milk output and body weight of animals. The total dry matter intake is then estimated according to the quantity of animal feed intake that is obtained from pasture, taking into consideration the quantity of feed procured and the composition of feeds required to attain a given volume of milk and sustain an animal of a given body weight. The data obtained from the different dairy agribusinesses was used to estimate weighted averages for further analysis.

Data from farm gate to retail activities in the dairy industry was sourced from the selected dairy agribusiness companies. Data on the current retail sector in the country was obtained from SAMPRO. During the farm and dairy processing phases, emissions arise mainly from using electricity or fossil fuels. Therefore, details of the quantities of electricity and fuel used by companies along the entire value chain were sourced from the selected companies. These data points were obtained through interviews with managers of the selected dairy companies. Average energy usage was estimated from the figures obtained from the various dairy companies. The energy usage or consumption estimates were multiplied by emission coefficients to derive the corresponding GHG emissions.

Data on GHG emissions from electricity and other sources of energy was obtained from the Electricity Supply Commission (ESKOM) of South Africa and the International Energy Agency (IEA, 2009). The emission factor for electricity usage was obtained from Eskom (2014) and IPCC (2006b). Details of GHG emissions for transportation from the dairy farms to the dairy processing facilities were solicited from the dairy companies in South Africa. Average GHG emissions per kilogram of milk transported were calculated for the selected companies. Transportation of dairy products from dairy processing units to retailers was mainly via road transport. Information on the total distance, transportation mode, and emissions per unit of distance travelled and emissions per time unit (cooling system) was obtained from various companies. Data on CO_2 and N_2O emission factors for fuel (diesel and petrol) used in transport and the agricultural sector was obtained from IPCC (2006b) and South Africa's GHG inventory 2000–2010. GHG emissions arising from transportation were computed for milk. Data on energy consumption for packaging dairy products was sourced from the selected dairy companies. The data from the different regions were calculated using weighted averages. The emission factors used for the various emission activities and for the different sectors are provided in Table 4.1 below.

Table 4.1: Overview of emission activity and sources of emission factors

Activity	Sector/sub-category	Emission factors		
		CO_2	CH_4	N_20
Diesel[a]	Transport	74100 kg/TJ	3.9 kg/TJ	3.9 kg/TJ
Petrol[a]	Transport	69300 kg/TJ	33 kg/TJ	3.2 kg/TJ
Diesel[a]	Agricultural	74100 kg/TJ	3 kg/TJ	0.6 kg/TJ
Petrol[a]	Agricultural	69300 kg/TJ	3 kg/TJ	0.6 kg/TJ
Electricity[d]	Energy	0.98 kg/kWh^{-1}[d]		4.17g//kWh^{-1}[d]
Lactating cows	TMR-enteric		132 kg/h/year[b]	0.86 kg/h/year[c]
Lactating heifers	TMR-enteric		127 kg/h/year[b]	0.84 kg/h/year[c]
Lactating cows	Pasture -enteric		127 kg/h/year[b]	0.03 kg/h/year[c]
Lactating heifers	Pasture-enteric		116 kg/h/year[b]	0.03 kg/h/year[c]
Lactating cows	TMR-Manure		14.80 kg/h/year[b]	0.86 kg/h/year[c]
Lactating heifers	TMR-Manure		14.70 kg/h/year[b]	0.84 kg/h/year[c]
Lactating cows	Pasture -Manure		4.98 kg/h/year[b]	0.03 kg/h/year[c]
Lactating heifers	Pasture -Manure		4.80 kg/h/year[b]	0.03 kg/h/year[c]

Sources:
a. IPCC (2006b)
b. GHG National Inventory (2014)
c. Du Toit (2013)
d. Eskom (2014)

Data on farming system and practices was collected at the national level for the various production systems from SAMPRO. Data on manure and manure management was obtained from the dairy agribusiness companies at the farm level. Details of methane emission factors were obtained from Du Toit et al. (2013), GHG National Inventory (2014), and IPCC (2006b). In addition, the emission factors for CH_4 and N_2O for lactating cows kept under total mixed ration (TMR) and pasture management systems were obtained from IPCC (2006b) and GHG National Inventory (2014). Details of these are provided in Table 4.1 above. Additionally, data on milk yield, manure, and organic and synthetic fertiliser usage were obtained from the dairy agribusinesses selected for the study. Finally, the characteristics of the dairy farms surveyed were sourced from the dairy agribusiness considered. Other internal sources of data include Professional Livestock Associations and Breed Societies, the Department of Agriculture, Forestry and Fisheries (DAFF), the Department of Environmental Affairs (DEA), the Department of Energy (DOE), and the Agricultural Research Council (ARC).

2.5. ALLOCATION

The primary product from the dairy farms is milk. However, dry or spent cows are slaughtered for meat; manure is obtained for fertilising pastures and feed crops; and calves are also obtained from the dairy farms. The dairy companies considered in this study apply all the manure from the cows for feed production, and hence there was no need for allocating the manure. Furthermore, there was no allocation made between the primary product and the dry cows or calves. In terms of feed products, such as high protein concentrate, soya bean and sun flower cakes, maize meal, and silages made from sorghum, lucerne, maize and oats, we employed economic allocation, as highlighted by Flysjö et al. (2008) to apportion the GHG emissions related to the feed products and their co-products. Additionally, allocation to manure was done following Flysjö et al. (2008).

2.6. DESCRIPTION OF THE SOUTH AFRICAN DAIRY PRODUCTION SYSTEMS

Three systems of feeding dairy cows in South Africa are described in this study. These are: (i) semi-intensive, farm-based rations obtained from available crops, pastures and crop residues, with minimal rations being purchased; (ii) an intensive, zero-grazing dairy system using a total mixed ration; and (iii) a traditional, extensive or dual-purpose system (Milk SA, 2014). High quality and protein feed for dairy cows is obtained from legumes such as lucerne, and also from products such as sunflower, soya beans oil cake meals, fish meal, and cotton seed. Energy-providing feedstuffs are sourced from grains (e.g. maize, wheat, and sorghum), grain by-products (hominy chop), and by-products from the sugar cane industry, such as molasses (Milk SA, 2014). Forage serves as the main source of fibre for dairy cows. It is also a source of energy, protein and minerals. Dairy farmers obtain their forage from natural veld pastures, legumes, grass hay and silage. Most dairy farmers prepare a total mix ration (TMR) by combining forage with available protein and energy sources. The farmers weigh and blend all feedstuffs into one ration that gives sufficient nutrition to the dairy cows. Total mix ration comprises the required energy, protein, minerals and vitamins desirable for the dairy cow. At some point in production, farmers give supplemental feed to the dairy cows.

According to Milk SA (2014), dairy farmers turn green, perishable forage into hay, which is safely stored for feeding dairy cows. Farmers make hay from teff, lucerne, weeping love grass, smutsfinger grass, foxtail buffalo grass (Bloubuffel), cowpeas, and Rhodes grass. Commercial dairy farms have designed machinery, such as the hay baler, to bale the hay. On the other hand, smaller-scale dairy farms rely on traditional method of hay preparation, using equipment such as rakes for spreading the hay. Besides hay, silage is also prepared for feeding dairy cows in South Africa. The crops commonly used to make silage include maize, sorghum and canola. Maize is the commonest silage crop in South Africa (Milk SA, 2014). Sorghum silage is best for cows during the later stages of lactation. Farmers rely on canola during winter and during winter rainfall. Irrigated and established pastures are used as an important source of nutrition for dairy farms in certain parts of South Africa. Commonly planted pastures are grasses such as ryegrass and kikuyu, and legumes such as clover. About 56% of dairy cows in South Africa rely on pasture, 38% on total mixed ration (TMR), and 6% on a mixed or dual purpose system (Ercole, 2013). The dairy cows in this case study were kept under a total mixed ration (TMR) system; hence, the emission factors used were those applicable for TMR.

2.7. EMPIRICAL ISSUES

The empirical specifications and calculation methods employed in the estimation of the carbon footprint followed the procedures outlined in the IPCC (2007) guiding principles. According to IPCC (2007) guiding principles, GHG emissions are expressed as the product of specific emission activity data multiplied by its emission factor. This is expressed empirically as:

$$EM = AD \times EF \tag{4.1}$$

where EM denotes GHG emissions; AD is the activity data; and EF is the emission factor for the specific activity. Prior to estimation of the emissions, accurate data and unit conversions must be ensured. Country-specific emission factors are more preferred, but in the absence of country-specific emission factors, default values from IPCC guidelines were employed. In this study, the methane emission from enteric fermentation by dairy cows was calculated as specified in Equation (2) and follows Du Toit et al. (2013):

$$\text{Methane}_q = \sum EF_i \times N_i \quad (4.2)$$

where $Methane_q$ is the estimated quantity of methane emitted; EF is the emission factor of dairy cow measured in kg/head/year[1]; and N_i is the number of dairy cows. The emission factors for dairy cows followed the approach employed by Du Toit et al. (2013) for a South African case study. Empirically, the emission factors were specified as:

$$EF = \left((Y_d / 100) \times TEI \times 365\right) / F \quad (4.3)$$

where EF is defined above; Y_d is the percentage of total energy intake yielded as methane; and TEI is the total energy intake measured in $\text{MJ/head}^{-1}/\text{day}^{-1}$. The total feed intakes which were transformed into energy terms were recorded by the selected dairy farms using electronic feed calculation systems. The constant factor (F) was obtained from Brouwer (1965) and expressed in $\text{MJ}(\text{kgCH}_4)^{-1}$. Detailed explanations of the factors are outlined in Du Toit et al. (2013). In terms of methane emissions from manure, the estimations were made based on the IPCC (2007) guidelines and South African National Inventory values. The manure emission factors for cattle kept on pasture or range lands were calculated in accordance with the Australian approach employed by Gonzalex-Avalos and Ruiz-Suarez (2001). The Australian approach was used because South Africa's climate and environmental conditions are similar to those of Australia (GHG National Inventory, 2014). Empirically, the methane emission from the manure of dairy cows was calculated as:

$$EF = \left(VS \times EP \times MCF \times P_m\right) \times 365 \quad (4.4)$$

where VS is the volatile solids of the manure; EP is the emission potential obtained from the IPCC (2006) as $0.24\ m^3\ \text{CH}_4(kgVS)^{-1}$; MCF is the methane conversion factor evaluated for total mixed ration and pasture based systems of dairy cattle production; and P_m is the density of the methane. It is worth noting that the volatile solids (VS) of the manure can be calculated as:

$$VS = DMI \times (DMI - DMD) \times (1 - ACM) \quad (4.5)$$

where DMI denotes the dry matter intake of the animals, DMD denotes dry matter digestibility, and ACM represents ash content of the manures. The dry matter digestibility and ash content of the manure are stated as a fraction. Nitrous oxide emissions from the dairy cows were estimated using the crude protein input and nitrogen storage approaches, as outlined in ANIR (2010). The intake of crude protein was expressed as the product of dry matter intake and crude protein of feed intake. This empirically specified as:

$$CPI = DMI \times CP \quad (4.6)$$

where CPI denotes crude protein intake; DMI refers to dry matter intake; and CP denotes the fraction of crude protein in feed consumed. In addition, nitrogen emitted from faeces was estimated based on the approach employed by Freer et al. (1997) and Du Toit et al. (2013). In line with these authors, nitrogen emitted from faeces is calculated as:

$$F = \left\{0.3(CPI \times (1 - [(DMD + 10/100)]) + 0.105(ME \times DMI \times 0.008) + (0.0152 \times DMI)\right\} / 6.25 \quad (4.7)$$

where *DMD* and *DMI* are defined as above; and *ME* denotes metabolisable energy measured in MJ/kg of dry matter and is estimated as: 0.1604DMD – 1.037, according to Minson and McDonald (1987). The conversion of crude protein into nitrogen was based on a factor of 1/6.25. Nitrogen retention was estimated following ANIR (2010) procedure and this is specified empirically as:

$$NR = \left\{(0.032 \times Y) + \left\{0.212 - 0.008(L-2) - [(0.140 - 0.008(L-2)/(1 + \exp(-6(Z - 0.4)))]\right\}\right\} \times (LWG \times 0.92)\right\} / 6.25 \quad (4.8)$$

where *NR* represents nitrogen retention, *Y* denotes milk yield in kilogram per day, *Z* denotes relative sizes of dairy cows, *L* denotes relative intake, and *LWG* is the live weight gain of the dairy cows. Nitrogen emitted from urine (*Un*) per kilogram per animal per day was estimated based on ANIR (2010). ANIR (2010) specified nitrogen emitted from urine as:

$$U_n = (CPI / 6.25) - NR - F - [(1.1 \times 10^{-4} \times W^{0.75}) / 6.25] \quad (4.9)$$

where *NR* and *F* are defined as above. This equation implies that the figure for nitrogen emitted from urine is obtained by deducting nitrogen retention and nitrogen emitted from faeces (F), as well as dermal protein lost from nitrogen intake (ANIR, 2010). The total yearly faeces per cow were expressed as $AF = (365 \times N \times F) \times 10^{-6}$ and the total annual urine was expressed as:

$AU = (365 \times N \times U) \times 10^{-6}$. In terms of manure management, total emissions from the various systems were calculated for faeces as $F_{mms} = (AF \times MMS \times EF_{mms} \times C_g)$ and $U_{mms} = (AU \times MMS \times EF_{mms} \times C_g)$ for urine; where *AF* denotes annual faeces, *AU* represents annual urine, and *MMS* is the proportion of manure managed under the various systems. Emission factors for the various systems are denoted as EF_{mms}. C_g is the ratio for converting rudimentary mass of N_2O to molecular weight (C_g =44/28). The total nitrous oxide emitted is obtained by summing the emissions from faeces and urine under the different manure management systems.

3. RESULTS

3.1. DESCRIPTIVE CHARACTERISTICS OF THE SELECTED DAIRY FARMS

The average characteristics of the dairy farms selected for this study are presented in Table 4.2 below. The table shows that the average herd size for the dairy agribusinesses is 2133. Out of this, 38.68 % are lactating cows, while dry cows and heifers account for 18.71 % and 41.54 %, respectively. Bulls account for only 1.07 % of the total herd. The high proportion of heifers gives an indication of how much dairy farmers in South Africa focus on the replacement of dry cows. The average number of days for lactation was found to be 300 days. This period is less than the lactating period for dairy cows in milk producing countries such as Sweden, but more than the lactating period for dairy cows in New Zealand (Flysjö et al., 2011). The non-lactating period for dairy cows was found to be about two months. The average live weight of cows for the selected dairy farms was 545 kg.

In terms of milk yield, our findings revealed an average milk yield of 25.83 litres per cow, per day. This does not deviate much from the average milk output of 26.78 kilogram per cow per day as reported by Milk South Africa (2015). However, it must be emphasised that the yield varies depending on the breed of cows, with Holsteins having the highest average yield of about 29 litres, followed by Ayrshires and Jerseys, with averages of 23.07 and 19.88 kilograms of milk per cow per day, respectively (Milk South Africa, 2015). These average milk outputs are considered to be low, relative to milk output in developing countries (Robinson and Erasmus, 2010). Given the average milk yield of 26.78 kilogram per cow per day, and the lactation period of 300 days, the total milk output cow for the entire lactation period is 8034 kilograms.

Table 4.2: Average characteristics of the dairy farms surveyed

Parameter	Description	Amount
Herd size	Number of cows per farm	2133
Lactating cows	Number of cows in lactation	825
Dry cows	Number of dry cows	399
Heifers	Number of heifers	886
Bulls	Number of bulls	23
Lactating period	Days	300
Non-lactating period	Days	60
Milk yield	Average milk yield (kg/cow/day)	26
Live weight	Average live weight of cow (kg/cow)	545

Source: Field Survey, 2016

3.2. IMPORTANT INVENTORY VARIABLES CONSIDERED IN THE CARBON FOOTPRINT ASSESSMENT

The summary statistics of the important variables considered in the carbon footprint assessment are presented in Table 4.3 below. It must be emphasised that the values are standardised to 1 kilogram of milk produced at the farm gate. In terms of feed intake, the results show that roughages account for the largest share of the total dry matter intake, as this accounts for about 54.21 % of the total dry matter intake. This is followed by grains with an estimated amount of 0.20 kg of dry matter. Concentrates and grazing accounted for 13.08 % and 14.02 % of the total dry matter intake, respectively. The total dry matter intake was 1.07 kilograms. Comparing the total dry matter intake of cows in South Africa to those in developed countries such as New Zealand and Sweden, it is revealed that the dry matter intake of dairy cows in South Africa is lower than the dry matter intake of dairy cows in New Zealand, but higher than those of Sweden (Flysjö et al., 2011).

Table 4.3: Summary statistics of inventory data standardised to 1 kg of corrected milk with 4 % fat and 3.3 % protein

Parameter	Units	Amount
Feed intake	Kilogram of dry matter intake (DMI)	
Grazing		0.15
Roughage		0.58
Grains		0.20
Concentrates		0.14
Total dry matter intake		1.07
Land occupied	m^2	
Grazing		1.34
Roughage		1.03
Grains		0.63
Concentrates		0.29
Total land occupied		3.29
Energy consumption	MJ	
Electricity		0.30
Petrol		0.06
Diesel		0.17
Nitrogen	Grams of N	
Chemical fertiliser		14.00
Organic fertiliser		26.32
Emissions	Grams	
Enteric fermentation (CH_4)		24.30
Excreta and manure management (CH_4)		0.91
Direct emissions of nitrous oxide (N_2O)		0.82
Indirect emissions of nitrous oxide (N_2O)		0.27
NH_3		5.70
NO_3		4.37

Source: Field survey, 2016

Concerning land occupation, the results indicate that the largest land use was for grazing, as it accounts for 1.34 square meters per animal. This accounts for 40.73 % of the total land occupation and the grazing is mostly done by heifers on established pastures. The second largest land use was for roughage production and this accounts for 31.31 % of total land occupation. This implies that although the dry matter intake of roughages is high, its land occupation is lower than that of grazing. Grains and concentrates had the lowest land occupation, respectively. The total land occupation was found to be 3.29 square meters. This estimate is higher than the land occupied for similar purposes in countries such as New Zealand (Flysjö et al., 2011). This is not surprising, given that about 80 % of South Africa's agricultural land is suitable for livestock production (DAFF, 2012).

In terms of energy usage, the results show that dairy producers in South Africa utilise more electricity, relative to the consumption of diesel and petrol. As indicated, 0.30 MJ of electricity is used for every kilogram of milk produced at the farm gate. This is followed by diesel and petrol, with estimated consumptions of 0.17 MJ and 0.06 MJ, respectively. It must be emphasised that the energy values presented here pertain to consumption at the farm level and for feed production. Off-farm energy utilisation for transportation and production of other feed ingredients is not included in Table 4.3. However, they were accounted for in the calculations.

The dairy producers rely mostly on organic fertiliser for fertilising field and forage crops. The organic fertilisers recorded about 12.32 grams (46.81%) of nitrogen more than chemical fertiliser application did. The organic fertilisers or manures used by the producers are not imported. They are obtained internally from the animals' dropping and within the production system. The chemical fertilisers mostly used by dairy farmers are urea and ammonium nitrate. However, emissions from urea production are substantially lower than those of ammonium production because of nitrous oxide quantities emitted during the production of nitrous acid (Jenssen and Kongshaug, 2003).

Regarding emissions, Table 4.3 shows that the methane (CH_4) emission from enteric fermentation was significantly higher than the methane emitted from excreta and manure management. Specifically, methane emission from enteric fermentation was about 96.26 % higher than the emissions from excreta and manure management were. Direct and indirect emissions of nitrous oxide were found to be 0.82 g and 0.27 g, respectively. Direct emissions of nitrous oxide emanated from soils as a result of chemical fertiliser application, as well as from manure and crop residues.

The estimations of direct emissions utilised the IPCC (2006b) default values, as outlined in the South African GHG inventory 2000–2010. Similarly, indirect emissions of nitrous oxide emanated from ammonia volatilisation and nitrate leaching. Additionally, the application of urea can also lead to high volatilization losses (NH_3). This was accounted for since it contributes to N_2O and also causes terrestrial and aquatic acidification. The calculation of indirect emissions followed the IPCC (2006b) default values.

Figure 4.1 below sets out a detailed framework that outlines the South African milk production system and carbon emission from cradle to farm gate. As shown in the figure, off-farm and on-farm activities that result in the emissions of various carbon footprint parameters are clearly highlighted.

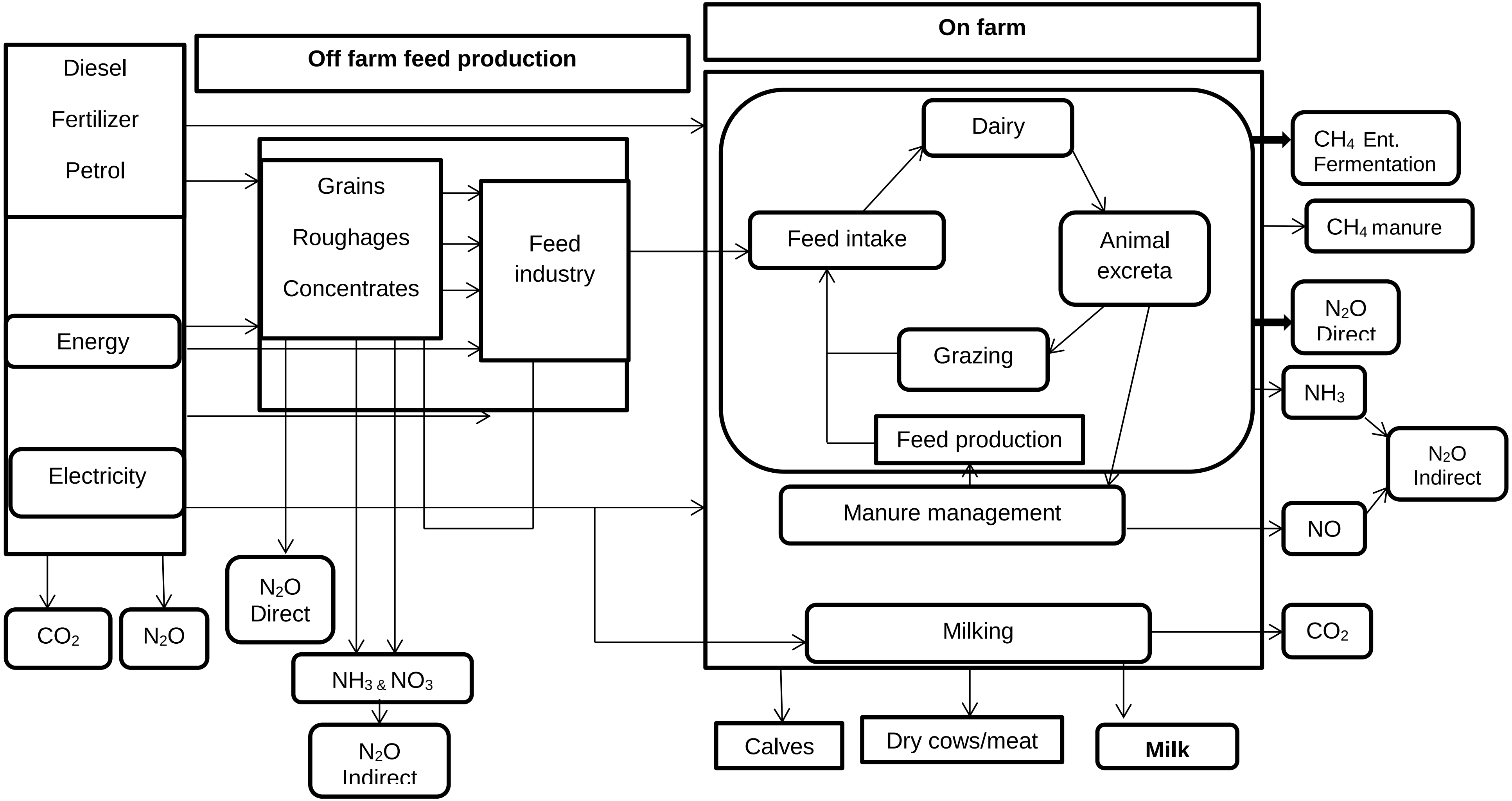

Figure 4.1: Framework of South African milk production and carbon emission from cradle to farm gate

Author's design, 2017

3.3. CARBON FOOTPRINT OF 1 KILOGRAM OF MILK PRODUCED AT THE FARM GATE (4 % FAT AND 3.3 % PROTEIN) IN SOUTH AFRICA

The total greenhouse gases (GHG) emitted per kilogram of milk produced at the farm gate, as well as the contributions from the various parameters, are presented in Table 4.4. The results reveal that the total carbon footprint of 1 kilogram of milk produced at the farm gate (4 % fat and 3.3 % proteins) and processed in South Africa is 2.72 kg CO_2e per kg. This amount is higher than the global average carbon footprint 2.4 CO_2 per kg of fat and protein corrected milk, as reported by Gerber et al. (2010). This implies that there is a need for measures to be taken to reduce carbon footprints along the dairy value chain in South Africa. However, the estimated carbon footprint of 2.72 kg CO_2e per kg for South Africa is lower than the average carbon footprint of 7.5 kg CO_2e per kg of fat and protein corrected milk which is reported for the sub-Saharan Africa region (Gerber et al., 2010).

In terms of the dairy cattle production systems, the estimated carbon footprint of 2.72 kg CO_2e per kg of milk under the mixed production system in South Africa is the same as the carbon footprint of the grassland system (Gerber et al., 2010). This suggests that the carbon footprint of the grassland or sole grazing system of dairy cattle production in South Africa might be higher than the global estimated carbon footprint reported for sole grazing systems. The contributions from the individual parameters to the total carbon footprint are also presented in Table 4.4. The results show that methane is the highest contributor to the total carbon footprint of milk in South Africa, as it contributes about 1.58 kg CO_2e per kg of the total carbon footprint of 2.72 kg CO_2e per kg. The above results show that the impact of methane for the South African environmental impact (global warming) of milk is about 57.9 %.

It is worth noting that 98.73 % of the total methane emission emanated from enteric fermentation. Comparing these estimates with methane contribution to greenhouse gases (GHG) for developed countries (52 %), it is evidenced from this study that the methane contribution to greenhouse gases (GHG) in South Africa is about 5.9 % higher (Gerber et al., 2010). At the national level, the estimated methane emission value does not deviate much from the preliminary estimates of 1.3–1.5 kg CO_2e per kg for milk reported by Milk South Africa (2011). Although Milk South Africa (2011) did not employ the LCA assessment methodology, the estimates does not differ very much.

The next highest contributor to the total carbon footprint of milk in South Africa comprises nitrous oxide emissions, as these constitute 31.6 % of the total estimated carbon footprint of 1 kilogram of milk produced at the farm gate. This estimate is lower than the average nitrous oxide contribution to total greenhouse gases (GHG) for developing countries, as highlighted by Gerber et al. (2010).

Table 4.4: GHG emissions from milk with 4 % fat and 3.3 % protein produced in South Africa

Parameters	Emission values (kg CO_2e per kg of FPCM)	Percentage contribution
Methane (CH_4) emissions		
Emissions of CH_4 from enteric fermentation	1.56	57.2
Emissions of CH_4 from excreta	0.02	0.7
Other emissions of CH_4	0.00	0.0
Sub-total methane (CH_4)	**1.58**	**57.9**
Nitrous oxide (N_2O) emissions		
Direct emissions of N_2O from excreta	0.45	16.6
Direct emissions of N_2O from fertiliser usage	0.22	8.0
Emissions of N_20 from fertiliser production	0.10	3.6
Indirect emissions of N_2O from NH_3 excreta	0.04	1.3
Other direct emissions of N_2O	0.02	0.8
Indirect emissions of N_2O from NH_3 fertiliser	0.02	0.7
Other indirect emissions of N_2O	0.02	0.6
Sub-total nitrous oxide (N_2O)	**0.87**	**31.6**
Carbon dioxide (CO_2) emissions		
Emissions of CO_2 from fertiliser production	0.17	6.7
Emissions of CO_2 from fertiliser application	0.04	1.6
Emissions of CO_2 from diesel usage	0.02	0.7
Emissions of CO_2 from electricity usage	0.02	0.7
Emissions of CO_2 from petrol usage	0.01	0.4
Emissions of CO_2 from transport	0.01	0.3
Other CO_2 emissions	0.00	0.1
Sub-total carbon dioxide (CO_2)	**0.27**	**10.5**
Overall Carbon Footprint	**2.72**	**100**

The authors found the contribution of nitrous oxide to GHG emissions in developing countries to be about 38 %. The results further revealed that more than half of the nitrous oxide emissions come directly from excreta and manure management. This is followed by the application and production of synthetic fertilisers, respectively. Direct emissions of nitrous oxide from fertiliser usage and fertiliser production account for about 25.29 % and 11.49 % of the total nitrous oxide emitted. Indirect emissions of nitrous oxide from animal excreta dropped on the land during grazing and from the manure managed also accounted for 4.6 % of the total nitrous oxide emitted.

Lastly, the results reveal that carbon dioxide (CO_2) emissions contribute the least to the total carbon footprint of milk in South Africa, as it accounts for only 10.5 % of the total carbon footprint. This estimate is lower than the average carbon dioxide (CO_2) contribution to greenhouse gases (GHG) in developing countries (21 %) but higher than the contribution from developed countries, which was found to be about 10 % (Gerber et al., 2010). Specifically, the results show that fertiliser production alone accounts for 62.96 % of the total carbon dioxide emitted in milk production. In addition, the application of fertiliser contributes 14.81 % of the total carbon dioxide emitted. Summing the emissions from fertiliser production and application results in 77.77 % of the total carbon dioxide emitted. The remaining carbon dioxide emissions were associated with fuel consumption, transportation and electricity usage. The contribution from energy usage to the total carbon footprint is minimal.

3.4 SENSITIVITY ANALYSIS FOR CHANGES IN PARAMETERS

In order to ascertain how the total carbon footprints would be affected if the factors contributing to them were to be varied, a sensitivity analysis was conducted for changes in parameters. The results of the sensitivity analysis are presented in Table 4.5 below. In conducting the sensitivity analysis, each parameter was changed at a time, and the effects of the changes on the total carbon footprint, methane, carbon dioxide and nitrous oxide are presented in Table 4.5. The sensitivity analysis was done for parameters that had significant impacts on the estimated total carbon footprint of milk.

Table 4.5: Sensitivity analysis for varying individual carbon footprint parameters

Parameters	Total carbon footprint (kg CO_2e)	CH_4	N_20	CO_2
Actual estimated CF	**2.72**			
Parameter (increase in percentage)		Increase (percentage)		
Dry matter intake (15%)	3.05(12.13%)	15.50	7.43	0.00
Nitrogen fertiliser usage (10%)	2.75(1.10%)	0.00	33.11	18.91
Crop residues (10%)	2.72(0.00%)	0.00	0.25	0.00
EF enteric fermentation (20%)	3.17(16.54%)	28.30	0.00	0.00
SA methane conversion factor[a]	3.19(17.28%)	48.00	0.00	0.00
EF N_2O_{dir} nitrogen fertiliser usage (100%)	2.85(4.78%)	0.00	59.99	0.00
EF N_2O_{dir} from excreta (100%)	3.07(12.87%)	0.00	78.00	0.00
EF N_2O_{indir} from NH_3 excreta (100%)	2.73(0.37%)	0.00	24.75	0.00
EF N_2O_{indir} from NH_3 fertiliser (100%)	2.78(2.21%)	0.00	79.75	0.00
Diesel usage (20%)	2.74 (0.74%)	0.00	0.00	28.88
Electricity usage (20%)	2.73(0.37%	0.00	0.00	9.99
Petrol usage (20%)	2.73(0.37%)	0.00	0.00	10.11
Transport (20%)	2.73(0.37%)	0.00	0.00	4.67
Other energy (20%)	2.73(0.37%)	0.00	0.50	3.55

a. South African emission factor from GHG Inventory 2000–2010 and Du Toit (2013)

The results show that a change in the emission factor from the IPCC (2006b) default value to a country-specific factor resulted in the highest increase in carbon footprint, as it resulted in 17.28 % relative to the actual estimated carbon footprint. The second parameter that resulted in a higher increase in carbon footprint estimate was the emission factor used for enteric fermentation. The results indicate that a 20 % increase in the emission factor for enteric fermentation increased the actual carbon footprint by 16.54 %. This is followed by the emission factor used for nitrous oxide emitted directly from nitrogen in excreta dropped on grazing land (12.87 %), dry matter intake (12.13 %) and the emission factor used for nitrous oxide emitted directly from nitrogen fertiliser usage, respectively.

The change in the emission factor for nitrous oxide indirectly emitted through NH_3 fertiliser resulted in an increase of more than 2 % in the carbon footprint. In addition, a 10 % increase in nitrogen fertiliser usage resulted in a 1.10 % increase in the carbon footprint. The results further show that raising energy usage (diesel, petrol, electricity, transportation and other energy) by 20 % accounted for increases of less than 1 % each to the total carbon footprint. The increase in the emission factor for nitrous oxide indirectly emitted from NH_3 excreta resulted in a 0.37 % increase in the total carbon footprint. The results further indicate that changes in dry matter intake impact on enteric fermentation and quantities of excreta, which in turn affects CH_4 and N_20. Increasing fertiliser application impacts on the quantities of N_20 and CO_2 emitted.

4. DISCUSSION

Minimising the impacts of food and agricultural production and consumption activities on the environment demands an in-depth assessment of the food production sector to identify the key parameters that contribute greatly to negative environmental effects and to outline the possible mitigation strategies that could be employed to lessen the negative consequences. The findings reveal that the carbon footprint of corrected milk in South Africa is higher when compared with the global average carbon footprint for the same product. The high carbon footprint estimate for South Africa provides the rationale for policymakers and producers along the dairy value chain to adopt measures or strategies aimed at reducing carbon footprints in South Africa. Nonetheless, the estimated carbon footprint of 1 kilogram of milk produced at the farm gate is lower than the average carbon footprint of the same product for the sub-Saharan Africa region. Therefore, the study suggests that there should be country-specific and provincial-specific carbon footprint estimates made for the different products in order to assess the real impacts of the various production and consumption activities on the environment.

Regarding production systems, the study concludes that the carbon footprint of milk produced under the mixed system in South Africa is higher than global average for the same system of production is. This carbon footprint estimate compares favourably with the carbon footprint of milk produced under a grassland system, as reported by Gerber et al. (2010). The insight drawn from this finding is that the carbon footprint of the grassland or sole grazing system in South Africa might be higher than the global estimated carbon footprint reported for sole grazing system is. This might be attributed to the low milk yield attained under the sole grazing system. The low milk yield results in high carbon footprints. Therefore, it is about time that dairy producers and agribusinesses should decide on which system of dairy production should be adopted. Currently, 56 % of dairy cows in South Africa are raised on grazing or pasture (Ercole, 2013).

The study concludes that methane has the highest impact of the greenhouse gases (GHG) in the dairy industry of South Africa. This high methane emission conclusion concurs with existing findings by Gerber et al. (2010) which revealed that methane is a major contributor to greenhouse gases (GHG), accounting for more than fifty per cent of total greenhouse gases (GHG) in developed and developing countries. Specifically, the findings reveal that about 98.73 % of the total methane emission is attributed to enteric fermentation. It is also concluded that the impact of methane on GHG emission in milk production in South Africa is higher, relative to developed countries, by 5.9 %. After methane, nitrous oxide was found to be the next largest contributor to the total carbon footprint of milk in South Africa, with direct emissions from excreta and manure management being the largest contributor to total nitrous oxide emissions.

Carbon dioxide (CO_2) emissions contribute the least to the total carbon footprint of milk in South Africa. This finding contradicts the National Treasury report which opined that the highest contributor to total GHG emissions in South Africa was carbon dioxide (CO_2) (GHG National Inventory (2014). The GHG Inventory Report for South Africa indicated that about 80 % of the national GHG emission is attributed to carbon dioxide (CO_2). This shows that there is a need for carbon footprint assessments of the different sectors to be undertaken to identify the key parameters of, and contributors to, national GHG emissions. Therefore, conducting a carbon footprint assessment is vital for understanding the environmental issues that need to be tackled from holistic point of view in order to become more environmentally sustainable. In order to attain a more reliable and accurate understanding of GHG emissions and impacts in developing countries in the future, it is vital to gain an in-depth understanding of the key contributors to the total carbon footprints of products at the national-, regional-, sector- and industry-specific levels.

The sensitivity analysis reveals that changes in a parameter can significantly influence a total carbon footprint estimate. This is in line with the findings of Flysjö et al. (2011) that use New Zealand and Swedish dairy farm case studies. Specifically, the sensitivity results indicate that reasonably changing one parameter, holding all the others constant, in our analysis resulted in a considerable increase in the total carbon footprint of 17.28 % (see Table 4.5 above). Changing the emission factor for methane had the largest impact on the estimated total carbon footprint. Besides varying the emission factor for methane, increasing emissions from enteric fermentation resulted in the second largest impact on the carbon footprint. This is followed by varying emission factors for direct nitrous oxide emission and dry matter intake, respectively. The identified parameters contributing the largest impacts on the carbon footprint in this study differ from the findings of Basset-Mens et al. (2009) in New Zealand. The authors found dry matter intake to be the highest contributor to carbon footprint uncertainties, followed by emission factors used for nitrous oxide emitted (direct) and methane emitted through enteric fermentation. The differences in uncertainties and impacts from the parameters across different countries provide the rationale for undertaking detailed sensitivity analyses for country-specific case studies and for different products in order to gain clearer understanding of the carbon footprints of different food products under different production systems.

It is worth noting that the emission factors chosen for nitrous oxides emitted from agrarian lands are known to cause significant variations in uncertainty calculations for different countries (Rypdal and Winiwarter, 2001). Therefore, as shown by our sensitivity analysis, the value of the emission factor employed for nitrous oxide emitted is an essential determinant of the total estimated carbon footprint value. Additionally, the findings indicate that the method and emission factor employed in the estimations of methane that arises from enteric fermentation are vital in quantifying the total estimated carbon footprint, given that the results have proved this parameter to have the largest contribution to the total carbon footprint of milk produced and processed in South Africa.

An additional critical factor for the resultant carbon footprint is dry matter intake. This factor is crucial because it has an influence on the greenhouse gases emitted from enteric fermentation and is allied with emissions from animal excreta. In this study, only a 15 % increase in dry matter was examined in our sensitivity analysis. This could be attained by increasing feed efficiency, decreasing feed losses, and enhancing feed intake by animals in the course of grazing. Enhancing the dry matter intake would demand an increase in feed production and this would also increase milk output. An increase in milk output will result in lower carbon footprint estimates. It must be emphasised that details of the data on quantities of fertiliser, petrol, diesel, electricity and feed products purchased are known, since farmers keep records of them. Nonetheless, the actual quantity of feed that goes into an animal's body through grazing and/or mixed rations is hard to quantify precisely, and as such, there is a consequent high uncertainty (Flysjö et al., 2011). An important issue worth mentioning comprises the potential emissions that might arise from land usage and variations in land usage. However, this was not considered in this study due to lack of data and large uncertainties. We found that no deforestation was carried out to secure more land for growing feed crops such as soybean, yellow maize, and lucerne. However, carbon can be sequestered from pastures and grasslands, although there were significant uncertainties and lack agreement on estimation procedures, and as such, this was not accounted for in this study.

5. CONCLUSIONS

The core objective of this study was to examine the carbon footprint of milk, as well as identifying the parameters that account for the largest impact on the carbon footprint of milk produced and processed in South Africa. The overall carbon footprint of milk with 4 % fat and 3.3 % proteins produced and processed in South Africa is 2.72 kg CO_2e per kg. The study concludes that methane is the highest contributor to this total carbon footprint, followed by nitrous oxide and carbon dioxide, respectively, in South Africa. The study also concludes that certain specific parameters impact significantly on the estimated carbon footprint, namely the country-specific methane emission factor, the emission factor for methane derived from enteric fermentation, the emission factor for direct nitrous oxide emission, and the dry matter intake factor. In order to attain more accurate and consistent carbon footprint estimates at national and regional levels in the future, it is imperative to expand our knowledge on the key practices, activities and parameters that affect key contributors to carbon footprints, such as methane and nitrous oxide, but not excluding carbon dioxide. This can be achieved by establishing country- and regional-specific emission factors to be used as benchmarks for calculating carbon footprints at local levels and across industries. The study suggests that a carbon footprint assessment is an expedient tool for evaluating the possible impacts of food production and products on climate variation. Furthermore, the study suggests the need for the provision of uncertainty ranges for diverse parameters, as well as the application of clear of data input and estimation procedures, especially in countries where little has been done in establishing country-specific emission factors.

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CHAPTER 5

MODELLING CONSUMERS' HETEROGENEOUS PREFERENCES AND WILLINGNESS TO PAY FOR FOOTPRINT ATTRIBUTES AND QUANTIFICATION OF WELFARE IMPLICATIONS OF WATER AND CARBON FOOTPRINTS SUSTAINABILITY POLICIES ON CONSUMERS IN SOUTH AFRICA

This chapter presents results on modelling consumers' heterogeneous preferences and willingness to pay for water and carbon footprint information and quantifies the welfare implications of water and carbon footprints sustainability policies on consumers in South Africa. This will help to understand consumers' sustainability behaviour and the segment of South African consumer's whose welfare will be improved or reduced by sustainability policy changes. The chapter is presented in two papers. The first article is entitled "Consumers' stated preferences for water and carbon footprint-labelled food products? Insights from Low and High Income Classes" and the second one is titled as "Compensating welfare estimates of water and carbon footprint sustainability policy changes in South Africa"

5.1 ARTICLE FOUR: CONSUMERS' STATED PREFERENCES FOR WATER AND CARBON FOOTPRINT-LABELLED FOOD PRODUCTS? INSIGHTS FROM LOW AND HIGH INCOME CLASS CONSUMERS (UNPUBLISHED)

ABSTRACT

In recent years, governments, policymakers, and managers of private food companies and agribusinesses are interested in understanding how consumers will react to environmentally sustainable attributes and information on food product labels. This study examines consumers' stated preferences for water and carbon footprint-labelled food products from the viewpoint of low and high income South African consumers. Discrete choice experimental data was collected from low and high income consumers to possibly assess variations in preferences for environmentally sustainable products based on income classifications. It was found that consumers' preferences for environmentally sustainable attributes vary significantly between low and high income classes. The findings revealed that there are profound heterogeneous consumer segments within low and high income classes. The heterogeneity within both sub-samples is better explained at the segment level, rather than at individual level. For both product categories, the findings reveal that there are more distinct consumer segments among low income consumers, relative to high income consumers. The low income respondents consist of water sustainability advocates, carbon reduction advocates, keen environmentalists, and environmental neutrals. The high income respondents entail keen environmentalists, environmental cynics, and environmental neutrals. The inherent significant variations in preferences for environmentally sustainable attributes across segments and income groups would help in formulating feasible and segment-specific environmental sustainability policies and marketing strategies aimed at changing consumers' attitudes towards environmentally sustainable products. Demographic targeting of consumer segments, sustainability awareness, and segment-specific educational campaigns meant to enhance subjective and objective knowledge of environmental sustainability are important tools for food companies and agribusinesses to promote and market environmentally sustainable food products.

Keywords: Carbon footprint; heterogeneity; preferences; water footprint; South Africa; sustainable food products

1. INTRODUCTION

In recent years, the evaluation of consumers' preferences for environmentally sustainable-labelled food products is gaining particular attention, especially in developed countries (Grebitus, Steiner & Veeman, 2015; Grebitus, Steiner & Veeman, 2016; Peschel, Grebitus, Steiner & Veeman, 2016). Carbon and water footprint sustainability attributes are receiving much prominence in the food sector (Grebitus et al., 2016; Peschel et al., 2016). The interest in these environmental sustainability attributes is triggered by the association between the production and consumption of agricultural food products and the effects of these activities on the environment and water resources (IPCC, 2007). More emphasis has been placed on the food and agricultural sector because it has been recognised as a major consumer of the available scarce water resources, utilising about 86% of all global freshwater (International Water Management Institute, 2007). Additionally, the agricultural sector, in general, is known to account for about 30-35% of the global GHG emissions (Foley et al., 2011).

Population growth, climate change, pollution, industrialisation and urbanisation place further stress on semi-arid and arid countries fresh water sources and the environment as a whole (Backeberg & Reinders, 2009). Water and carbon footprint sustainability assessment across various sectors of the economy is gaining much attention, because the current water scarcity situation and environmental effects in developing economies such as South Africa poses threat to human survival and sustainable development (Department of Environmental Affairs, 2015). Therefore, governments, policymakers and researchers are interested in knowing how environmentally sustainable attributes and information will change consumers' and producers' sustainability behaviour. Managers of private food companies and agribusinesses are interested in knowing whether there are segments of consumers who have an interest in environmentally sustainable products, as well as identifying the drivers of consumers' decisions to purchase these products. Sustainability attributes such as carbon and water footprint labels have significant impacts on consumers' preferences and choice behaviour (Grebitus et al., 2016: 2015). An understanding of consumers' behaviour towards environmental sustainability attributes provides vital information for formulating sustainability policies and marketing strategies (Hoekstra, Chapagain, Aldaya & Mekonnen, 2011; Leach et al., 2016). Such information assists in minimising the increasing pressure on the environment, water resources and agri-food production systems.

Despite the relevance of understanding consumers' preferences and choice of environmentally sustainable attributes, existing studies have focused only on developed countries (Grebitus et al., 2016; Leach et al., 2016; Peschel et al., 2016), with no such studies in arid and semi-arid regions of Africa, including South Africa, where water scarcity and climate changes pose serious threats to the livelihoods of people. Therefore, current knowledge is insufficient to understand how South African consumers will react to changes in water and carbon sustainability attributes and policy changes. Lack of information on consumers' behaviour towards water and carbon sustainability attributes has led to a lack of connection and understanding between consumers' purchasing behaviour and environmental footprint labelling in South Africa. Stakeholders in the food industry are uncertain as to whether consumers might change their consumption patterns to a more sustainable option.

Therefore, the main objective of the study was to assess consumers' preferences for water and carbon footprint sustainability attributes, as well as the drivers influencing consumers' preferences for environmental sustainability attributes. Particular emphasis is placed on identifying consumers' preferences for environmentally sustainable products from the viewpoint of low and high income classes in South Africa. This will help in identifying specific environmental sustainability policies for low income- and high income-dominated communities and markets. Additionally, the preliminary likelihood ratio test results revealed that data from low and high income sub-samples could not be pooled together (Wooldridge, 2002). The main hypothesis tested in this study is that preferences for environmentally sustainable products differ significantly among low and high income consumers in South African. Secondly, it was hypothesised that consumers have heterogeneous preferences for water and carbon footprint sustainability attributes. Thirdly, it was hypothesised that consumers' trust in food labelling regulatory bodies, awareness, and knowledge of environmental sustainability all impact positively on choices of sustainable food product attributes. It is believed that the findings from this study will guide food companies and policymakers to understand how and which categories of South African consumers might change their consumption patterns to be more sustainable. Furthermore, an understanding of consumers' sustainability behaviour helps in identifying possible markets for sustainable food products (Grebitus et al., 2015). To the best of the authors' knowledge, this will be one of the first studies to evaluate consumers' attitudes towards environmental footprints and sustainability attributes from an African perspective and also from the viewpoint of different income classes. The next section presents a relevant literature review, followed by the study methodology. The results and discussions are presented in section four. Conclusions are provided in the final section.

2. LITERATURE REVIEW

The concept of carbon and water footprints is well grounded in two internationally recognised approaches. Firstly, carbon and water footprint assessment is well-rooted in the LCA approach as described in ISO standards 14040, 14044 and 14046 (ISO, 2006:2014). The second concept of assessing water footprints, which has been gaining much attention in recent years, is the Global Water Footprint Standard of the Water Footprint Network (Hoekstra et al., 2011).

The amount of greenhouse gasses emitted along a product's lifecycle is referred to as the carbon footprint (ISO, 2006). The water footprint assessment quantifies the amount of fresh water utilised in the production of a particular product (Hoekstra et al., 2011). Consumers have in recent years become more conscious of the inadvertent negative implication of food production on the environment and water resources (Leach et al., 2016). Although consumers are conscious about and understand the unintended implications of food production on water resources and the environment, sustainability attributes such as the amount of carbon emitted and the water used in the production of a particular product cannot be substantiated at the point of sales or shops (Darby & Karni, 1973). However, these credence attributes can be converted into search attributes through the use of carbon and water footprint sustainability labels (Peschel et al., 2016). Nonetheless, current food labels focus on nutritional, best-before dates, country of origin, health claims, animal welfare and Fair Trade labels, with no or little emphasis on carbon and water footprint sustainability information.

In the agricultural sector, some authors have assessed carbon footprint labelling in respect of exports of agricultural products (Edwards-Jones, Plassmann, York, Hounsome, Jones & Canals, 2009) and legal issues concerning carbon labelling (Cohen & Vandenbergh, 2012). In terms of preference, Shumacher (2010) evaluated consumers' preferences for ecological labelling and found that consumers who are price conscious prefer products with a low carbon footprint. A recent study by Peschel et al. (2016) revealed that a consumer's decision to purchase environmentally sustainable products in Germany and Canada hinges on his or her subjective and objective knowledge level. Grebitus et al. (2015) found that human values are highly relevant in understanding consumers' behaviour and preferences for carbon and water footprint-labelled products. Grebitus et al. (2016), in their cross-cultural analysis of preferences for food and non-food products with carbon and water footprint sustainability labels, revealed that consumers are highly heterogeneous in their preferences for sustainability attributes, regardless of their ethnic background. This implies that preferences for carbon and water footprint labels vary from country to country.

As highlighted by Grebitus et al. (2016: 2015), consumers' choice of carbon and water footprint-labelled products is highly heterogeneous, with varying human systems from country to country and culture to culture. However, the existing literature (Grebitus et al., 2013: 2015: 2016; Peschel et al., 2016; Schumacher, 2010; Upham, Dendler & Bleda, 2011; Van Loo, Caputo, Nayga, Seo, Zhang & Verbeke, 2015) have not explore the sustainability behaviour and preferences among low and high income consumers. Therefore, there is a gap in the literature on consumers' behaviour and their choices of environmentally sustainable products, especially in the context of different classes. The present paper contributes to the existing knowledge and the current debate on environmentally sustainable food products by assessing consumers' preferences for water and carbon footprint sustainability attributes using choice experimental data from different income groups in South Africa.

3. METHODOLOGY

3.1. CONCEPTUAL FRAMEWORK AND EMPIRICAL STRATEGY

The present paper follows the random utility theory, which assumes that consumers are rational and prefer products that give them the highest utility (Hensher & Greene, 2003; McFadden, 1974). Notably, consumers often choose product alternatives that offer them the highest utility on any given choice scenario. The underlying assumption of the random utility is that consumers tend to have heterogeneous preferences for product attributes. Assuming that a given product attribute is made up of both observable and unobservable components, the utility of the consumer can be stated empirically as:

$$U_{jt} = V_{jt} + \mu_{jt} \quad (5.1.1)$$

where U_{jt} is the latent unobservable utility for the j^{th} alternative in the choice scenario; V_{jt} is the observable systematic portion of utility determined by the attributes, and μ_{jt} is the random component of the utility, which is independently and identically distributed over all alternatives and choice scenarios. The probability that the consumer selects environmentally sustainable labelled product alternative *j* is given by:

$$\begin{aligned} Pr(j \neq f \ \forall \in N) = Pr(\beta_1 X_{j1} + \beta_2 X_{j2} + \ldots \\ + \beta_n X_{jn} + \mu_j \geq \beta_1 X_{f1} + \beta_2 X_{f2} + \ldots + \beta_n X_{fn} + \mu_f) \end{aligned} \quad (5.1.2)$$

where *N* is the total set of alternatives of the selected products available to the consumer, *Xjn* is the *nth* attribute for alternative *j*, and β_n is a vector of parameters associated with the *nth* attribute of the *jth* alternative.

In this paper, the latent class (LC) model was employed to account for heterogeneity at segment level. Some authors have employed mixed logit models (Grebitus et al*.,* 2015: 2016) and the inclusion of interaction variables in conditional logit models (Birol, Hanley, Koundouri & Kountouris, 2009) to address unobserved preference heterogeneity for environmental attributes. However, the former approach becomes useful in continuous distributions (Green & Hensher, 2003), whilst the latter has been statistically sub-optimal (Birol et al*.,* 2009). The latent class model becomes appropriate when preference heterogeneity is better explained at the segment level. The latent class approach helps to identify different consumer segments for which specific policies can be designed. Specifically, consumers are assumed to be organised implicitly into a set of Z classes. The class to which the consumer belongs to hinges on the consumer's observed personal, social, economic, perceptive, attitudinal and behavioural factors. If consumer i faces a discrete choice among J_i alternative products in Q_i choice situations, the probability that the consumer i chooses alternative J in choice situation q in class z is represented as:

$$\mathrm{Pr}_{jiq/z} = \frac{\exp(x'_{iq,j}\beta_z)}{\sum_{j=1}^{J_i}\exp(x'_{iq,j}\beta_z)} = F(i, q, j/z) \qquad (5.1.3)$$

Since the choice sets vary by choice situations, we denote the specific choice made by the consumer as Y_{iq} , and express its probability as:

$$P_{iq/z}(j) = \mathrm{Pr}(Y_{iq} = j / \text{class} = z) \qquad (5.1.4)$$

Given that Q_i choices are independent in the class assignment (Hensher & Greene, 2003); the contribution of consumer i to the likelihood function is the joint probability of $Y_i = [Y_{i1,} Y_{i2,} ......Y_{iQ}]$. Simplifying equation (4) further leads to:

$$P_{i/z} = \Pi_{q=1}^{Q_i} P_{iq/z} \qquad (5.1.5)$$

Since the class assignment is not known to the analyst prior to the study, the probability that consumer i belongs to class *z* is denoted by M_{iz} and this is specified as:

$$M_{iz} = \frac{\exp(x'_i\lambda_z)}{\sum_{z=1}^{Z}\exp(x'_i\lambda_z)}, z = 1, ...Z, \lambda_Z = 0 \qquad (5.1.6)$$

where x_i is the set of observable characteristics that forms the class membership estimates of the model, and the Z[th] parameter vector is standardised to zero to secure identification of the model and compare the remaining classes relative to it. The log likelihood function for sampled respondents is expressed as:

$$\ln L = \sum_{i=1}^{N} \ln P_i = \sum_{i=1}^{N} \ln\left[\sum_{z=1}^{Z} M_{iz}\left(\prod_{q=1}^{Q_i} P_{iq/z}\right)\right] \quad (5.1.7)$$

The log likelihood is maximised with respect to the Z structural parameter vectors, β_z and Z-1 latent class membership parameter vectors, λ_z is a conventional problem in maximum likelihood estimation.

3.2. SAMPLING AND DATA DESCRIPTION

The survey was conducted in the Gauteng province of South Africa using trained interviewers. Gauteng is the most populous province in South Africa and very diverse in terms of social, economic and demographic characteristics (Statistics South Africa, 2012). This allowed for high representation in the data. Specifically, the data was collected from Centurion, Pretoria and Midrand (Johannesburg). The data consisted of 47.3% Blacks, 43.3 % White, 16% Coloured and 2% Indians, and thus, showing that the data have a representation of all the different racial groups in South Africa. Multistage sampling procedure was employed to sample 402 meat consumers from households. The study was conducted in Centurion located between Pretoria and Midrand (Johannesburg).

The survey focussed on meat buyers, with particular reference to beef because beef is one of the meat products extensively purchased and, as such, it was easy to find more respondents. Also, the water footprints of beef products in South Africa are considered to be large in some regions, relative to the global averages (Mekonnen & Hoekstra, 2010; Owusu-Sekyere et al., 2016). Prior to the data collection, the survey instrument was pre-tested amongst 15 respondents in the selected supermarkets. Face-to-face interviews were conducted in the selected markets using samples of the labelled products. The surveyed sample consisted of 402 meat consumers. Out of this, 150 were sampled from Midrand, 120 from Centurion and 132 from Pretoria. The response rate for the survey was 75%. The questionnaire consisted of both closed and open-ended questions, as well as Likert scale-type questions. The questionnaire focused on the choice experiment, respondent's socioeconomic characteristics, knowledge of environmental sustainability and attitudinal data. We initially assessed respondents' subjective and objective knowledge of environmental sustainability before the choice experiment. The assessment of subjective and objective knowledge followed the approach of Brucks (1985).

3.3. CHOICE EXPERIMENTAL DESIGN

In line with recent studies, the attribute-based choice experiment was employed in this study (Grebitus et al., 2015: 2016). The choice experiment allows respondents to choose from a set of varying product alternatives with a different combination of product attributes. Respondents' preferences and the evaluation of the attributes can be revealed based on their preferred choices without subjectively asking them to value the product attributes. This, according to Norwood and Lusk (2011), helps to minimise social desirability bias. The choice experiment consisted of different combinations of water usage (water footprint), carbon emissions (carbon footprint) and prices. Different choice sets were designed for beef and milk. The water footprint values were obtained from the estimates (Owusu-sekyere et al., 2016; Mekonnen & Hoekstra, 2010). The carbon equivalents were obtained from Milk South Africa (Milk SA) and Scholtz et al. (2014). The selected prices considered for the products were the mean observed prices for beef rump steak and fresh full-cream milk without carbon and water footprint labels in the selected shops, with standard deviations of plus and minus one (Grebitus et al., 2013: 2015).

Specifically, water footprint, carbon footprint and price attributes had three levels in the choice sets designed for beef and milk (see Table 5.1). The choice set and survey instrument are presented in appendix A. The attributes and their levels were combined using Ngene software to create random parameter panel-efficient design with three alternatives (A, B and "none") (Choice Metrics, 2014). D-error efficiency and blocking strategy were also used during the design. The blocking strategy circumvents respondent fatigue during the survey. Twenty choice sets were generated using the Ngene software and blocked into 10, with each block containing two choice sets. Each person was randomly allocated to a block. Since the concept of carbon and water footprint is new, there was a possibility that some respondents would not have been aware of water and carbon footprints. Hence, statements explaining the carbon and water footprints, their measurements and the meaning of the footprint values were explained to respondents in their local and preferred language prior to the survey (See

Appendix 5B). These statements were approved by the Water Research Commission (WRC) of South Africa prior to the survey. The choice data was estimated using NLOGIT 5.

Table 5.1: Attributes and their level in the choice experiment

Attribute	Beef rump steak	Fresh full cream milk	Categorical level
	Levels	Levels	
1. Water footprint	1. 15415 l/kg 2. 17300 l/kg 3. 17387 l/kg	1. 1020 l/kg 2. 1025 l/kg 3. 1030 l/kg	Low Medium High
2. Carbon footprint	1. 22.90 $kgCO_2e$ 2. 26.37 $kgCO_2e$ 3. 27.50 $kgCO_2e$	1. 1.3 $kgCO_2e$ 2. 1.5 $kgCO_2e$ 3. 1.9 $kgCO_2e$	Low Medium High
3. Price	1. ZAR 159.99/ kg 2. ZAR 179.99/ kg 3. ZAR 185.00/ kg	1. ZAR 11.98/l 2. ZAR17.45/l 3. ZAR20.00/l	Low Medium High

4. RESULTS AND DISCUSSIONS

4.1. DESCRIPTIVE RESULTS

Descriptive statistics of variables included in the model are presented in Table 5.2. The mean age for the pooled sample – low and high income sub-samples – was found to be about 35 years. This is in accordance with Stats SA's population estimates, which reveal that about 66% of the South African population are aged approximately 35 years or less (Stats SA, 2014). The mean years of formal education for the pooled sample were about 15 years, while that of the low and high income respondents was found to be 14 and 15 years, respectively. In terms of income, the mean monthly income for the pooled sample was found to be ZAR 10 132.24. The monthly income of the high income respondents was ZAR 2 244.08 higher than that of the low income respondents. The average household size of the low income respondents was four, while that of the high income respondents was 3. Most of the respondents were females, and the majority were married. About 53.50% of the respondents were aware of the Department of Water and Sanitation's campaign on current and future threats pose by climate change in South Africa. In terms of respondents' subjective and objective knowledge regarding environmental sustainability, the results reveal that the average subjective knowledge (SUBKI) and objective knowledge (OBJKI) indexes for the pooled sample were 3.41 and 2.68, respectively. This implies that respondents consider themselves as moderately knowledgeable about environmental sustainability. The subjective knowledge index for low income respondents was 2.81, compared with 3.33 for the high income respondents. This suggests that the subjective knowledge of the high income respondents concerning environmental sustainability was higher than that of the low income respondents. However, the values indicate that both low and high income respondents had moderate subjective knowledge levels.

Table 5.2: Descriptive statistics of respondents' socioeconomic characteristics

Variable	Description	Low income (n=252)	High income (n=150)	Pooled (n=1809)
		Mean (SD)	*Mean (SD)*	*Mean (SD)*
Age	Years	38.01(11.38)	38.17(11.67)	38.08(11.51)
Education	Years of formal education	14.05(2.34)	15.34(2.26)	15.08(2.31)
Income	Monthly income in ZAR	9721.03(99.83)	11965.11(58.96)	1013.24(43.98)
Household size	Number of people in respondent's household	4.04(1.76)	3.30(1.42)	4.01(1.73)
Subjective knowledge index (SUBKI)	Subjective knowledge about environmental sustainability	2.81(1.04)	3.33(0.95)	3.41(1.00)
Objective knowledge index (OBJKI)	Objective knowledge about environmental sustainability	2.38(1.04)	2.97(0.91)	2.68(1.10)
Variable	Description	*Percentage*	*Percentage*	*Percentage*
Female	1 if female, 0 otherwise	64.90	71.30	67.70
Marital status	1 if respondent is married, 0 otherwise	54.10	56.30	52.20
Awareness	1 if respondents is aware of the Department of Water and Sanitations campaign on climate changes	50.40	55.40	53.50
Trust	1 if respondent trust in food labelling regulatory bodies	65.77	75.60	73.44

Similarly, the objective knowledge of the low income respondents (2.38) was less than that of the high income respondents (2.97). Generally, subjective knowledge levels were higher than objective knowledge levels. This implies that what respondents think they know is higher than what is actually true about environmental sustainability. This concurs with the findings of Peschel et al. (2016). An analysis of the correlation between the constructs reveals that they are only slightly correlated with Pearson's correlation coefficients of r =0.13 and r =0.15 for the low and high income group, respectively at 5% level.

4.1. *EMPIRICAL RESULTS*

Prior to the empirical estimations, the likelihood ratio test was employed to formally test whether the data from low and high income respondents could be pooled together (Wooldridge, 2002). The test results reveal that the data from the two sub-samples could not be pooled together and hence the empirical results are presented separately. The Ben-Akiva and Swait (1986) test for comparing non-nested probabilistic choice models revealed that the latent class model best fits the data, relative to the mixed logit model. The results of the mixed logit are presented in Appendix 5A. Heterogeneity in the current data is better explained at segment level. The results of the latent class model are thus presented. Using the selection criteria of McFadden (ρ^2), AIC and BIC, the four-latent class model was found to be optimal for the low income sample, whereas the three-latent class model was found to be optimal for the high income sample. The results for both product and respondent categories reveal the existence of significant heterogeneity in terms of preferences for water usage, carbon emission and price across latent classes, as indicated by differences in magnitude, direction and significance of the utility function estimates. This supports the recent findings of Grebitus et al. (2015). Furthermore, the results for both sub-samples show that price is significantly negative in all the classes, as expected, with varying utilities. This means that all the consumer classes are sensitive to price and consider price as a relevant attribute in their decision to purchase environmentally sustainable food products.

4.1.1. *LATENT CLASS ESTIMATES FOR BOTH PRODUCT CATEGORIES AMONG LOW INCOME CONSUMERS*

The results from the four-latent class model for the low income respondents are presented in Table 5.3. The results are presented for beef rump steak and full-cream milk. For beef rump steak, the largest class was found to be class one. This class consists of 51.20% of the low income respondents. Members of this class obtain significantly negative utility from water usage (water footprint), but insignificant utility from carbon emissions (carbon footprint). This implies that the higher the water usage for beef production, the lower the preference from members of this class. This class is labelled as “water sustainability advocates”. The second largest class was found to be class two with 26.90% of the low income respondents. Members of this class obtain negative utility from carbon emissions (carbon footprint) and the no-choice option, but insignificant utility from water usage (water footprint). This suggests that the higher the carbon emitted during beef production, the lower the preference for the product from members of this class. This class is labelled as "carbon reduction advocates". The negative estimate of the no-choice option (none) implies that respondents in this segment prefer to select one of the product options rather than the no-choice option. This means that respondents' utility will be reduced if the preferred product option is not presented.

The next largest class was found to be class three, accounting for 13.40% of the low income respondents. Members of this class obtain negative utilities from water and carbon footprint variables and the no-choice option. The negative coefficient estimates for water and carbon footprint variables imply that members of this class have a lower preference for beef products with high water usage and carbon emission. Respondents in this class prefer to select one of the product options rather than the no-choice option (none). Therefore, members of this class are considered as "keen environmentalists". Class four consists of only 8.40% of the low income respondents. Members of this class obtain positive utility from the no-choice option, implying that members of this class prefer to choose a beef product without carbon and water footprint information. Members of this class are regarded as "environmental neutrals" because their class membership estimates are normalised.

Table 5.3: Latent class results for low income consumers

Attributes	Beef rump steak				Fresh full cream milk			
	Class 1	Class 2	Class 3	Class 4	Class 1	Class 2	Class 3	Class 4
Water footprint	-2.99** (0.27)	-7.14(6.41)	-8.68***(0.98)	1.64(1.23)	-4.17***(0.61)	-2.85(3.33)	-3.20***(1.03)	2.58(1.99)
Carbon footprint	-0.96(0.65)	-2.97***(0.43)	-2.63***(0.33)	0.89 (0.95)	-4.56(3.44)	-9.12**(4.29)	-1.79**(0.76)	5.22(4.50)
None	-0.23(0.75)	-1.10***(0.01)	-1.94***(0.29)	1.24* (0.74)	-2.69(3.04)	-4.16**(1.61)	-1.02*(0.53)	-6.66***(0.93)
Price	-0.15***(0.01)	-0.17** (0.07)	-0.39***(0.05)	-0.24***(0.03)	-0.18***(0.02)	-0.56***(0.12)	-0.16***(0.02)	-0.99***(0.15)
Class share	**51.20%**	**26.90%**	**13.40%**	**8.40%**	**36.00%**	**33.8%**	**19.20%**	**11.00%**
Class membership estimates								
Constant	1.34***(0.40)	0.70(0.49)	-0.46 (0.38)		3.88(3.80)	0.69(0.45)	-0.92***(0.38)	
Age	-0.76**(0.38)	0.17(0.62)	0.08***(0.01)		-0.48***(0.14)	0.14 (0.48)	0.30***(0.07)	
Female	0.56**(0.23)	-0.17***(0.04)	0.17(0.62)		0.65**(0.27)	-0.56**(0.23)	0.39(0.58)	
Marital status	1.09(0.96)	1.23(1.72)	0.89***(0.13)		0.02 (0.63)	0.34 (0.83)	0.29**(0.15)	
Education	0.83* (0.49)	0.23*(0.69)	0.56**(0.23)		0.70**(0.33)	0.57*(0.31)	0.18***(0.04)	
Household size	0.56(0.43)	0.15 (0.78)	0.74*** (0.25)		0.07(0.11)	0.13(0.16)	0.29***(0.08)	
Income	0.16**(0.08)	0.62(0.80)	0.19**(0.08)		0.37*(0.19)	0.16(0.27)	0.42**(0.07)	
Awareness	0.23*(0.07)	0.08***(0.02)	0.12***(0.03)		0.44***(0.13)	0.63***(0.16)	0.91***(0.17)	
Trust	0.11(0.08)	0.12(0.09)	0.09***(0.03)		0.14 (0.13)	0.23(0.16)	0.21***(0.04)	
SUBKI	-0.32*** (0.08)	1.07(0.99)	0.11*** (0.01)		-0.18*(0.05)	0.66(0.96)	0.29***(0.05)	
OBJKI	-0.11*** (0.02)	0.77(0.52)	0.06*** (0.01)		-0.16**(0.07)	0.13 (0.37)	0.09***(0.02)	
Diagnostic statistics	LL= -509.36; AIC=1048.72; BIC=1135.66 Pseudo-R^2=0.72; McFadden (ρ^2)=0.22				LL= -467.95; AIC=963.90; BIC=1043.57 Pseudo-R^2=0.70; McFadden (ρ^2)=0.21			

For full-cream milk, the results further reveal class one as the largest, consisting of 36% of the low income respondents. This segment obtains significantly negative utility from the water footprint variable. This indicates that members of this class have a significantly lower preference for milk products with high water usage. Consistently, this segment of respondents is also referred to as "water sustainability advocates". The second class consists of 33.80% of the low income respondents. Members of this segment obtain negative utility from high carbon footprint values, implying that members of this class have a lower preference for milk products with a high carbon emission, but insignificant utility from the water footprint. Therefore, this class is referred to as "carbon reduction advocates". Additionally, members of this class attain significantly negative utility from the no-choice option (none).

Class three was found to be the third largest class with 19.20% of the low income respondents. The utility estimates show that members of this class attain negative utility from high water usage and carbon emission. This means that members of this segment have a negative preference for milk products with high water and carbon footprints. Members of this segment have a negative preference for milk products without water and carbon footprint information, as indicated by the significantly negative utility estimate for the no-choice option. Hence, members of this class are referred to as "keen environmentalists". Finally, the fourth class consists of 11% of the low income respondents. Positive utility is attained from the no-choice option (none) by members of this segment. Members of this class are referred to as "environmental neutrals".

The class membership estimates were discussed together for both product categories. The class membership estimates show that respondents in class one are more likely to be females with high levels of formal education and income – a result consistent with that of Peschel et al. (2016) who found that females are more likely to be interested in products with low water usage. Class one members are also more likely to be aware of the Department of Water and Sanitation's campaigns on threats posed by climate change, relative to class four. Respondents in this class are less likely to be older individuals, with low subjective and objective knowledge of environmental sustainability, compared with class four. This is indicated by the negative coefficient of age, subjective knowledge and objective knowledge variables.

Respondents in class two are less likely to be females. This is contrary to the findings of Peschel et al. (2016). Members of this class are more likely to have high education and awareness levels, compared to class four. This is contrary to the findings of Grebitus et al. (2015) who found no significant influence of education and gender on preferences for carbon footprint attributes. Class three members, on the other hand, are more likely to be older individuals who are married with large household sizes, as indicated by the significant positive parameter estimates for age, marital status and household size variables. Members of this class are also more likely to have high education and income levels. The significantly positive parameter estimates for the awareness variable indicates that members of this class are more likely to be aware of the Department of Water and Sanitation's campaigns on climate threats, compared with class four. Class three members also have trust in food labelling regulatory bodies, relative to the fourth class. Furthermore, members of class three are more likely to have high subjective and objective knowledge of environmental sustainability, compared with class four.

Class membership estimates for the fourth class were normalised to zero and the remaining classes were discussed relative to that. Therefore, class membership estimates are not presented for class four. The McFadden (ρ^2) statistics of 0.22 and 0.21 for beef and milk, respectively indicate that the models are satisfactory (Hensher, Rose & Greene, 2005).

4.1.2. LATENT CLASS ESTIMATES FOR BOTH PRODUCT CATEGORIES AMONG HIGH INCOME CONSUMERS

Table 5.4 presents the latent class results for the high income sample, and for both products. For beef rump steak choices, class one was found to be the largest; accounting for 56% of the respondents. The utility estimates for water footprint, carbon footprint and no-choice (none) were significantly different from zero and negative. This means that the preference of class one members for beef products is reduced if water usage and carbon emissions are high. Members of this class prefer to choose one of the product options with water and carbon footprint labels, rather than the no-choice option (none). Hence, class one members are labelled as "keen environmentalists".

Class two constitutes the second largest segment, consisting of 25.10% of the high income respondents. Members of this class have no significant preference for water footprint and carbon footprint attributes. However, they obtain positive utility from the no-choice option attribute. This means that members of this segment prefer beef products with no water and carbon footprint labelling. Therefore, this class is referred to as “environmental cynics”. Class three accounts for 18.90% of the respondents. Members of this class obtain negative utility only from the water footprint attribute. This suggests that the preference for beef products is reduced when the product has a high water footprint value. Class three is regarded as “environmental neutrals” since their class membership estimates are normalised.

For full-cream milk choices, the results show that class one consists of 56.50% of the respondents. Water footprint, carbon footprint and no-choice (none) variables were significantly different from zero and negative. Members of this class are also considered to be “keen environmentalists”. Class two accounts for 32.80% of the high income respondents. Members of this class have a significantly positive preference for milk products without water and carbon footprint labels, but an insignificant preference for water and carbon footprint-labelled milk. Class two members are labelled as “environmental cynics”. Finally, class three consists of 10.70% of the respondents. Members of this class also obtain negative utility from water usage (water footprint) only and are labelled as “environmental neutrals”.

The class membership estimates show that for both product categories, class one members are more likely to be older and married individuals with high education and awareness levels, relative to class three. Members of this class have trust in food labelling regulatory bodies. Also, class one members are more likely to have high subjective and objective knowledge of environmental sustainability, relative to class three. Members of class two are less likely to be older individuals with low income levels, compared with class three. Members of this segment are likely to be females with large household sizes. The negative parameter estimates of the subjective knowledge index (SUBKI) and objective knowledge index (OBJKI) means that members of this class have low subjective and objective knowledge of environmental sustainability, relative to class three. These members are less likely to trust food labelling regulatory bodies.

Class membership estimates for the third class are not presented. The McFadden (ρ^2) statistics of 0.23 and 0.22 for both product categories indicate that the models are fit.

Table 5.4: Latent class results for high income consumers

Attributes	Beef rump steak			Fresh full cream milk		
	Class 1	Class 2	Class 3	Class 1	Class 2	Class 3
Water footprint	-79.56***(6.71)	-5.46(3.44)	-0.64***(0.20)	-13.04**(6.25)	-3.61(4.89)	-2.61***(0.19)
Carbon footprint	-11.66***(3.12)	-1.08(0.88)	0.44(0.34)	-7.45**(3.04)	-0.13(2.31)	3.80(8.09)
None	-3.20*** (0.66)	7.23***(0.69)	-0.14 (0.70)	-3.02***(0.35)	8.91***(1.49)	-0.09 (0.97)
Price	-3.30***(0.05)	-0.23*** (0.03)	-0.08***(0.01)	-2.41**(0.96)	-0.34***(0.01)	-0.57***(0.15)
Class share	**56%**	**25.10%**	**18.90%**	**56.50%**	**32.80%**	**10.70%**
Class membership estimates						
Constant	-1.60***(0.24)	-2.11***(0.29)		-1.81***(0.23)	-15.26***(5.27)	
Age	0.32**(0.12)	-0.67***(0.22)		1.05***(0.11)	-0.79**(0.29)	
Female	-0.21(0.13)	0.17***(0.04)		-0.07(0.54)	0.56*(0.33)	
Marital status	0.49*(0.26)	-1.23(1.72)		1.06*(0.63)	-0.10(0.47)	
Education	0.52**(0.20)	1.33(0.99)		0.15**(0.07)	-1.44(0.98)	
Household size	0.36(0.33)	0.45**(0.18)		0.35(0.34)	0.16**(0.08)	
Income	0.52 (0.41)	-0.42**(0.20)		1.45(1.49)	-0.35*(0.18)	
Awareness	0.36***(0.12)	0.65(0.41)		0.57***(0.18)	-0.38**(0.19)	
Trust	0.20***(0.02)	-0.37**(0.19)		0.23**(0.09)	-0.43**(0.17)	
SUBKI	0.24*** (0.04)	-0.06**(0.02)		0.54*** (0.13)	-0.16(0.12)	
OBJKI	0.30**(0.13)	-0.37***(0.11)		0.35***(0.10)	-0.26***(0.09)	
Diagnostic statistics	LL= -514.80; AIC=1051; BIC=1251.98 Pseudo-R^2=0.73; McFadden (ρ^2)=0.23			LL= -480.23; AIC=988.46; BIC=1070.55 Pseudo-R^2=0.66; McFadden (ρ^2)=0.22		

4.1.3. RELATIVE IMPORTANCE OF THE ATTRIBUTES FOR DIFFERENT PRODUCTS AMONG LOW AND HIGH INCOME RESPONDENTS

The relative importance ratings of the sustainability attributes presented in Figure 5.1 are for both products among the low income consumers. From Figure 5.1A & 5.1B, water footprint was rated as the most important attribute for low income consumers' beef choices among the water sustainability advocates. This attribute accounts for 56% of the variation. Among the carbon reduction advocates, carbon footprint accounted for 48% of the variance. The keen environmentalists rated both water footprint and carbon footprint attributes highly, as these attributes account for 46% and 40% of the variations, respectively. For the environmental neutrals, price was rated as the most important attribute, accounting for about 58% of the variation. For the low income consumers' milk choices, water footprint attribute accounted for 54% of the variation among the water sustainability advocates. The carbon footprint attribute accounted for 50% of the variance in the carbon reduction advocates' segment. Water footprint and carbon footprint attributes explained 47% and 44% of the variation respectively among the keen environmentalists. Lastly, environmental neutrals rated price as the most important attribute, explaining 48% of the variance.

Beef rump steak

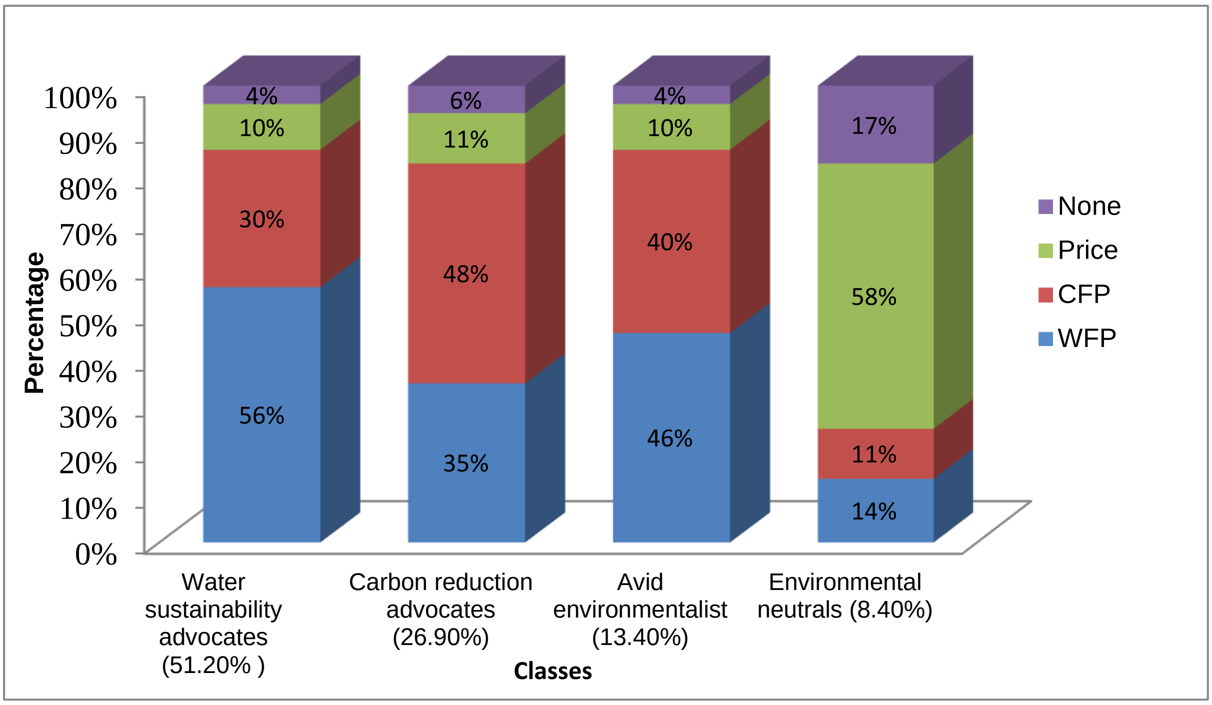

Figure 5.1.5.1A – Low income consumers' relative importance ratings of attributes for beef

Fresh Full Cream Milk

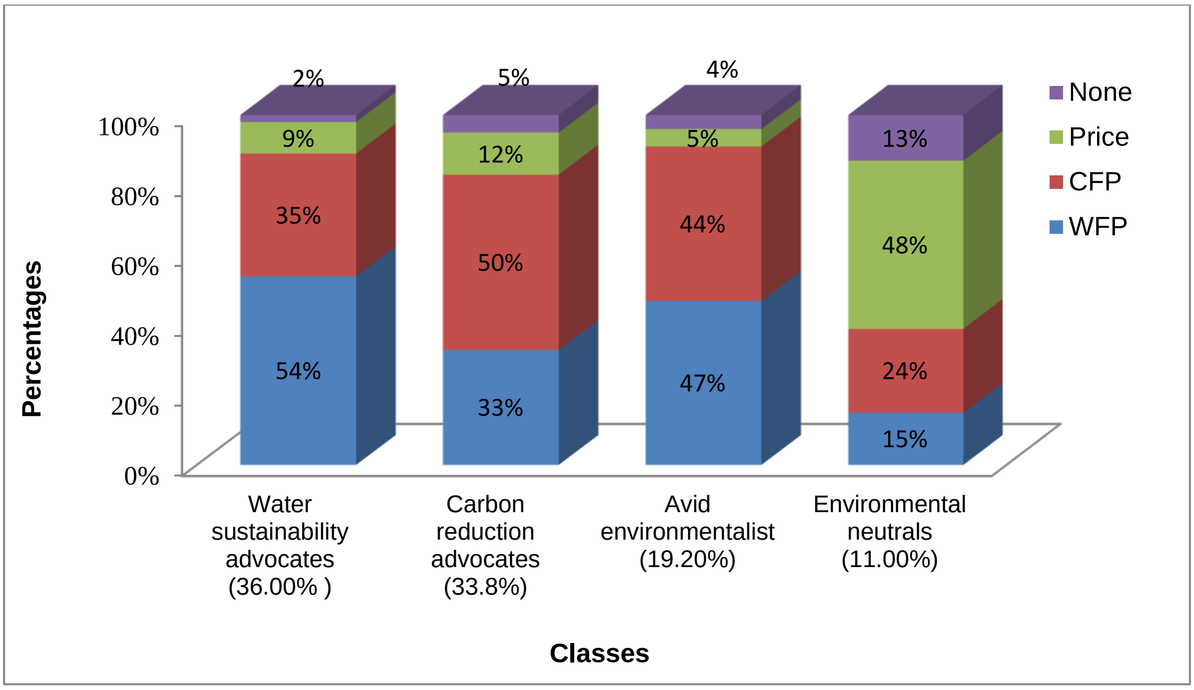

Figure 5.2.5.1B – Low income consumers' relative importance ratings of attributes for milk

Figures 5.2A & 5.2B present high income consumers' relative importance ratings of the attributes. The figure shows that both water footprint and carbon footprint attributes account for 91% of the variation among the keen environmentalist for high income consumers' beef choices. Specifically, the water footprint variable accounted for 58% of the variance, whereas carbon footprint accounted for 33%. For the environmental cynics, the most important attribute was price, as it accounted for 54% of the variance. Within the environmental neutrals segment, price also accounted for 38% of the variance. For milk choices, keen environmentalists further rated the water footprint attribute as most important, responsible for 56% of the variance. Environmental cynics considered price as the most important attribute, explaining 49% of the variance. Lastly, environmental neutrals rated price as the most important attribute, with 40% variation explained by this attribute.

Beef rump steak

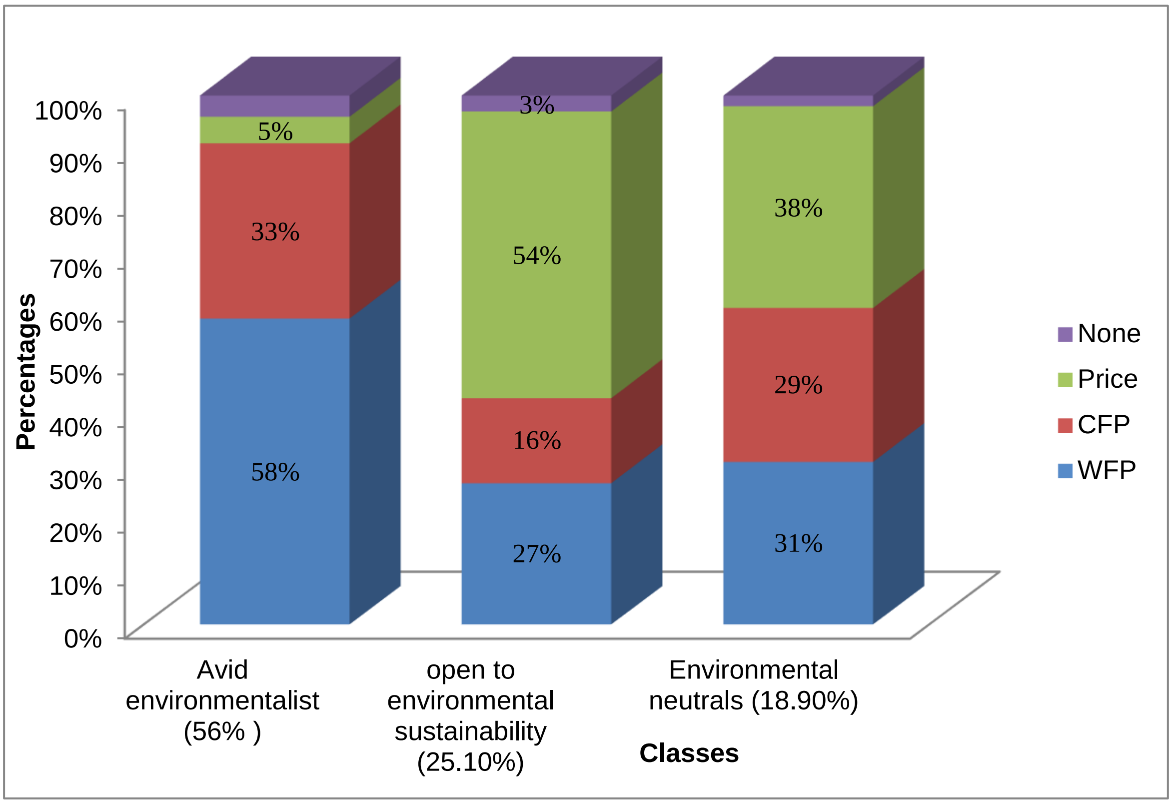

Figure 5.3.5.2A – High income consumers' relative importance ratings of beef attributes

Fresh Full Cream Milk

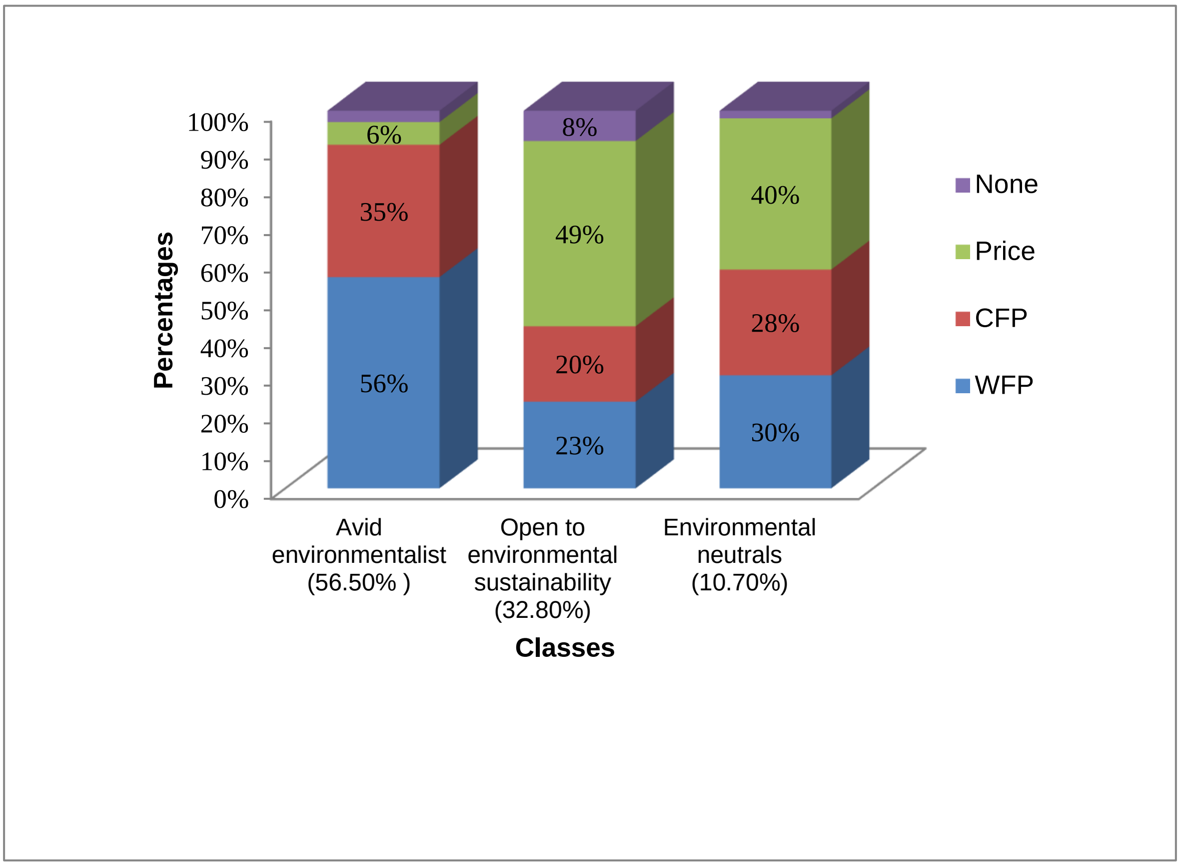

Figure 5.4.5.2B – High income consumers' relative importance ratings of milk attributes

5. CONCLUSIONS

The core objective of this research was to assess preferences for water and carbon footprint sustainability attributes from the viewpoint of different income categories in South Africa. The study also determined how socioeconomic characteristics, awareness, trust and environmental sustainability knowledge levels impact on consumers' choice of water and carbon footprint-labelled food products. A latent class modelling technique was employed for attribute-based choice experimental data from beef and milk consumers. Based on the findings, it is concluded that consumers' preferences for environmentally sustainable food products vary significantly between low and high income groups in South Africans. Different latent classes were found for both product categories among low and high income respondents.

Secondly, it was concluded that preference heterogeneity exists for water usage and carbon emission during beef and milk production among low and high income respondents. Additionally, heterogeneity in preferences exists for beef and milk products without water and carbon footprint labelling information. The heterogeneity in preferences found for the sustainability attributes was better explained at segment level, relative to individual level. This implies that future research on consumers' behaviour and choice of environmentally sustainable products in South Africa should consider using modelling techniques that account for heterogeneity, especially models that identify different consumer segments.

The practical implications of the findings are that policymakers should consider the identification of different consumer segments as a feasible strategy and possibly design segment-specific water and carbon footprint labelling information and policies to initiate change towards environmental sustainability. For both product and respondent categories, price played a significant role in influencing respondents' decision to choose environmentally sustainable food products. The identification of different distinct consumer segments among low and high income respondents and the failure to pool data from the two sub-samples provide the rationale for researchers to critically think about and test the suitability of combining attribute-based choice experimental data from different income stratifications. These augment previous findings and arguments by Grebitus et al. (2015) and Wooldridge (2002).

The low income respondents consisted of four distinct consumer segments labelled as water sustainability advocates, carbon reduction advocates, keen environmentalists and environmental neutrals. The high income respondents consisted of three distinct consumer segments, namely keen environmentalists, environmental cynics, and environmental neutrals. This demonstrates that there is greater diversity among low income respondents in terms of preferences for environmentally sustainable attributes, relative to high income respondents. It is worth noting that the proportion of keen environmentalists among the high income sample is higher than that of the low income sample.

The findings generally reveal that most consumers prefer beef and milk products labelled with low water usage and carbon emissions. Therefore, producers and agribusinesses can create niche markets for environmentally sustainable food products. The study further concludes that consumers' trust in food labelling regulatory bodies, awareness, and knowledge of environmental sustainability, as well as traditional socioeconomic factors, impact significantly on their choices of environmentally sustainable food products. Specifically, keen environmentalists among the low income respondents have their choices of environmentally sustainable attributes influenced by trust, awareness of threats associated with climate change, and subjective and objective knowledge of environmental sustainability. This signifies the importance of awareness creation and knowledge building on environmental sustainability when it comes to communal and municipal policy. Consumers' knowledge of environmental sustainability was found to be somewhat low.

Water sustainability advocates, who form the largest segment among the low income respondents, were found to have low subjective and objective knowledge about environmental sustainability. This highlights the urgent need for communal and municipal policymakers to educate the general public on environmental sustainability through awareness creation, educational programmes, and campaigns aimed at instilling environmental sustainability behaviour into people. Regarding carbon reduction advocates, the main driver of their choice of footprint-labelled food products was found to be awareness of threats posed by climate change.

Among the high income respondents, the choices made by keen environmentalists are based on high awareness, trust, and subjective and objective knowledge levels, in addition to socioeconomic characteristics such as age, gender, education and income. The environmental cynics' choices are influenced by low subjective and objective knowledge levels, as well as the lack of trust in labelling regulatory bodies. Therefore, building trust and improving the subjective and objective knowledge levels of this segment can are important drivers in changing the behaviour of this group.

Given the diversified segments of consumers, it will be efficient for food producers, communal and municipal policymakers to design different environmental sustainability policies and marketing strategies for different consumer segments. For instance, it will be important to educate people on the prospective benefits of saving water, the consequences of wasting water, the cost of water and the water scarcity situation, including threats posed by climate change, across different consumer segments in their local or dominant language.

In the low income- and high income-dominated communities and markets, environmental and ecological footprint labels can be presented in the local language pertaining to the area. This will make environmental sustainability labelling easier and simpler for the majority of people to understand, rather than using a technical language that is difficult to understand. Also, footprint messages should be conveyed to consumers in plain labelling statements that are easy to understand. From a marketing point of view, building consumers' trust in sustainability labelling regulatory bodies is a relevant marketing strategy. The findings generally provide vital information for private food companies and agribusinesses to take action based on the identified segments of consumers who prefer environmentally sustainable food products and their segment characteristics.

Price premiums can be obtained from the sale of environmentally sustainable products, identified through footprint labelling. Demographic targeting of consumer segments, awareness creation and segment-specific educational campaigns aimed at enhancing subjective and objective knowledge of environmental sustainability are important tools for food companies and agribusinesses to promote and market environmentally sustainable food products.

The paper's strength lies in its large sample of both low and high income respondents. To the best of our knowledge, this is one of the first studies that examine preferences for environmentally sustainable products from the viewpoint of different income groups and also from an African perspective. As limitations, it has to be noted that our sampled respondents consisted of consumers who purchase beef and milk products from formal supermarkets where sustainability labelling is practised. Hence, the external validity was limited given that the consumers who buy products from the informal markets were not included in our survey. It is suggested that future research should consider consumers who purchase products from the informal markets to ascertain if the behaviour of consumers reported in this paper is robust compared to the behaviour of consumers in the informal markets in the context of this study. Secondly, this study focused only on beef and milk. Future research can consider examining other food and non-food products to determine if the results reported in this paper are vigorous compared to other food and non-food products. Finally, the stated preference choice experimental approach and the questionnaire method employed may have some component of self-selection which can lead to bias results (Grebitus et al., 2016). This potential limitation was minimised by attaining large samples for both categories of respondents.

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APPENDIXES

Appendix 5A. Mixed logit results for different income classes

Random parameters	**Low income consumers**			
	Beef rump steak		Fresh full cream milk	
	Coefficient(Std. error)	z-Value	Coefficient(Std. error)	z-Value
Water footprint	-0.7227*** (0.1778)	-4.06	-2.0944***(0.4897)	-4.28
Carbon footprint	-0.2642**(0.1337)	-1.98	-2.3782***(0.7893)	-3.01
None	0.1036*** (0.0132)	7.85	0.4451*(0.2669)	1.67
Non-Random parameter				
Price	-0.0562*** (0.0055)	-10.22	-0.1475***(0.0437)	-3.38
Standard deviation estimates				
Water footprint	1.1110*** (0.1941)	5.72	0.2515**(0.0985)	2.55
Carbon footprint	0.3624***(0.0848)	4.27	0.1876*(0.0998)	1.88
None	0.2653**(0.1141)	2.33	2.0612***(0.3710)	5.56
Diagnostic statistics	LL=;-560.53; LR=24.06***; AIC=1129.06		LL=-535.06; LR=34.25***; AIC=1078.12	
Random parameters	**High income consumers**			
Water footprint	-1.4254*** (0.2367)	-6.02	-1.1344**(0.4117)	-2.76
Carbon footprint	-0.5328***(0.1621)	-3.29	-1.3702***(0.3193)	-4.29
None	-0.6463***(0.1450)	-4.46	-1.3351***(0.2439)	-5.47
Non-Random parameter				
Price	-0.1036***(0.0132)	-7.87	-0.2716** (0.0275)	-9.88
Standard deviation estimates				
Water footprint	1.1104***(0.2769)	4.01	0.3215***(0.1085)	2.96
Carbon footprint	0.6426**(0.3056)	2.10	0.6160***(0.1298)	4.75
None	0.0545***(0.0052)	10.50	0.3612***(0.1110)	3.25
Diagnostic statistics	LL=-533.05; LR=79.03***; AIC=1074.10		LL=-543.77; LR=64.44***; AIC=1095.54	

Appendix 5B. Pre-survey information

Attribute	Meaning
Water footprint	Refers to the quantity of fresh water used in the production, storage and distribute either beef or milk. Specifically, the water used to produce feed, water intake by live animals, water used at the processing level and all volumes of water used until the product reached the market. The lower the water usage, the better for the environment.
Carbon footprint	The amount of greenhouse gases emitted along the entire product (beef and milk) life cycle. The lower the carbon emitted, the better for the environment

5.2 ARTICLE FIVE: COMPENSATING WELFARE ESTIMATES OF WATER AND CARBON FOOTPRINT SUSTAINABILITY POLICY CHANGES IN SOUTH AFRICA (UNPUBLISHED)

ABSTRACT

The implementation of environmental sustainability policies in the food and agricultural sector demands an understanding of consumers' preferences for environmentally sustainable food products and the welfare effects arising from their preferences and willingness to pay. We employed choice experiment and latent class model to estimate consumers' preferences and compensating surplus estimates for water and carbon footprints policy changes in South Africa. Our findings reveal that there is profound preference heterogeneity at segment level for water and carbon footprint attributes. Three distinct consumer segments were identified. Besides socioeconomic factors, we demonstrate that public awareness creation and campaigns on threats posed by climate changes, trust in food labelling regulatory bodies, subjective and objective knowledge on environmental sustainability significantly explain consumers' choice of environmentally sustainable products. Our compensating surplus estimates indicate that the welfare effects arising from water and carbon footprint sustainability policies vary from one class to another. Our findings suggest that there are pertinent segmental equity issues that need to be addressed when designing environmental sustainability policies. Future studies on preferences for environmentally sustainable products should not be limited to a willingness to pay estimates only; rather compensating surplus estimates should be computed in addition, for efficient and effective policy guidance.

Keywords: Carbon footprint; Choice experiment; Compensating surplus; Latent class; Sustainability policies; Water footprint; Welfare effects

1. INTRODUCTION

Governments and policy-makers across the globe are increasingly getting interested in the design and implementation of environmental or ecological sustainability policies (IPCC, 2007). Carbon and water footprint sustainability assessment, in particular, is gaining particular attention, as some industries, agribusinesses and governments rely on these sustainability indicators to evaluate their environmental and water-related risks and impacts. The food and agricultural sector are one of the sectors where carbon and water footprint assessment is gaining much prominence. This is as a result of the association between production and consumption of agricultural food products and the effects of these activities on water resources and the environment (IPCC 2007). For instance, food and agricultural production utilize about 86 % of the global freshwater (IWMI 2007). In terms of carbon emissions, the agricultural sector in general accounts for about 30-35% of the global GHG emissions (Foley et al. 2011).

Given the significant impacts that the food and agricultural sector have on the environment and water resources, governments, producers and policy-makers in recent years are keen on coming out with policies and strategies aimed at changing producers and consumers sustainability behaviour, while sustaining the environment. The South African government in 2013 developed a policy document known as "Carbon Tax Policy Paper". This policy paper outlines ways of minimizing environmental challenges, particularly GHG emissions. It also touches on water scarcity, water pollution and climate change as a whole (Carbon Tax Policy Paper 2013). The development of such policy document is anticipated to propel the needed policy and price signals to producers, manufacturers, businesses, institutions and consumers of the need to make sure that future investments are carried out in an environmentally sustainable manner (Carbon Tax Policy Paper 2013; Suranjan et al. 2017). This sustainability policy initiative is expected to motivate producers to change their production patterns to a more sustainable one, through the adoption of innovative technologies with minimal environmental effects (Carbon Tax Policy Paper 2013).

The introduction of the carbon tax is expected to have a significant impact on prices of food and non-food products, which in turn will have some economic and welfare implications on consumers (Kearney 2008). For instance, the extra cost incurred by investors to produce environmentally sustainable products will either be transferred to the consumer or bear by the producer or shared by both. On the other hand, the government can provide incentives to ecologically sustainable producers. Food producers, agribusinesses and companies are expected to make their sustainability information available through product labelling, since sustainability information cannot be identified at the point of sale without labels. Carbon labelling has received some attention in the food and agricultural industry in South Africa.

Currently, the Water Research Commission has also directed their attention to water footprint assessment; particularly in the agricultural sector because the sector has been identified as a major user of scarce water resource in South Africa (DWA 2013). Therefore, the commission and concerned food companies seek to rely on sustainability campaigns and awareness creation through footprint labelling as a possible marketing strategy for marketing environmentally sustainable food products, with the aim of sustaining water. Consumer preferences for environmental environmentally sustainable food products have received some attention in the recent literature (Grebitus et al. 2015:2016; Peschel et al. 2016). Peschel et al. (2016) assessed German and Canadian consumers' decision to buy environmentally sustainable products and found out that consumer preference for such products hinges on subjective and objective knowledge levels. Grebitus et al. (2016) performed cross-cultural analysis of preferences for food and non-food products with carbon and water footprint labels and revealed that consumers are highly heterogeneous in their preferences, regardless of their cultural background. Grebitus et al. (2015) further found that human values are very relevant in explaining consumers' behaviour and preferences for carbon and water footprint labelled products in Germany. Additionally, an assessment of carbon footprint labelling in respect of exports of agricultural product (Edwards-Jones et al., 2009) and legal issues concerning carbon labelling (Cohen and Vandenbergh 2012) have been explored.

Ecological footprints have been used as an indicator for sustainability assessment in areas such as the mining industry (Suranjan et al. 2017) as well as the impact of globalisation on ecological footprints (Figge et al. 2017). However, the growing body of literature has focused consumer preferences (Grebitus et al. 2015: 2016; Peschel et al. 2016; Schumacher 2010), trading (Edwards-Jones et al. 2009) and labelling issues (Cohen and Vandenbergh 2012; Van Loo et al. 2015). None of these studies has considered the welfare impacts arising from consumers' preferences and choices of footprint labelled products. Nonetheless, Ambrey and Daniels (2017) have related carbon footprints to individuals' wellbeing, without considering water footprint. Additionally, these studies have focussed only on developed countries, with little or no study in arid and semi-arid African countries, including South Africa. Therefore, current knowledge on the impact of consumers' behaviour and choices of environmentally sustainable products on their welfare is insufficient. In the context of the current paper, compensating surplus or consumers welfare is defined as the income change needed to keep consumers at their initial utility level assuming that the carbon and water sustainability policy changes highlighted in this study are implemented (McKenzie and Pearce 1982; Vartia 1983).

The main objective of this paper is to estimate consumers' willingness to pay and compensating surplus estimates of water and carbon footprint sustainability policy changes in South Africa. The overall effect of introducing a new product or changes in product attributes on consumer welfare is described as the compensating surplus. Consumer surplus in this context is related to changes in the price of environmentally sustainable food products and/or their attributes (Morey 1985). It can also be explained as changes in utility arising from changes in sustainability policies, measured in monetary terms (Morey 1984). Compensating surplus estimation approach was chosen over compensating variation because Morey (1985) and Hanemann (1984) opined that compensating surplus is appropriate in situations where changes in policies are as a result of government provisions or restrictions, as it is with our case study. Compensating variation is appropriate in instances where consumers are assumed to optimally alter their consumption pattern due to changes in policies Morey (1985). However, this assumption is not always the case Hanemann (1984).

The welfare effects (gain or loss) resulting from carbon and water footprint sustainability policies are very important for policy decision making (Grebitus et al. 2013). An understanding of the segment of consumers or individuals whose welfare will be improved or reduced due to the sustainability policy changes will add to the current policy debate on environmental sustainability. Welfare assessment of environmentally sustainable policy changes provides economic justification for implementing such policies. Welfare assessments also help to minimise the economic costs of sustaining the environment and reduce environmental risk (Carbon Tax Policy Paper 2013). It further provides evidence-based policy scenarios for developing the food and agricultural sector, for improved policy-making and regulations towards environmentally sustainable food production, marketing and consumption (Thøgersen and Ölander 2002). The rest of the paper is outlined as follows. Section 2 presents the methodology of the study. Section 3 presents the results and discussions of the study. Section 4 provides conclusions and policy implications from the study.

2. METHOD AND DATA

2.1. CHOICE EXPERIMENT AND COMPENSATING SURPLUS ESTIMATION APPROACHES

The choice experiment method was employed in this study to solicit the relevant data because it is one of the prominent methods used in recent literature for evaluating preferences for environmental sustainability attributes (Grebitus et al. 2013: 2015: 2016; Peschel et al. 2016). The choice experiment encompasses establishment of a hypothetical market for the product in consideration, described in terms of its attributes or characteristics (Birol et al. 2006). Respondents are requested to make their choices from different choice sets presented to them in a sequential manner during the survey. This approach is based on Lancaster's characteristics methodology which states that the overall utility obtained from a product originates from the product's characteristics, rather than the product itself (Lancaster 1991). The theory of how respondents choose between different discrete choice sets is modelled under the random utility theory which assumes respondents to be rational and preferring products that give them the highest utility (McFadden 1974). The underlying assumption of the random utility is that consumers are heterogeneous in their preferences for sustainable product attributes (Grebitus et al. 2013; Hensher et al. 2005). Hence, the latent class model is adopted to account for unobserved heterogeneity among different consumer segments. Compensating surplus estimates for each segment will be determined afterwards.

Under the latent class modelling approach, consumers are assumed to be organised implicitly into a set of classes. The class to which a consumer belongs to, whether known or unknown, is unobserved by the analyst. Consumers within each class are presumed to homogeneous but vary across different classes (Wedel and Kamakura 2000). The number of classes in the sampled respondents is determined by the data. Belonging to a specific latent class hinges on the consumer's observed personal, social, economic, perception, attitudinal and behavioural factors. Assuming that a rational consumer *i* belonging to class *l* obtain utility *U* from product option *k*, the random utility is specified as:

$$U_{ik/l} = \beta_l Z_{ik} + \ell_{ik/l} \quad (5.2.1)$$

where β_l denotes class specific vector of coefficient, Z_{ik} represents a vector of characteristics allied with each product option and the error term of each class is denoted by $\ell_{ik/l}$. The error term is assumed to be distributed independently and identically. The likelihood that product option *k* is chosen by consumer *i* in *l* class is specified as:

$$\Pr_{ik|l} = \frac{\exp(\beta_l Z_{ik})}{\sum_n \exp(\beta_l Z_{in})} \quad (5.2.2)$$

The probability that consumer *i* belongs to a particular class is denoted by P_{il} and defined by a probability function *G*. The likelihood that consumer *i* belongs to class *l* is represented by the function $G_{il} = \delta_l X_i + \varsigma_{il}$ where X_i denotes a vector of consumers' personal, social, economic and other relevant factors and ς_{il} represents the error term. The error term is assumed to be distributed independently and identically. The likelihood of consumer *i* belonging to class *l* is then specified as:

$$P_{il} = \frac{\exp(\delta_l X_{il})}{\sum_s \exp(\delta_l X_i)} \quad (5.2.3)$$

The combined possibility that consumer *i* belongs to class *l* and selects product option *k* is represented by:

$$P_{ikl} = (P_{ik/l}) * (P_{il}) = [\frac{\exp(\beta_l Z_{ik})}{\sum_n \exp(\beta_l Z_{in})}] \times [\frac{\exp(\delta_l X_i)}{\sum_l \exp(\delta_l X_i)}] \quad (5.2.4)$$

The choice experiment employed and the random utility underlying the latent class model adopted in this study correspond with utility-maximizing theory and demand (Birol et al. 2009). Therefore, compensating surplus welfares estimates can be calculated from the estimated parameters (Birol et al. 2009; Hanemann 1984) using the formula below:

$$CSW_l = \frac{\ln \sum_l \exp(IV_{l1}) - \ln \sum_l \exp(IV_{l0})}{\beta_{price}} \quad (5.2.5)$$

where CSW_l is the compensating surplus welfare estimate for a particular class. IV_{l0} and IV_{l1} represents indirect utility before and after sustainability policy changes. Once the utility estimates for consumer segments are estimated, their willingness to pay estimates can be computed as:

$$WTP = -\frac{\partial U / \partial X}{\partial U / \partial P} = -\frac{\beta_{sustainability\ attributes}}{\beta_{price}} \quad (5.2.6)$$

where *X* is a vector of the product attributes. *P* denotes the price. $\beta_{sustainability\ attributes}$ is a non-monetary coefficient of sustainability attributes and β_{price} is the monetary coefficient on price. The class-specific WTP estimates are computed using parametric bootstrapping technique.

2.2. SAMPLING AND DATA DESCRIPTION

The survey was conducted in the Gauteng province of South Africa using trained interviewers. Gauteng is the most populous province in South Africa and very diverse in terms of social, economic and demographic characteristics (Statistics South Africa, 2012). This allowed for high representation in the data. Specifically, the data was collected from Centurion, Pretoria and Midrand (Johannesburg). The data consisted of 47.3% Blacks, 43.3 % White, 16% Coloured and 2% Indians, and thus, showing that the data have a representation of all the different racial groups in South Africa. Multistage sampling procedure was employed to sample 402 meat consumers from households. The study was conducted in Centurion located between Pretoria and Midrand (Johannesburg).

The survey focussed on meat buyers, with particular reference to beef because beef is one of the meat products extensively purchased and, as such, it was easy to find more respondents. Also, the water footprints of beef products in South Africa are known to be larger, relative to the global averages (Mekonnen & Hoekstra, 2010; Owusu-Sekyere, Scheepers & Jordaan, 2016). Prior to the data collection, the survey instrument was pre-tested amongst 15 respondents in the selected supermarkets. Face-to-face interviews were conducted in the selected markets using samples of the labelled products. The surveyed sample consisted of 402 meat consumers. Out of this, 150 were sampled from Midrand, 120 from Centurion and 132 from Pretoria. The response rate for the survey was 75%. The questionnaire consisted of both closed and open-ended questions, as well as Likert scale-type questions. The questionnaire focused on the choice experiment, respondent's socioeconomic characteristics, knowledge of environmental sustainability and attitudinal data. We initially assessed respondents' subjective and objective knowledge of environmental sustainability before the choice experiment. The assessment of subjective and objective knowledge followed the approach of Brucks (1985).

2.3. EXPERIMENTAL DESIGN

An attribute-based choice experimental design was employed. The choice experiment allows respondents to choose from a set of product alternatives, with different attribute combinations. The choices made by respondents' aid in revealing their preferences, without subjectively asking them to value the product attributes. This method minimises social desirability bias (Norwood and Lusk 2011). The choice experiment consisted of different combinations of water usage (water footprint), carbon emissions (carbon footprint) and prices. Different choice sets were designed for beef rump steak. The water footprint values were estimated using South African data and the Water Footprint Network Standard Approach as outlined in the Water Footprint Assessment Manual. Water footprint estimate for beef from Mekonnen and Hoekstra (2010) was also included. The carbon equivalents were obtained from Milk South Africa (Milk SA) and Scholtz et al. (2014). The prices considered were the mean observed prices for beef rump steak without carbon and water footprint labels, with standard deviations of plus and minus one (Grebitus et al. 2015).

Water footprint, carbon footprint and price attributes had three levels each in the choice sets designed (Table 5.5). The attributes and their levels were combined using Ngene software to create random parameter panel efficient design with three alternatives (A, B and “none”) (Choice Metrics 2014). D-error efficiency and blocking strategy were also used during the design. The blocking strategy circumvents respondent fatigue during the survey (Savage and Waldman 2008). All the choice questions were generated using the Ngene software and blocked into ten, with each block containing two choice sets. Each person was randomly allocated to a block. Since the concept of carbon and water footprint is new, the possibility that some respondents may not be aware of water and carbon footprints was resolved by generating statements explaining the carbon and water footprints, their measurements and meanings of the footprint values to the respondents in their local and preferred language before the survey. These statements were approved by the Water Research Commission (WRC) of South Africa before the survey. The likelihood ratio test was employed to formally test whether the data from the two markets could be pooled together (Wooldridge 2002).

Table 5.5: Attributes and their level in the choice experiment

Attribute	Beef rump steak	Categorical level
3. Water footprint	4. 15415 l/kg 5. 17300 l/kg 6. 17387 l/kg	Low Medium High
4. Carbon footprint	4. 22.90 kgCO_2e 5. 26.37 kgCO_2e 6. 27.50 kgCO_2e	Low Medium High
3. Price	4. ZAR 159.99/ kg 5. ZAR 179.99/ kg 6. ZAR 185.00/ kg	Low Medium High

The Water Research Commission (WRC) of South Africa approved these statements prior to the survey. The likelihood ratio test was employed to formally test whether the data from the two markets could be pooled together.

3. RESULTS AND DISCUSSION

3.1. DESCRIPTIVE CHARACTERISTICS OF RESPONDENTS

The descriptive characteristics of respondents are presented in Table 5.6. The average age of the sample was about 35 years. This compares favourably with Stats SA's population estimates which indicate that about 66% of the South African population are about 35 years (Stats SA 2014). The mean number of years of formal education was 15 years and an average monthly income of ZAR10132.24. Most of the respondents were females, as indicated by a percentage of 67.70%. The high proportion of female is not surprising given that women are mostly in charge of household grocery shopping and purchasing decisions in South Africa (Mare et al. 2013). About 53.50% of the respondents were aware of the department of water and sanitation's campaign on threats posed by climate changes in South Africa. This suggests the need for more awareness and campaigns on climate changes, as 46.50 % of the people were not aware. Most of the respondents (73.44%) trust in food labelling regulatory bodies in South Africa. In terms of respondents' subjective and objective knowledge regarding environmental sustainability, the results revealed an average subjective knowledge (SUBKI) index of 3.41. Similarly, the objective knowledge index was found to be 2.68. The subjective and objective knowledge estimates show that the respondents consider themselves as moderately knowledgeable about environmental sustainability. Generally, the index for subjective knowledge is higher than objective knowledge; implying that what respondents think they know about environmental sustainability is higher than what is actually observed or practical. This is in agreement with findings of Peschel et al. (2016) among Canadian and German consumers

Table 5.6: Descriptive statistics of respondents' socioeconomic characteristics

Variable	Description	Mean (SD)
Age	Years	35.08(11.51)
Education	Years of formal education	15.08(2.31)
Income	Monthly income in ZAR	10132.24(43.98)
Subjective knowledge index (SUBKI)	Subjective knowledge about environmental sustainability	3.41(1.00)
Objective knowledge index (OBJKI)	Objective knowledge about environmental sustainability	2.68(1.10)
Variable	Description	Percentage
Female	1 if female, 0 otherwise	67.70
Awareness	1 if respondents is aware of the department of water and sanitations campaign on climate changes	53.50
Trust	1 if respondent trust in food labelling regulatory bodies	73.44

3.2. LATENT CLASS ESTIMATES

The latent class model estimates are provided in Table 5.7. Prior to the latent class estimation, the likelihood ratio test was employed to formally test whether the data from the two supermarkets could be pooled together (Wooldridge 2002). Based on the test results, the null hypothesis for pooling the data was not rejected. Also, Ben-Akiva and Swait (1986) test was conducted to ascertain whether the latent class model or mixed logit models best fit our data. It was found that the latent class model is the best fit and that the heterogeneity in our data is better explained at the segment level, rather than at individual level. Therefore, we present the results of the latent class model. Using McFadden's (ρ^2), AIC and BIC selection criteria, three-latent class model was found to be optimal. The McFadden (ρ^2) statistic of 0.21 indicates that the model was fit (Hensher et al. 2005). The results reveal that the respondents are heterogeneous in their preferences for water usage, carbon emission, and price. This is indicated by the differences in magnitude, direction, and significance of the utility function estimates. This concurs with recent findings of Grebitus et al. (2015). Three distinct consumer classes were found. Price is significantly negative in all the classes as expected and in accordance with economic theory (McFadden 1974). This means that all the three classes of consumers are sensitive to price and consider it as a relevant attribute in their decision to purchase environmentally sustainable food products (Grebitus *et al.* 2015: 2016; Peschel *et al*. 2016). Therefore, pricing environmentally sustainable products should be carefully reviewed in order not to exceed what consumers are willing to offer.

For class 1, the utility estimates show that low levels of water usage and carbon emissions are significantly positive. This means that respondents in this class prefer beef products with low water and carbon footprints. Medium water usage level was significantly negative. Also, High levels of water usage and carbon emission variables were significantly negative. This suggests that apart from low water and carbon footprint levels, respondents in this class will not prefer beef products with medium or high footprint estimates. This is confirmed by the status quo bias observed for the "none" option. The significantly negative coefficient estimate of "none" option implies that respondents in this class prefer to select one of the product options than to choose the "none" option. This class accounts for 46 % of the sampled respondents. The class membership estimates for this class reveal that having high levels of formal education, income, as well as subjective and objective knowledge on environmental sustainability, increases the likelihood of a particular respondent belonging to this class, relative to class three. Additionally, members of class one are likely to be aware of threats posed by climate changes through the department of water and sanitations campaigns. They are also likely to trust food labelling regulatory bodies in South Africa. Members of this class are likely to be younger individuals, as indicated by the significantly negative coefficient of age variable.

For the second class, the utility estimates for low levels of water usage and carbon emissions are significantly different from zero and positive. High levels of water usage and carbon emission variables are significantly negative. This suggests that members of this class have negative preferences for beef products with high water and carbon footprints. The status quo variable "none" is significantly different from zero and positive. This implies that respondents in this class also prefer beef products without water and carbon footprint sustainability information. Class two accounts for 35.10% of respondents. The class membership estimates for this segment indicate that respondents in this class are likely to be older females with low income, relative to class three members. Respondents in this class are less likely to trust food labelling regulatory bodies, relative to class three members. They are also less likely to report having high subjective and objective knowledge on environmental sustainability, compared with class three members.

For class three, the significance and directions of the utility function estimates differ. The utility function estimates for low water usage and carbon emission levels are significantly different from zero and positive. This suggests that respondents in class three do prefer beef products with low water and carbon footprints. However, their utility estimates for this level are lower relative to the other two classes. The utility estimates for medium and high levels were positive but insignificant at the conventional levels, relative to the other classes. Members of this class also have positive utility estimates for medium and high carbon footprint estimates, compared with the other two classes. However, their preferences were not significant. The status quo variable "none" is significantly positive; indicating that respondents in class three prefer products without water and carbon footprint sustainability information. Class three accounts for 18.90 % of the respondents. Class membership estimates for this class were normalised to zero, such that the other classes could be compared with it.

Table 5.7: Latent class results for beef consumers

Attributes	Class 1	Class 2	Class 3
Water footprint			
Low	2.55***(0.65)	2.07***(0.43)	0.33**(0.13)
Medium	-0.75***(0.23)	-0.50(0.36)	0.24(0.12)
High	-1.56**(0.71)	-0.46*(0.24)	0.14(0.17)
Carbon footprint			
Low	1.57***(0.41)	1.25***(0.33)	0.22***(0.03)
Medium	-0.69(0.40)	1.16(0.81)	1.02(0.73)
High	-1.36***(0.42)	-1.08**(0.48)	0.54(0.37)
None	-3.11*** (0.66)	1.23***(0.69)	0.74**(0.30)
Price	-0.35***(0.11)	-0.37*** (0.07)	-0.18***(0.05)
Class share	**46%**	**35.10%**	**18.90%**
Class membership estimates			
Constant	-1.66***(0.24)	-2.43***(0.39)	
Age	-0.57**(0.2)	0.33**(0.12)	
Female	-0.34(0.24)	0.27**(0.11)	
Education	0.72**(0.22)	0.23(0.19)	
Income	0.62**(0.31)	-0.32**(0.12)	
Awareness	0.46**(0.22)	0.55(0.41)	
Trust	0.41** (0.20)	-0.39**(0.19)	
SUBKI	0.27** (0.11)	-0.16*(0.09)	
OBJKI	0.21**(0.09)	-0.13*(0.07)	
Diagnostic statistics	LL= -514.80; AIC=1051; BIC=1251.98; McFadden's (ρ^2) =0.21		

Values in parentheses are standard errors
*** =significant at 1%, ** =significant at 5%, * = significant at 10%

3.3. *WILLINGNESS TO PAY ESTIMATES FOR WATER AND CARBON FOOTPRINT SUSTAINABILITY ATTRIBUTES*

Class-specific willingness to pay estimates for the different levels of sustainability attributes evaluated at 95% confidence interval are presented in Table 5.8. The WTP estimates for the attributes were estimated across the latent classes in order to ascertain the differences in preference structure. The results show that respondents in class one and class two are willing to pay ZAR7.29, ZAR 5.59 and ZAR 1.83, respectively for a kilogramme of beef with low water footprint level. This suggests that for low water footprint levels, respondents in class one offered the highest amount, whereas class three members offered the lowest amount. Respondents in class one are willing to accept ZAR 2.14 and ZAR 4.46 as compensations to choose beef products with medium and high water footprint levels, respectively. In terms of carbon emissions, respondents in all the classes were willing to pay ZAR4.49, ZAR 3.38 and ZAR 1.22 per kilogramme of beef with for low carbon emission levels, respectively from class one to three. The above results show that for all the three classes willingness to pay estimates for low water usage are higher than low carbon emissions. This implies that preference for low water footprint among consumers is higher than low carbon footprints. Finally, class two and three members were willing to pay for beef products without water and carbon footprint sustainability information, whereas class one members will only choose this product when they are compensated with ZAR 8.89. Given that class one forms the largest share of the respondents, the estimates suggest that willingness to pay premiums for low water and carbon footprint products can be a possible marketing strategy for producers.

Table 5.8: Class specific willingness to pay estimates and 95% confidence intervals

	Class 1 (ZAR)	Class 2 (ZAR)	Class 3 (ZAR)
Water footprint			
Low	7.29 (5.22 to 9.57)	5.59 (3.55 to 7.99)	1.83 (0.40 to 2.95)
Medium	-2.14 (-4.33 to -1.85)	NS	NS
High	-4.46 (-7.75 to -3.15)	-1.24 (-4.44 to -0.99)	NS
Carbon footprint			
Low	4.49 (2.45 to 8.10)	3.38 (2.33 to 5.80)	1.22(1.03 to 1.99)
Medium	NS	NS	NS
High	-3.89 (-6.42 to -3.05)	-2.84 (-4.12 to -2.05)	NS
None	-8.89 (-10.06 to -5.50)	3.32 (2.69 to 5.45)	4.11 (3.24 to 6.90)

NS: Not significant: All values are in South African Rand (ZAR)
Values in parentheses are confidence intervals at 95%.

3.4. SUSTAINABILITY POLICY SIMULATIONS AND COMPENSATING SURPLUS ESTIMATES

The willingness to pay estimates presented in Table 5.8 are not compensating surplus welfare estimates for changes in water and carbon footprint sustainability policy scenarios. As a result of that, respondents' compensating surplus estimates conditional on belonging to any of the three classes, for changes in environmental sustainability management policies over the existing condition, is created by three sustainability labelling scenarios. Scenario 0: Is the existing condition where carbon and water footprint sustainability information are not accounted for by producers and as such there is no footprint labelling of products. Scenario 1: Under this scenario, carbon, and water footprints are reduced to low levels and the values are presented on beef products through labels. Scenario 2: Under this scenario, carbon, and water footprints are reduced to medium levels and the values are presented on beef products through labels. Scenario 3: Under this scenario, carbon and water footprints remain high and the values are presented on beef products through labels. Compensating surplus estimates for these scenarios are presented in Table 5.9.

The results indicate that sustainability management scenarios one and two resulted in welfare gains in class one. Specifically, the highest welfare gain for respondents in class one is ZAR 17.08, followed by ZAR 8.80 per month per person for scenarios one and two, respectively. However, scenario three resulted in a welfare loss of ZAR 6.73 per month per person. These findings indicate that welfare of respondents in the first class improves the most when they made to pay more for products with low water and carbon footprints and compensated for choosing products with a medium level of water usage and carbon emissions.

For class two, the only welfare improvement was attained for scenario one. The remaining two scenarios resulted in a welfare loss for respondents in this class. Albeit, scenario two is insignificant in class two, the welfare estimates revealed that paying for medium water and carbon footprint levels will not result in any welfare improvement. For respondents in class three, the improvement in welfare is attained from scenario one. Specifically, the only welfare gain for respondents in class three is ZAR 3.14 per month per person. This suggests that welfare of respondents in the third class improves the most when they are paid low premiums for purchasing products with low water usage and carbon emissions. Scenarios two and three resulted in welfare losses in this class. The results show that for both classes two and three, welfare losses are associated with scenarios two and three.

Table 5.9: Compensating surplus estimates for carbon and water footprints labelling scenarios

Scenarios	Class 1	Class 2	Class 3
Scenario 1	17.08 (10.45 to 20.55)	4.26 (2.11 to 5.33)	3.14 (1.55 to 4.99)
Scenario 2	8.80 (4.22 to 9.50)	-0.28 (-1.56 to -0.09)	-4.00 (-9.10 to -2.43)
Scenario 3	-6.73 (-8.76 to -3.78)	-3.43 (-4.12 to -2.55)	-2.75 (-4.49 to -1.78)

Values in parentheses are confidence intervals at 95%.
All values are in South African Rand (ZAR) per consumer per month

4. *CONCLUSION AND POLICY IMPLICATIONS*

In this paper, choice experiment and latent class modelling approaches have been employed to estimate consumers' preferences and compensating surplus estimates for water and carbon sustainability policy changes in South Africa. The study concludes that there is considerable preference heterogeneity at segment level for water and carbon sustainability attributes of beef products. Specifically, the study concludes that there are three distinct consumer segments within the sampled respondents, with each class exhibiting different preference attitude for the same set of water usage and carbon emission levels. Respondents in segment one derive positive utilities from low levels of water usage and carbon emissions, while negative utilities are attained from medium and high levels of the same attributes. Segment two members also derive positive utilities from low levels of water and carbon footprint values, while negative utilities are derived from high levels of same footprint attributes. Respondents in segment three derive positive utilities from low water usage and carbon emission levels. Members in this segment derive positive but insignificant utilities from medium and high water usage and carbon emission levels.

The profound heterogeneity in preferences is explained by socioeconomic factors such as age, gender, education and income of respondents. Besides socioeconomic factors, public awareness creation and campaigns on threats associated with climate changes play a significant role in influencing consumers' preferences for environmentally sustainable products. Therefore, demographic targeting of consumer segments, awareness creation and segment-specific educational campaigns aimed at enhancing subjective and objective knowledge on environmental sustainability are important tools for governments, food companies, and agribusinesses for promoting and marketing environmentally sustainable food products. Additionally, respondents' subjective and objective knowledge levels on environmental sustainability significantly impact on their choices of environmentally sustainable products. Hence, enhancing and improving the subjective and objective knowledge levels of people regarding environmental sustainability are important drivers that can be employed to change the behaviour of South Africans and Africans as a whole. The study concludes that trust in regulatory bodies in charge of food labelling, including environmental sustainability labelling is very relevant in ensuring preferences for sustainable products.

Willingness to pay for different levels of water usage and carbon emissions varies across the identified classes. The study concludes that willingness to pay exists for low water usage and carbon emissions in classes all the identified segments. It is concluded further that respondents willing to pay for low water footprint level exceed what they are willing to offer for low carbon footprint level. The compensating welfare evaluations reveal that the introduction of water and carbon footprint sustainability policy scenarios have varied implications on consumers. The only welfare improvements for classes two and three are related to the changes in water and carbon footprint scenario one when respondents pay premiums for products with low water and carbon footprint values. However, it is worth noting that welfare of class one members are improved considerably when they pay premiums for low water and carbon footprint levels, while they receive compensation for medium levels of water usage. Generally, the welfare gains and losses vary from one class to another. Therefore, there are imperative segmental equity issues that need to be taken into consideration when designing environmental sustainability strategies to change consumers' behaviour, while aiming at minimising environmental impacts.

The main implication of these findings is that preferences for environmentally sustainable products should not be limited to only willingness to pay estimates; rather, compensating surplus estimates should go along with WTP estimates for efficient and effective policy purposes. Therefore, food policy-makers should take into account whose welfare will be impacted positively or negatively by environmentally sustainable food policy changes. Successful implementation of water and carbon footprints policies will need a compromise between environmental sustainability and improvements in the welfare of the general public. If the aim is to maximise the welfare of consumers and to sustain the environment, then the cost of producing environmentally sustainable products should not be transferred to all consumer classes equally, because of the variation in welfare effects. This study has contributed to the existing literature on the preferences for environmentally sustainable food product by adding welfare implications of consumers' choices.

As limitations, it has to be noted that our sampled respondents consisted of consumers who purchased beef products from formal supermarkets that practised sustainability labelling. Hence, the external validity was limited given that consumers who buy products from informal markets were not included in our survey. It is suggested that future research should consider consumers who purchase products from the informal markets to ascertain if the behaviour of consumers reported in this paper is robust compared to the behaviour of consumers in the informal markets in the context of this study. Secondly, this study focused only on beef. Future research should consider examining other food and non-food products to determine if the results reported in this paper are vigorous compared to other food and non-food products. Finally, the stated preference choice experimental approach and the questionnaire method employed may have some component of self-selection, which can lead to biased results (Grebitus et al. 2016). This potential limitation was minimised by obtaining a large sample of respondents.

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CHAPTER 6

CONCEPTUAL MODEL FOR ASSESSING CONSUMERS' HETEROGENEOUS PREFERENCES FOR ENVIRONMENTAL SUSTAINABILITY ATTRIBUTES IN SOUTH AFRICA

The previous chapter assessed consumers' preferences and willingness to pay for water and carbon footprint sustainability labels, as well as the welfare implications that arise from changes in sustainability policies. However, it is very important to synthesise and identify the characteristics or key factors that significantly describe each of the consumer segments and preference attitudes identified. Therefore, this chapter presents a comprehensive conceptual model that depicts relevant factors that need to be taken into consideration when assessing consumers' preferences and choice of environmentally sustainable attributes in South Africa. The conceptual model further identifies different consumer segments and explains their behaviour based on their segment membership estimates, using a discrete choice experiment and a latent class modelling technique. The model outlines how the socio-economic and demographic characteristics of consumers, their awareness of current and future climate changes and water scarcity, and subjective and objective knowledge on environmental sustainability as well as trust beliefs will impact on environmentally sustainable choices. Consumers' knowledge levels are related to their ethics and beliefs about the environment, as well as their values and consumers' induced trust in sustainability information and sustainable products. Consumer values and induced trust impact on their attitudes, which in turn determine consumers' emotional engagement and trust intents.

6.1 SOCIAL, ECONOMIC AND DEMOGRAPHIC FACTORS THAT DETERMINE CONSUMERS' PREFERENCES AND CHOICE OF ENVIRONMENTALLY SUSTAINABLE ATTRIBUTES

From Figure 6.1, it is shown that an understanding of the choice behaviour of consumers in terms of environmental sustainability begins with a background of the socio-economic and demographic characteristics pertaining to the segment of consumers under investigation. An assessment of South African consumers' preferences for water and carbon footprints attributes using a latent class estimation approach has revealed certain important socio-economic characteristics that need to be considered in future studies.

These factors include consumer's age, gender, marital status, household size, education, income and location. The study reveals that there is variation in preferences for water and carbon footprint sustainability attributes in terms of age, with older individuals having more concern about the environment, relative to younger people, in South Africa. This is a justification for decision-makers to design educational strategies aimed at sensitising the youth towards environmental sustainability. This can be done by introducing a short course or educational programme on environmental sustainability at the basic and high school levels. This would help in changing subjective and objective knowledge, as well as the attitudes of the younger generation towards sustainability.

A segment of the younger consumers who have been exposed to the consequences of climate variations in recent years is more concerned about carbon footprint labelling. This is in line with the findings of Kempton (1991) who found that younger U.S. consumers who had experienced the current changes in climate and anticipate the future problems have higher preferences for environmentally sustainable product choices. Therefore, age is said to have different *apriori* expectations across different consumer classes, and as such, is said to be indeterminate.

Gender plays a significant role in determining consumers' related preferences for environmentally sustainable product choices. For instance, females dominate in most of the purchasing decisions in most African settings. Hence, gender differentials should be taken into consideration when analysing a consumer's choice of environmentally sustainable products. The magnitude and direction of the gender variable varies from one latent class to another.

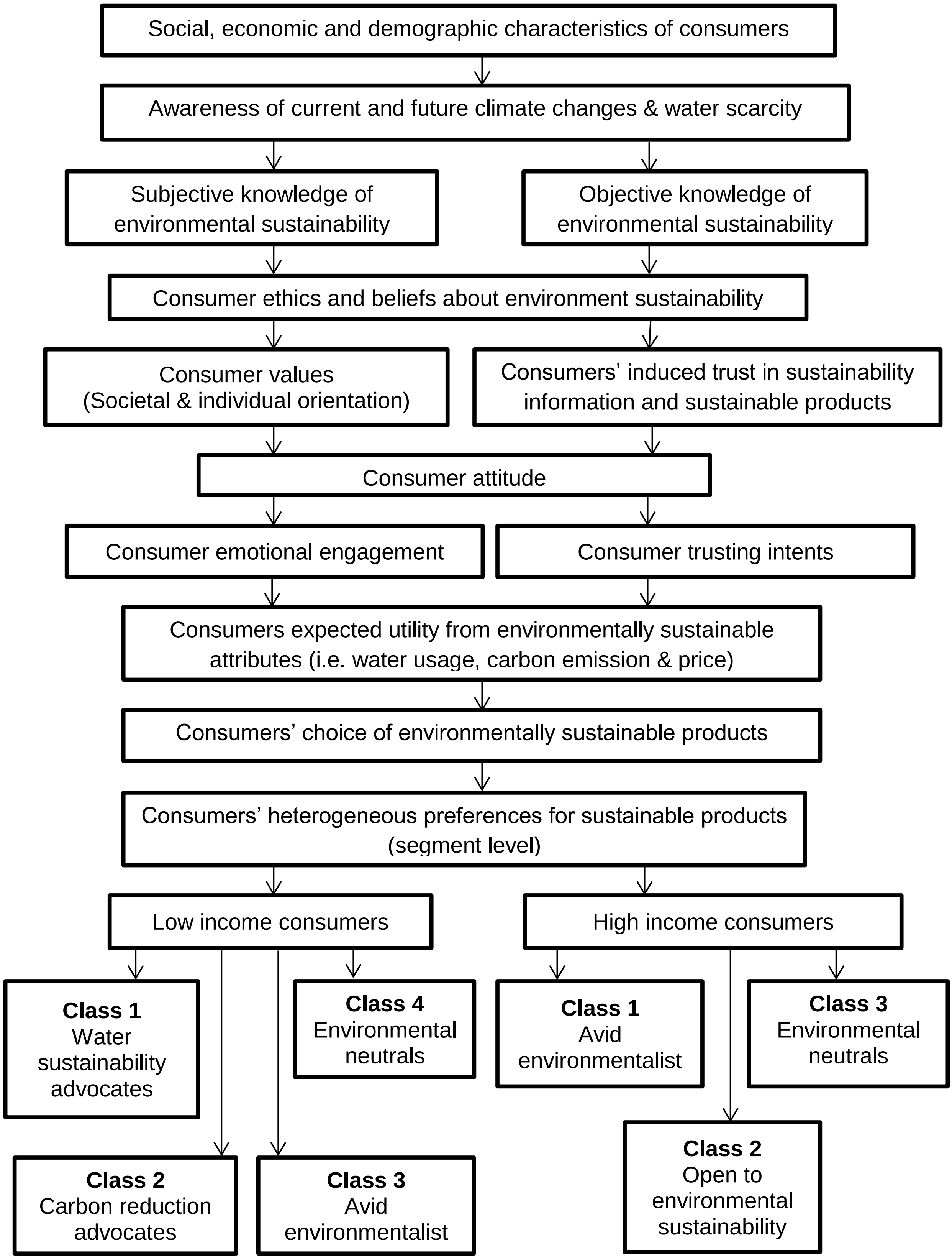

Figure 6.1: Conceptual model for assessing consumers' heterogeneous preferences for environmental sustainability attributes

Marital status and household size were found to be significant determinants of consumers' environmentally sustainable product choices, particularly among consumers who have interest in environmental sustainability. Across different consumers classes, the magnitude, direction and significance levels of these variables vary substantially. An existing study by Da Silva et al. (2014) has indicated that married people tend to think more about sustainability, relative to unmarried people. However, where married people have large household sizes, their demand increases and as such, they become financially constrained. Therefore, they tend to be less willing to pay premiums for products with indirect benefits (Owusu and Anifori, 2013).

The educational level of consumers plays a significant role in sustainability decisions of the consumers. Across all classes, the study finds that education has a significant impact on the choices of South African consumers, with highly educated individuals having positive preference attitudes towards environmental sustainability. This is translated into their choices and willingness to pay premiums for ecologically sustainable food and non-foodstuff. Similar findings were found among German and Canadian consumers (Grebitus et al., 2015).

Income was found to be a significant determinant of environmental sustainability choices of consumers in South Africa. This is consistent with economic theory since products with low water and carbon footprints considered in this study had slightly higher prices, compared with those with high footprints. Therefore, people with high income have the appropriate purchasing power and their likelihood of paying more for ecologically sustainable products is higher, all things being equal. This is consistent with the findings of Da Silva et al. (2014). Nonetheless, since preference heterogeneity among consumers in South Africa is better explained at segment level, the magnitude, direction and significance levels vary from class to class.

Finally, the location of consumers has significant impact on their preference attitude towards environmental sustainability. Consumers who reside in provinces and municipalities where climatic effects and water scarcity are major issues of concern are more conscious of environmental sustainability and have higher preferences for environmentally sustainable products. As shown in Figure 6.1 above, the socio-economic and demographic characteristics are directly linked to the consumers' awareness of existing and upcoming climate variations and water scarcity. Hence, the next section discusses consumers' awareness in detail.

6.2 CONSUMERS' AWARENESS OF CURRENT AND FUTURE CLIMATE CHANGES AND WATER SCARCITY

This section provides discussion on consumers' awareness and consciousness of the present and impending climate variations and their impact on water sustainability. The framework reveals that a consumer's awareness of the present and impending climate variations and water scarcity has significant impact on the consumer's choice behaviour in terms of environmental sustainability. Across all consumer classes, it was found that consumers who were unaware of the present and impending climate variations and their impact on water sustainability were less likely to prefer environmentally sustainable produce. This was established in the study by asking sampled respondents about their awareness of the Department of Water and Sanitation's campaign on climate changes and wise water-usage. The results revealed that the Department of Water and Sanitation's campaigns on sustainable water usage have significantly positive impacts on the choice behaviour of people regarding environmental sustainability. Therefore, it is suggested that there should be increased numbers of public awareness and campaign messages regarding the prospective benefits of saving water, the consequences of wasting water, the cost of water, and water scarcity and environmental sustainability as a whole in the country, using the dominant language of the people. Increased awareness and campaigns on environmental sustainability would enhance the knowledge of consumers, given that the concepts of water and carbon footprints are new to many people. The next section discusses consumers' subjective and objective knowledge levels in detail.

6.3 CONSUMERS' KNOWLEDGE ON ENVIRONMENTAL SUSTAINABILITY

Since the concept of water and carbon footprints are new to most consumers, it is imperative to assess consumers' knowledge levels on environmental sustainability (Brucks, 1985). Consumers' knowledge on environmental sustainability was conceptualised in two distinct ways: objective knowledge and subjective knowledge. Objective knowledge on environmental sustainability is a real knowledge paradigm that is assessed by a set of questions pertaining to environmental sustainability, whereas subjective knowledge is defined as what individuals consider or understand about environmental sustainability (Brucks, 1985).

Table 6.1: Nine subjective knowledge assessment questions for water footprint

Item	1	2	3	4	5
1. I know pretty much about water footprint of a product.					
2. I know how to judge the water footprint of a product.					
3. I think I know enough about water footprint to feel pretty confident when purchasing food products.					
4. I do not feel very knowledgeable about water footprint of products.					
5. Among my circle of friends, I'm one of the “experts” in water footprint.					
6. Compared to most other people, I know less about water footprint.					
7. I have heard of most of the campaigns to reduce water wastage.					
8. When it comes to water footprint, I really don't know a lot.					
9. I can tell if a product is water efficient and worth the price or not.					

Note: Scales (1= no knowledge …. 5= very knowledgeable)
Authors’ own elaborations

Following Peschel et al. (2016) and Brucks (1985), respondents’ subjective and objective knowledge regarding environmental sustainability was assessed using a five-point Likert scale, starting from “no knowledge-1” to “very knowledgeable-5”. Nine knowledge assessment questions were developed and used to calculate a subjective knowledge index regarding a water footprint. This assessment tool is presented in Table 6.1 and can be replicated for a carbon footprint as well as for future studies. The responses obtained from respondents from the nine questions are used to calculate a subjective knowledge index. The subjective knowledge index is included as a continuous variable in the latent class membership estimates. The results from the latent class model estimates for South African consumers show that subjective knowledge on water and carbon footprints impacts significantly on consumers’ choice of environmentally sustainable food products.

Table 6.2 below presents six objective knowledge assessment items used in estimating the objective knowledge index for environmental sustainability used in a latent class model. Items 2, 3 and 6 were reversed prior to the estimation of the index since these statements were negative from the view point of environmental sustainability. The estimates from the latent class results reveal that objective knowledge has significant impact on consumers’ choice of environmentally sustainable food products in South Africa. Specifically, objective knowledge impacts positively on consumers’ decision to search for sustainability attributes.

Table 6.2: Six objective knowledge assessment items for environmental sustainability

Item	1	2	3	4	5
1. Environmentally sustainable products are those produced with low carbon emissions and water utilisation					
2. Environmental footprint has the same meaning as carbon footprint					
3. Water footprint and carbon footprint means the same thing					
1. Water footprint measures the volume of fresh water used along the entire life cycle of a product.					
2. Carbon footprint relates to the quantity of greenhouse gases emitted along a product life cycle.					
3. Environmentally sustainable products are those produced with high carbon emissions and water utilisation					

Note: Please rate the following statements on using the following scales (1=strongly disagree, 2= disagree, 3=neutral, 4= agree, 5=strongly agree)
Source: Authors' own elaborations and Peschel et al. (2016)

This implies that there is a need for the improvement and enhancement of the subjective and objective knowledge of the general populace regarding environmental sustainability, given the threat that the current and future climate changes pose to human survival. Consumers who have a high subjective and objective knowledge index have a higher probability of choosing environmentally sustainable products. The insight drawn from this finding is that South Africans who have greater concerns for the environment are those who have higher knowledge of environmental issues. This translates into willingness to pay price premiums for environmentally sustainable products and is consistent with the findings of Laroche et al. (2001). These categories of consumers with high levels of knowledge regarding the environment have ethical concerns and beliefs in sustainable products. This suggests that consumers' ethical concerns and beliefs are linked to their level of knowledge. Therefore, the next section discusses consumers' ethics and beliefs about environmental sustainability.

6.4 CONSUMERS' ETHICS AND BELIEFS ABOUT ENVIRONMENTAL SUSTAINABILITY

In the endeavour to evaluate consumers' preferences and WTP for environmentally sustainable products, the study revealed that consumers' ethical concerns and behaviour should be accounted for. The segments of consumers with higher ethical behaviour are those who intentionally and purposefully purchase certain products, such as organic or environmentally sustainable products, because of their individual and ethical beliefs. Consumers' beliefs are defined as their personal prospective decisions regarding certain unacceptable facets of their world. Beliefs help consumers to comprehend themselves and their environment (Grebitus et al., 2015). Carrigan et al. (2004) opined that the emergence of new markets, and innovative production and marketing practices are the result of the ethical consumption behaviour of consumer segments.

South African consumers who have ethical concerns about environmental issues have a higher probability of paying for environmentally sustainable products. Therefore, ethical concerns and beliefs about environmental sustainability constitute an important factor that needs to be considered in future estimations of consumers' preferences and choice of environmentally sustainable products in South Africa. Consumers' ethical concern about the environment can be a strong motivating factor for increasing public awareness of sustainable products, sustainable practices, and threats posed by unsustainable practices on the environment. The promotion, marketing and consumption of environmentally sustainable products will be difficult if ethical concerns of consumers are not met by producers, manufacturers and agribusiness companies.

6.5 CONSUMER VALUES AND INDUCED TRUST

Consumers' values have been identified as one of the factors in the conceptual model that influence their preference for environmentally sustainable products. This concept is widely adopted in the field of societal sustainability choices (Grebitus et al., 2015). Consumer value is described as a benchmark that helps consumers on several vital issues pertaining to their day-to-day lives (Rokeach, 1968). Consumer values are lasting beliefs that certain kinds of behaviour are individually and generally desirable (Rokeach, 1968). Consumer value acts as a standard that informs consumers about the desirable way of life and what to desire. Consumer value acts as a benchmark that informs consumers as to which attitudes they should uphold. In terms of environmental sustainability, consumers' values are employed to determine and to judge what practices and behaviours are environmentally sustainable. These will also help consumers to ascertain whether practices of others are sustainable or not sustainable. This suggests that consumer values have significant impact on their attitudes, emotional responses and preferences, which emphasising the need to take consumer values into account when analysing preferences for sustainability attributes.

Consumers' trust in sustainability information and labels plays a vital role in their decision to purchase sustainable products. Since consumers cannot verify the sustainability level of products from shops, registered certification bodies and authorised bodies in charge of consumer protection must ensure that the sustainability information provided on products through labels should contain the said claim and that the said sustainability standards are adhered to. This can be ensured through constant monitoring and inspection to ensure that the sustainability standards adopted by the government are complied with. An examination of the sampled consumers' preferences for environmentally sustainable products in South Africa shows that an individual's trust in certification and foods labelling regulatory bodies has a positive impact on preferences for environmentally sustainable products. Therefore, food companies and agribusinesses should focus on building consumers' trust in sustainable food products and sustainability labelling. Consumer values and induced trust tend to influence their attitudes. The next section describes consumers' attitudes towards environmentally sustainable food choices.

6.6 CONSUMER ATTITUDE

Consumers' attitude towards environmental sustainability has a significant impact on their preferences for sustainable food products. The consumers' attitude towards environmental sustainability is described as a continuous build-up of views and beliefs on environmental sustainability issues, which influences one's decision when choosing between sustainable and unsustainable food products (Rokeach, 1968). Attitudes, in general, are defined as individual assessments, which are dependent on individual beliefs about the possible outcomes of one's conduct, and the examination of whether the outcomes would be right or wrong (Trafimow and Finlay, 2002). Consumers' attitudes impact significantly on their emotional development, such as in consumers' perceptions. Individuals with strong attitudes towards sustainability of the environment have a higher likelihood to patronise environmentally sustainable products.

As indicated in Figure 6.1 above, a consumer's attitude towards sustainable products hinges on socio-economic and demographic factors, awareness of current and future climate changes and water scarcity, knowledge on environmental sustainability, ethics and belief about environmental sustainability, values, and generalised trust. In order to change South African consumers' attitudes towards environmental sustainability, there is the need for policymakers to consider the identification of different consumer segments as a feasible strategy and possibly design segment-specific environmental sustainability (water and carbon footprint) labelling information to change consumers' attitudes towards environmental sustainability. This is because the findings from the latent class model reveal that heterogeneity in preferences for sustainability attributes are better explained at the segment level.

6.7 CONSUMER EMOTIONAL ENGAGEMENT AND TRUST INTENTS

Consumers' preferences for environmentally sustainable food products are significantly linked to their emotional engagement with current climatic variations (Roeser, 2012). Consumers' emotional engagements are anticipated to cause an increase in their understanding of sustainability through assimilating the information contained on product labelling and this will, in turn, increase the likelihood of consumers selecting sustainable products. Consumers' emotions are significant factors in their perceptions about the negative consequences of climate change. Therefore, consumers' emotional engagement should be included in educational and awareness creation messages concerning the environmental risks associated with unsustainable practices and climate changes. It must be stressed that consumers' emotional engagement and trust intents are very important for South African consumers' ethical and real-world choice making. If consumers' emotional engagements are not included in environmental sustainability information, there will be ineffective communication on environmental sustainability.

6.8 CONSUMERS' EXPECTED UTILITY FROM ENVIRONMENTALLY SUSTAINABLE PRODUCTS

Consumers' expected utility derived from environmentally sustainable products was modelled under the random utility theory, which postulates that South African consumers are rational and prefer products that give them the highest utility (Hensher and Greene, 2003; McFadden, 1974). Notably, people will choose environmentally sustainable products if these offer them the highest utility in any given choice scenario, given their budget constraints. The utilities that consumers obtain from sustainability attributes such as a water footprint, a carbon footprint and price were examined using a latent class model. The expected utility to be attained by consumers from water and carbon footprints varies from class to class. However, it was generally revealed that the majority of the consumers receive negative utility from products with high water and carbon footprints, displayed through sustainability labelling. In other words, higher utilities would be attained from products with low water and carbon footprints. This suggests that low water and high carbon footprint information is associated with high expected utilities, which translates into an individual's preferences and WTP for environmentally sustainable products with low environmental impacts (low water and carbon footprint values).

Furthermore, the study reveals that South African consumers are sensitive to price and consider it as a relevant attribute in their decisions to purchase environmentally sustainable food products. In line with economic theory, the utility obtained from higher prices is negative, irrespective of how sustainably the product is produced. The insight from this is that the pricing of environmentally sustainable products should be considered with caution, since individuals are sensitive to price changes. In summary, positive utilities are anticipated from low water and carbon footprints. However, the magnitudes and levels of significance in terms of utilities attained by consumers vary from segment to segment. The expected utility from sustainability attributes influences consumers' choice of environmentally sustainable food products. The next section explains individuals' choice of ecologically sustainable product alternatives.

6.9 CONSUMERS' CHOICE OF ENVIRONMENTALLY SUSTAINABLE PRODUCTS

The choice of environmentally sustainable attributes depends on several factors, as discussed above. Among the sampled respondents considered for this study, it was found that most consumers prefer to choose environmentally sustainable products with low water and carbon footprint values. However, there are variations in preferences, explained by several factors or class membership estimates considered in this study. The choices of consumers were found to be heterogeneous in nature, and this is explained in the next section.

6.10 CONSUMERS' HETEROGENEOUS PREFERENCES FOR ENVIRONMENTALLY SUSTAINABLE PRODUCTS

Consumers' preference attitudes towards environmentally sustainable products in South Africa are heterogeneous in nature. This suggests that one's attitude towards environmental sustainability cannot be a representation for all. Specifically, the study reveals that individuals are not homogeneous in their preferences for water usage and carbon emission attributes. Thus, individuals are heterogeneous in their preferences for products without water and carbon footprint attributes. The study found that heterogeneity in preferences for environmental sustainability attributes is well explained at segment levels, relative to individual level. Therefore, the study suggests that an attempt to design environmentally sustainable strategies and policies would require research that unearths the different consumer classes. The identification of different consumer segments would require the application of estimation approaches that account for preference heterogeneity. The conceptual model depicted in Figure 6.1 above indicates that the sustainability attitudes among different income groups vary considerably. Among the low-income respondents, the framework revealed four distinct consumer segments and their distinct characteristics are presented in Table 6.1 above. Three distinct consumer segments were found within the high-income group, and their distinct characteristics are presented in Table 6.2 above. The identified classes Among the low-income respondents are described below.

- **LOW-INCOME CLASS**

CLASS 1: WATER SUSTAINABILITY ADVOCATES

As indicated in Table 6.1 above, water sustainability advocates are likely to be within the age range of 25 to 34 years. They are more likely to be females and married individuals. These members have undergraduate levels of education, with an average household size of two. Water sustainability advocates are more likely to have higher incomes, ranging from R5135 to R11 840. Water sustainability advocates are aware of the Department of Water and Sanitation's campaign on wise water use. This segment of consumers is less likely to have high subjective and objective knowledge on environmental sustainability. These members are less likely to have high trust levels when it comes to sustainability labelling information. Finally, this class of people are more likely to have strong personal and social orientation.

CLASS 2: CARBON REDUCTION ADVOCATES

Carbon reduction advocates are mostly males, within the age range of 35 to 44 years, and are more likely to be married. Members in this consumer class on average have honours levels of education, with an average household size of three. Consumers in this segment are within the income range of R5135 to R11 840. Carbon reduction advocates are aware of the existing and upcoming climate variation impacts on the environment. They have low subjective and objective knowledge on environmental sustainability, which is not resilient enough to influence their choice of sustainable products. They have moderate trust in sustainability labelling information, with moderate personal and social orientation levels.

CLASS 3: AVID ENVIRONMENTALIST

Avid environmentalists are mostly females within the age range of 45 to 54 years and are more likely to be married, with an average household size of five. Member in this class are more likely have a master's level of education and income range of R11 840 and above. They are aware of the existing and impending climate variation impacts on the environment. In terms of knowledge, avid environmentalists have high subjective and objective knowledge on environmental sustainability. They are more likely to have trust in sustainability labelling information. These class members are resilient in terms of personal and social orientation.

CLASS 4: ENVIRONMENTAL NEUTRALS

Environmental neutrals are males within the age range of 55 years and above, and are married with an average household size of six. Members of this class are less likely to have matric level of education and have income ranging from R1783 to R2979. These members are less probable of being aware of the existing and future climate variation impacts on the environment. Additionally, these members have low subjective and objective knowledge on environmental sustainability. They are more likely to have no trust in sustainability labelling information. Finally, they have low personal and social orientation. The personal and social orientation refers to the theory that explains why a person has particular behaviours, relationships and adaptations with other people and/or society in general.

Table 6.3 below presents the characteristics of the identified consumer segments among high-income respondents. The characteristics of the consumer segments are outlined in detail in the section below.

Table 6.3: Characteristics of identified consumer segments among low-income group

Characteristics	**Class 1** Water sustainability advocates	**Class 2** Carbon reduction advocates	**Class 3** Avid environmentalist	**Class 4** Environmental neutrals
1. Age	Class 1 members are likely to be within the age range of 25 to 34 years	Class 2 members are likely to be within the age range of 35 to 44 years	Class 3 members are likely to be within the age range of 45 to 54 years	Class 4 members are likely to be within the age range of 55 years and above
2. Gender	Class 1 members are more likely to be females	Class 2 members are likely to be males	Class 3 members are more likely to be females	Class 4 members are likely to be males
3. Marital status	Class 1 members are more likely to be married	Class 2 members are more likely to be married	Class 3 members are more likely to be married	Class 4 members are more likely to be married
4. Education	Class 1 members are more likely to have undergraduate level of education	Class 2 members are more likely have honour's level of education	Class 3 members are more likely have masters level of education	Class 4 members are less likely have matric level of education
5. Household size	Class 1 members have average household size of two	Class 2 members have average household size of three	Class 3 members have average household size of five	Class 4 members have average household size of six
6. Income	Class 1 members are more likely to have high income ranging from R5135 –R11840	Class 2 members are more likely to have income ranging from R5135 –R11840	Class 3 members are more likely to have income ranging from R11840 and above	Class 4 members are more likely to have income ranging between R1783 –R2979
7. Awareness	Class 1 members are aware of the department of water and sanitations campaign on wise water use	Class 2 members are aware of the current and future climate change impacts on the environment	Class 3 members are aware of the current and future climate change impacts on the environment	Class 4 members are less likely to be aware of the current and future climate change impacts on the environment
8. Subjective knowledge	Class 1 members are less likely to have high subjective knowledge on environmental sustainability	Class 2 members have low subjective knowledge on environmental sustainability	Class 3 members are more likely to have high subjective knowledge on environmental sustainability	Class 4 members have low subjective knowledge on environmental sustainability
9. Objective knowledge	Class 1 members are less likely to have high objective knowledge on environmental sustainability	Class 2 members have low objective knowledge on environmental sustainability	Class 3 members are more likely to have high objective knowledge on environmental sustainability	Class 4 members have low objective knowledge on environmental sustainability
10. Trust	Class 1 members are less likely to have high level of	Class 2 members are more likely to	Class 3 members are more likely to have trust in	Class 4 members are more likely to have no trust in

	trust in sustainability labelling information	have moderate trust in sustainability labelling information	sustainability labelling information	sustainability labelling information
11. Personal orientation	Class 1 members are more likely to be resilient in terms of personal orientation	Class 2 members are moderately resilient in terms of personal orientation	Class 3 members are more likely to have resilient personal orientation	Class 4 members are more likely to have low personal orientation
12. Social orientation	Class 1 members are more likely to have strong social orientation	Class 2 members are moderately resilient in terms of social orientation	Class 3 members are more likely to have strong social orientation	Class 4 members are more likely to have low social orientation

Source: Author's classifications

- **HIGH-INCOME CLASS**

CLASS 1: AVID ENVIRONMENTALIST

Avid environmentalists are likely to be males within the age range of 45 to 54 years. They are married and have an average household size of four. These members are more likely have a master's level of education and an income range of R11 840 and above. Avid environmentalists are aware of the present and impending climate variation impacts on the environment. Avid environmentalists are more likely to have high subjective and objective knowledge on environmental sustainability. These members are more likely to have trust in sustainability labelling information. Additionally, they are more likely to have strong personal and social orientation.

CLASS 2: OPEN TO ENVIRONMENTAL SUSTAINABILITY

This segment of consumers, "open to environmental sustainability", are within the age range of less than 25 years. They are likely to be females and unmarried. They are more likely to have an undergraduate level of education and an income range of R5135 to R11 840. They have an average household size of three. Members of this consumer segment have low awareness levels regarding the current and future climate change impacts on the environment. Additionally, they have low subjective and objective knowledge on environmental sustainability. These members are less likely to have trust in sustainability labelling information. Finally, they have moderate personal and social orientation levels.

CLASS 3: ENVIRONMENTAL NEUTRALS

Environmental neutrals are likely to be within the age range of 55 years and above. They are likely to be married females, with average household sizes of two. They are more likely to have matric level of education and an income range of R2979 to R5135. These members have a higher likelihood of being aware of the existing and impending climate variation and the probable impacts it will have on the environment. These members have moderate levels of subjective and objective knowledge on environmental sustainability. They are more likely to have no trust in sustainability labelling information. Furthermore, these members have moderate personal and social orientation levels.

Table 6.4: Characteristics of identified consumers segment among high-income respondents

Characteristics	**Class 1** Avid environmentalist	**Class 2** Open to environmental sustainability	**Class 3** Environmental neutrals
1. Age	Class 1 members are likely to be within the age range of 45 to 54 years	Class 2 members are likely to be within the age range less than 25 years	Class 3 members are likely to be within the age range of 55 years and above
2. Gender	Class 1 members are more likely to be males	Class 2 members are likely to be females	Class 3 members are likely to be females
3. Marital status	Class 1 members are more likely to be married	Class 2 members are less likely to be unmarried	Class 4 members are more likely to be married
4. Education	Class 1 members are more likely have masters level of education	Class 2 members are more likely to have undergraduate level of education	Class 4 members are more likely have matric level of education
5. Household size	Class 1 members have average household size of four	Class 2 members have average household size of three	Class 3 members have average household size of 2
6. Income	Class 1 members are more likely to have income ranging from R11840 and above	Class 2 members are more likely to have income ranging from R5135 –R11840	Class 3 members are more likely to have income ranging from R2979-R5135
7. Awareness	Class 1 members are aware of the current and future climate change impacts on the environment	Class 2 members are aware of the current and future climate change impacts on the environment	Class 3 members are more likely to be aware of the current and future climate change impacts on the environment
8. Subjective knowledge	Class 1 members are more likely to have high subjective knowledge on environmental sustainability	Class 2 members have low subjective knowledge on environmental sustainability	Class 3 members have moderate level of subjective knowledge on environmental sustainability
9. Objective knowledge	Class 1 members are more likely to have high objective knowledge on environmental sustainability	Class 2 members have low objective knowledge on environmental sustainability	Class 3 members have moderate objective knowledge on environmental sustainability
10. Trust	Class 1 members are more likely to have trust in sustainability labelling information	Class 2 members are less likely to have trust in sustainability labelling information	Class 3 members are more likely to have no trust in sustainability labelling information
11. Personal orientation	Class 1 members are more likely to have resilient personal orientation	Class 2 members have moderate personal orientation level	Class 3 members are have moderate personal orientation level
12. Social orientation	Class 1 members are more likely to have strong social orientation	Class 2 members have moderate social orientation	Class 3 members are more likely to have low social orientation

6.11 CHAPTER CONCLUSIONS

This chapter has presented a conceptual model for assessing consumers' heterogeneous preferences for environmental sustainability attributes in South Africa. The model conceptualises the significant factors that would guide researchers and policymakers in understanding the behaviour of South African consumers. The model reveals different consumer segments among the different income groups in South Africa. The identification of different consumer segments indicates that there are heterogeneous preferences for environmentally sustainable products in South Africa. Among the factors, the conceptual model indicates that preferences for water and carbon footprints attributes significantly hinge on important socio-economic characteristics such as consumer's age, gender, marital status, household size, education, income, and location. The practical implication for marketers and policymakers is that the socio-economic targeting of consumer segments based on these factors could help shift consumers' attention to environmentally sustainable choices and consumption patterns.

Secondly, the model revealed that the awareness and consciousness of consumers regarding the current and future climate changes, and their impact on the environment, must be taken into consideration when assessing consumers' preferences for environmentally sustainable products. This is because this factor has a significant impact on consumer preferences across different classes. This provides the rationale for state departments, such as the Department of Water and Sanitation, the Department of Environmental Affairs, and the Water Research Commission, to increase their awareness and educational campaigns regarding climate change, water scarcity, costs of unsustainable water usage, and the negative effects of unsustainable practices on the environment. This will go a long way towards changing the attitudes of the public about environmental sustainability.

Thirdly, the model highlights the need for subjective and objective knowledge assessments in analysing consumers' preferences for environmentally sustainable products. The need for knowledge assessment hinges on the fact that the concepts of water and carbon footprints are relatively new to most consumers. The study has developed a knowledge assessment tool for calculating a subjective knowledge index for water and carbon footprints. Additionally, an assessment tool for estimating objective knowledge on environmental sustainability has been developed for use in future studies. These assessment tools are very important in the sense that subjective and objective knowledge was found to constitute significant determinants of consumers’ choices of environmentally sustainable products. Additionally, the model further suggests that consumers’ ethical concerns and beliefs about environmental sustainability are important factors that need to be considered in future estimations of consumers’ preferences and choices of environmentally sustainable products in South Africa. The model also indicated that consumers’ values must be taken into consideration in an empirical assessment of consumers’ preferences for environmentally sustainable products. Furthermore, consumers’ trust in sustainability information and labels impacts significantly on consumers’ decisions to purchase sustainable products. The model further highlights the fact that consumers’ attitudes towards environmental sustainability play a significant role in their choices of sustainable food products, and as such, must be considered in future sustainability assessments from the consumers’ viewpoint. Consumers’ preferences for environmentally sustainable food products are significantly connected with their emotional engagement with current climatic variations, and as such, their emotional engagement and trust intents should be considered as relevant factors in South African consumers’ ethical and sustainable product choice making.

In terms of utility, it was found that the majority of the respondents are expected to receive negative utility from high water and carbon footprint estimates, as well as prices. In other words, consumers will prefer products with low water and carbon footprint values. However, consumers’ preference attitudes towards environmentally sustainable products were found to be heterogeneous in nature, and not homogenous. The heterogeneous preferences were better explained at segment levels, rather than the individual level. This implies that an attempt to design environmentally sustainable strategies and policies would require the identification of different consumer segments. The identification of different consumer segments will require the application of estimation approaches that account for preference heterogeneity. Examples of such approaches include the latent class modelling technique and a mixed logit model. Finally, the identified consumer segments that were revealed by the conceptual model were described in terms of their characteristics. Four consumer segments were identified within the low-income group. These segments include water sustainability advocates, carbon reduction advocates, avid environmentalists, and environmental neutrals. Within the high-income group, the study found that there are three distinct consumers segments. These are avid environmentalists, those open to environmental sustainability, and environmental neutrals. The detailed characteristics of these consumers segments have been presented. The above identification and description of the identified consumer segments provides detailed guidance for policymakers and agribusinesses for identifying the relevant segment to target when dealing with sustainability polices and marketing.

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CHAPTER 7

FRAMEWORK FOR ENVIRONMENTAL FOOTPRINT LABELLING IN SOUTH AFRICA

This chapter presents a framework for environmental footprint labels in South Africa. The first part of the chapter gives an introduction to the state of environmental footprint labelling in South Africa and this is followed by an overview of environmental sustainability and the footprint labelling of food products across the global food industry. The next section presents methods for estimating and conveying footprint estimates on food products. This is followed by a discussion of labelling designs that can be adopted by agribusinesses and food companies to convey footprint information on food products in South Africa. The next section then presents a review of the practical application and implementation of environmental sustainability labelling among the various stakeholders in the food industry in South Africa. The conclusion of this chapter is presented in the last section.

7.1 INTRODUCTION

Presently, food manufacturing companies and producers in South Africa are focused on food labels containing information such as on health claims, nutritional value, country of origin, animal welfare, organic production, and Fair Trade. Food labelling that concentrates on ecologically sustainable footprint labels, such as water and carbon footprints, is relatively new and has not been developed in South Africa. However, consumers in recent years have become conscious of the inadvertent negative implications of food production on water resources and climate (Leach et al., 2016). Although consumers are becoming conscious of and understand the unintended implications of food production on water resources and the environment, sustainability attributes such as the carbon emitted and water used in the production of a particular product cannot be substantiated at the point of sales or shops (Darby and Karni, 1973). Since attributes such as carbon emitted and water utilised in the production of a particular product are credence in nature, they can be converted into search attributes through the use of carbon and water footprint sustainability labels (Peschel et al., 2016).

From a policy perspective, some attention has been given to carbon emission from various sectors of the South African economy. In September, 2015, South Africa presented its INDC in parliament, which focuses on GHG emissions reduction to about 398 to 614 MtCO_2e for the period 2025–2030 (DEA, 2015). This comes about as a result of the fact that South Africa's contribution towards limiting global warming is regarded as inadequate (DoE, 2013). In terms of water usage, the government, through the Water Research Commission (WRC), has in recent years directed some attention to the importance of water footprint assessment in the agricultural section because fresh water is becoming increasingly scarce in South Africa (Backeberg and Reinders, 2009). Increases in population, pollution, industrialisation and urbanisation add further stress to the country's fresh water sources (Backeberg and Reinders, 2009). Given that the current water scarcity situation in the country is a threat to human survival and sustainable development, the conducting of water footprint sustainability assessments across various sectors of the economy is gaining much attention. There is pressure on government and policymakers regarding the allocation of water resources.

Notably, the agricultural sector is one of the main contributors to GHG emissions in the country. Accordingly, government, policymakers and researchers are interested in knowing how environmentally sustainable attributes and information would change the sustainability behaviour of consumers and producers. An understanding of consumers' behaviour towards environmental sustainability attributes provides vital information for formulating sustainability strategies and creating awareness about unsustainable practices. This section of the study therefore develops and suggests a flexible framework for designing environmentally sustainable footprint labels to assist consumers in making well-informed purchasing decisions. The concept and the methodology employed in quantifying water and carbon footprints are described in detail in Chapter 2. The water and carbon footprints of certain dairy products have been assessed using South African case studies. The study presents four integrated ways of designing carbon and water footprint labels for food products in South Africa, with the aim of enhancing consumers' sustainable purchasing behaviour in the country.

7.2 ENVIRONMENTAL SUSTAINABILITY AND FOOTPRINT LABELLING OF FOOD PRODUCTS

As already indicated, this study focuses on designing all-inclusive, environmentally sustainable footprint labelling that would assist in determining how sustainable a particular food product is with respect to carbon emissions, energy and water utilisation. Two sustainability indicators that have gained much attention in South Africa as metrics for assessing ecological impacts on sustainability are carbon and water footprints. The comprehensive assessment of carbon and water footprint sustainability indicators will give an idea as to whether food producers or actors along the food production chain are behaving sustainably in their production. This will also assist in ascertaining the environmental impacts of producing specific food products. The assessment of a carbon footprint followed the LCA approach, as described in ISO standards 14040 and 14044 (ISO, 2006). The water footprint quantifications followed the standard approach described by Hoekstra et al. (2011) and as accepted by the Water Footprint Network. Particular attention is given to carbon and water footprints because much of the pressure on the environment and water resources are associated with these indicators, especially in the food and agricultural sector.

Conceptually, a carbon footprint is described as the quantity of carbon CO_2 equivalents emitted along a product's value chain (life cycle) (Röös et al., 2014). The LCA analysis of a carbon footprint entails all stages of the product life cycle, such as production of raw materials, product manufacturing, transportation, usage, and waste management. It also accounts for all associated inputs and outputs, as well as the allied in-flows and out-flows from the environment (ISO, 2006). Greenhouse gases are emitted at different stages along the dairy production chain. For example, there is methane emission from enteric fermentation, excreta on fields, and manure management. There are direct and indirect emissions of nitrous oxide, principally through chemical fertiliser application and manure management. Carbon dioxide (CO_2) is emitted primarily through the burning of fossil energy sources in the use of farm machinery, like tractors for pasture and forage production, milk processing plants, and other farm implements, as well as in construction. In terms of crop production, carbon emissions are associated with the use of farm implements, transportation, chemical fertiliser application and production, manure management, processing, waste management, and emissions from the soil (Röös et al., 2014).

Regarding carbon and water footprint labelling, a search through literature has revealed that carbon footprint labelling has received some attention in the agriculture and food production sector. The first carbon footprint labelling started in Britain, where consumers demanded carbon footprint labelling from companies in 2007 (Leach et al., 2016; Gadema and Oglethorpe, 2011). However, this initiative did not last for long. Swedish consumers have revealed their preferences and willingness to pay for carbon footprint labelled products (Blomqvist, 2009). Blomqvist (2009) indicated that the labelling of food products with carbon footprints information has changed consumers' consumption patterns. Carbon footprint labelling of products is practised in Germany by companies such as Unilever and French Leclerc. Carbon footprint labelling of products is practiced in the United Kingdom by the Tesco Grocery Company. This company relies on stoplight carbon footprint labelling designed by Vanclay et al. (2011).

The stoplight labelling method designed by Vanclay et al. (2011) uses colours to indicate the levels of carbon emissions. Specifically, the colour green was used to signal below-average carbon emission, yellow indicates that the emission from that particular product is closer to the average, and black shows that product has above-average carbon emissions. This labelling approach was found to have some effect on consumers' purchasing behaviour, with consumers purchasing more products with green carbon footprint stoplight labelling. However, it was found that consumers' decisions to purchase products with green carbon footprint stoplight labelling hinged on how cheap the product was. This implies that price should be a significant factor to consider when designing footprint labels. Similar colour labelling of carbon footprint information on products was conducted in Australia using green, yellow and red colours (Sharp and Wheeler, 2013).

Although this is not practised on large scale, recent studies on consumers' attitudes, preferences and purchasing behaviour towards footprint-labelled products have gained much prominence (Grebitus et al., 2015; Grebitus et al., 2016; Peschel et al., 2016). Therefore, food producers and manufacturers should take advantage of the increasing awareness and adopt footprint labelling as a possible marketing strategy in the future. Despite the growing consumer awareness and consciousness about footprint labelling, uncertainties exist as to how to convey footprint labelling information to consumers in a manner that would change their purchasing behaviour (Grunert et al., 2014). For instance, factors such as prices, availability, trust, attitude and type of information placed on footprint labelled products can daunt consumers' decisions to buy footprint-labelled food products (Röös and Tjärnemo, 2011). This suggests that there is the need for footprint labelling design and approaches that will clearly explain footprint values, benefits and welfare implications of purchasing environmentally sustainable food products, identified through footprint labelling.

7.3 APPROACHES FOR ESTIMATING AND CONVEYING FOOTPRINT INFORMATION ON FOOD PRODUCTS IN SOUTH AFRICA

The appropriate designing of labelling methods that will help consumers to understand the environmental impact of their consumption patterns and sustainable farming practices adopted in the production of food and non-food products is very relevant. This section presents estimation procedures that could be adopted for estimating and conveying footprint labels on food products. The procedures include footprint mass, sustainability index, and fractional footprint valuation methods. The above methods can be presented in different labelling designs.

7.3.1 FOOTPRINT MASS APPROACH

Under this estimation method, the water footprint of the product per kilogram is reported on the label of a particular food product. In this study, particular emphasis is given to milk, and as such, the footprint mass estimation labelling method will report the water footprint per kilogram of milk on the packaging material. For example, the water footprint of milk containing 4 % fat content and 3.3 % protein has been found to be 1352 m^3 per tonne milk per year, which can be reported on milk products by breaking it down to the weight of a given product package. This method can also be used to label the carbon footprint of dairy products. However, carbon footprints are presented in carbon emission equivalents per kilogram of milk (kg CO_2-eq per 1 kg milk). The calculations of the water footprints follows the method described by Hoekstra et al. (2011) in the manual designed for assessing water footprints, whereas the carbon footprint estimations follow the LCA approach as described in ISO standards 14040 and 14044 (ISO, 2006). Detailed explanations of these approaches are outlined in the Chapter 2. Since dairy products, like other food products, are packaged in different sizes, the footprint estimates can further be calculated based on weights of the particular food product. This is expressed empirically as:

$$WFP_{mass} = WF_i \times TWT_i \qquad (7.1)$$

where WFP_{mass} is the calculated water footprint mass; WF_i is the water footprint per kilogram of the product in question, and TWT_i is the total weight of the packaged product. Similarly, the carbon footprint mass can be calculated in a similar manner as:

$$CFP_{mass} = CF_i \times TWT_i \tag{7.2}$$

where CFP_{mass} is the calculated carbon footprint mass; CF_i is the carbon footprint per kilogram of the product in question, and TWT_i is the total weight of the packaged product.

7.3.2 BLUE WATER SUSTAINABILITY INDEXING APPROACH

This method gives an indication as to whether the product was produced in a sustainable manner or produced in a catchment area where the environmental flow requirement at a certain time period was being met (Hoekstra et al., 2011). Blue water sustainability indexing can be measured as described by Hoekstra et al. (2011). This approach involves the estimation of the blue water footprint of a particular food product and the blue water availability in the catchment areas where the product in question was produced (Leah et al., 2016). The blue water sustainability index (BWSI) can be expressed as the ratio of the blue water footprint (*BWF*) to the blue water availability (*BWA)* at specific time period. This is expressed as:

$$BWSI[z,t] = \frac{BWF[z,t]}{BWA[z,t]} \tag{7.3}$$

$BWF[z,t]$ denotes the blue water footprint of product *z* in a specific catchment area at time *t*. The blue water footprint is defined above. $BWA[z,t]$ denotes blue water availability for product *z* at time *t*. Hoekstra et al. (2012) defined blue water availability for a particular catchment at a specific time period as the natural run-off in the catchment minus the environmental flow requirement. Based on the estimated blue water sustainability index, food products can be given a sustainability index denoted in a form of drops. It must be emphasised that a product might be produced in less water-stressed catchment far away, but the additional transportation can also lead to high carbon footprint. Additionally, what happens in the catchment where the producer operates can affect the sustainability index.

7.3.3 SUSTAINABLE PRACTICE ADOPTION INDEX APPROACH

The sustainability practice adoption approach can be estimated by looking at the number of sustainable production practices that a particular farmer or producer adopts. This method will rely on specific farm information on the sustainable practices used by the farmer, without necessarily calculating water or carbon footprint values. Some of the sustainable measures that can be compared include scheduled irrigation, rotational grazing, buffer strips, rain water harvesting, and substituting feed crops with high water footprints with lower ones. The higher the number of practices used by the farmer, the higher the sustainability rating will be. The sustainable practice adoption index (SPAI) can be expressed as the number of sustainable practices adopted by the farmer over the total number of potential sustainable practices. This is expressed as:

$$\text{SPAI} = \frac{\sum \text{Sustainable practices adopted}}{\sum \text{All potential sustainable practices}} \times 100 \tag{7.4}$$

The estimated sustainable practice adoption index (SPAI) is expressed in percentage terms. Farmers or producers who score more than fifty per cent can be assigned a sustainability rating. However, the number of all possible sustainable practices should be defined, based on the type of production or farming method, and monitored by the appropriate regulatory body (Leah et al., 2016).

7.4 LABELLING DESIGNS FOR CONVEYING FOOTPRINT INFORMATION ON FOOD PRODUCTS IN SOUTH AFRICA

The four labelling design methods that can be adopted to convey footprint information estimated using the three approaches are described in section 7.3. Four labelling designs have been outlined for the three footprint labelling estimation approaches. These are the drops labelling design, the traffic light labelling design, the stars labelling design, and the nutritional labelling design. These labelling designs are presented in Table 7.1 below and explained in detail in the next subsections.

7.4.1 DROPS LABELLING DESIGN

The drops labelling design uses a drop classification system to reveal how sustainable a product is in terms of water usage. This labelling system takes into account all the three water footprint indicators (blue, green and grey) and combines them into a single water footprint indicator, denoted as the total water footprint. The total water footprint labelling for a product can take the form of 1 drop (low water footprint), 2 drops (intermediate water footprint) or 3 drops (high water footprint). This implies that the higher the number of drops on the food product labelling, the higher the indicated water usage is. The drops labelling design is applicable to all the three footprint labelling approaches. Table 7.2 presents examples of how this labelling design could be put into practice. The drops labelling design can also be presented using different coloured drops to represent different levels of water footprint.

Table 7.1: Labelling designs for the different estimation approaches water footprint (WF) and carbon footprint (CF)

Labelling designs	**Estimating Approaches**		
	Footprint mass approach	Blue water sustainability indexing	Sustainable practice adoption index
1. Drops labelling design	1. Allocate drops to WF based on pre-defined footprint mass categories 2. Use different coloured drops to represent different pre-defined footprint mass categories	1. Allocate drops to WF based on pre-defined blue water sustainability index. 2. Use different coloured drops to indicate pre-defined blue water sustainability index	1. Allocate drops to WF based on the % of sustainable practice adopted by a producer 2. Use different coloured drops to represent different % of sustainable practices adopted
2. Traffic light labelling design	1. Allocate traffic light colours to pre-defined WF and CF mass categories 2. Report estimated WF and CF and colours	1. Allocate traffic light colours to pre-defined WF based on pre-defined blue water sustainability index. 2. Report estimated WF and colours	1. Allocate traffic light colours to low, medium and high WF and CF based on the % of sustainable practices adopted 2. Report estimated WF and CF percentages categorised into low, medium and high and colours
3. Stars labelling design	1. Allocate stars to WF and CF based on pre-defined footprint mass categories 2. Average the WF and CF stars	1. Allocate stars to WF based on pre-defined blue water sustainability index	1. Allocate stars to WF and CF based on the % of sustainable practice adopted by a producer 2. Average the WF and CF stars
4. Nutritional labelling design	1. Report estimated WF and CF mass	1. Report estimated WF based on pre-defined blue water sustainability index	1. Report estimated WF and CF mass based on the % of sustainable practice adopted

Blue drops can be used to represent the blue water sustainability on a product or to give an indication to consumers that the product was produced in a catchment area where blue water use is environmentally sustainable. Red drops can be used to represent blue water unsustainability or to indicate hotspots. This is depicted in Table 7.3. The blue water sustainability indexing approach is applicable in the latter design approach.

Table 7.2: Sample drops sustainability labelling design for fresh milk

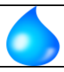
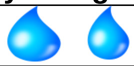
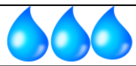
			
Environmental sustainability rating			
Water footprint			
Rating	low	intermediate	High
Water footprint relates to the use of scarce freshwater resources			

Table 7.3. Sample hotspot drops sustainability labelling design for fresh milk

		
Environmental sustainability		
Water footprint		
Catchment area	Blue water use is environmentally sustainable	Blue water use is environmentally unsustainable (hotspot)
Water footprint relates to the use of scarce freshwater resources		

7.4.2 TRAFFIC LIGHT LABELLING DESIGN

This system of labelling uses the colouring system of traffic lights to describe ranges of footprints estimated, based on any of the three estimation approaches. The colours of traffic light should be pre-defined to represent a given footprint mass, sustainability index and adoption index category. An example of this is presented in Table 7.4 for milk.

Table 7.4: Sample traffic light sustainability labelling design for fresh milk

Environmental sustainability rating			
Water footprint			
Carbon footprint			
Rating	low	intermediate	High
Water footprint relates to the use of scarce freshwater resources			
Carbon footprint relates to the contribution of climate change			

The colour green can be assigned to low footprint estimates, yellow can be assigned to intermediate footprint estimates, and red can be allotted to high footprint estimates. This design can be adopted for both water and carbon footprint labelling. The colours will make it easy for respondents who are avid in sustaining the environment in terms of carbon emission and water usage to compare and evaluate their product options. This labelling design has been tested in the United Kingdom and Australia, but for only for carbon labelling (Vanclay et al., 2011; Sharp and Wheeler, 2013).

7.4.3 STARS LABELLING DESIGN

Under the stars labelling design, stars are used to indicate how sustainable a product is in terms of water usage and carbon emission. In terms of water usage, this labelling system takes into account all the three water footprint indicators (blue, green and grey) and combines them into a single water footprint indicator. The total water footprint of a product can then be represented by stars in such way that the higher the water footprint is, the higher the number of stars on the product label will be. The star labelling for the water footprint of a product can take the form of 1 star (low water footprint), 2 stars (intermediate water footprint) and 3 stars (high water footprint). In terms of carbon footprint labelling, the star labelling design can range from 1 star (low carbon emissions) to 3 stars (high carbon emission). Table 7.5 below depicts an example of how star labelling designs can be adopted for the labelling of food products. In this example, water and carbon footprint sustainability information is presented using stars to indicate the level of sustainability. As discussed above, the sustainability rating displayed in Table 7.5 implies that the milk product in question has an intermediate water footprint and high carbon emissions. It must be emphasised that the categorisations should be based on pre-defined ranges accepted by the appropriate departments or institutions.

Table 7.3: Sample stars sustainability labelling design for fresh milk

Environmental sustainability rating	
Water footprint	★ ★
Carbon footprint	☆ ☆ ☆
Carbon footprint relates to the contribution of climate change	
Water footprint relates to the use of scarce freshwater resources	

7.4.4 NUTRITIONAL LABELLING DESIGN

This labelling design involves the inclusion of estimated water and carbon footprint information to the nutritional labels already made available on food products. This labelling design does not require a completely new label; rather, a section is created for the inclusion of water and carbon footprint information in the existing dietary label. In most markets in South Africa where nutritional information on food products is presented in grams, kilograms and/or litres, the footprint mass estimation approach will be more appropriate and simpler to incorporate into the existing labelling designs adopted by grocery companies. The inclusion on the footprint labelling to existing dietary labels will be very effective in providing consumers with vital information regarding the environmental impact of their consumption patterns. This is because the footprint information would be positioned on nutritional labels which consumers already rely on when making their purchasing decisions. Table 7.6 presents an example of a nutritional labelling design based on footprint mass calculation method.

Table 7.4: Nutritional labelling design with water and carbon footprint information for milk

Nutritional information	**Per serving**
Portion size	250ml
Energy	665kJ
Protein	8.0 g
Carbohydrate	11.8 g
Total Fat	9.3 g
Mono unsaturated fatty acids	2.3 g
Poly unsaturated fatty acids	0.4 g
saturated fatty acids	6.8 g
Trans fatty acids	0.5 g
Cholesterol	25mg
Dietary Fibre	1.0g
Sodium	102mg
Calcium	289mg
Sustainability information based on 1 litre milk weight	
Water footprint	3.704l water
Carbon footprint	1.44 kg CO_2
Carbon footprint relates to the contribution of climate change	
Water footprint relates to the use of scarce freshwater resources	

As noted above, the water footprint of milk containing 4 % fat content and 3.3 % protein has been found to be 1352 m^3 per tonne of milk per year (Owusu-Sekyere et al., 2016). Converting this amount to kilograms per day will result in 3.704x 10^{-3} litres per kilogram of milk. This is equivalent to 3.704 litres of water per gram of milk. This amount can be included in nutritional labelling, as indicated in Table 8.6. In terms of a carbon footprint, the emissions range between 1.3 and 1.5 kg CO_2 equivalent/kg milk in South Africa (Scholtz et al., 2014) and constitute an average of 1.4 kg CO_2 equivalent per kilogram of milk. Given that the sustainability estimates in Table 7.6 are based on a 1-litre weight, this approximates 1.44 kg CO_2 emitted per litre of milk. This is because a litre of milk weighs about 1.03 kg. The average CO_2 emission equivalent per litre of milk can be included in nutritional labelling, as demonstrated in Table 7.6.

7.5 PRACTICAL APPLICATION AND IMPLEMENTATION OF ENVIRONMENTAL SUSTAINABILITY LABELS AMONG DIFFERENT STAKEHOLDERS IN THE FOOD INDUSTRY

These environmental sustainability estimation approaches and labelling designs can be successfully implemented through different stakeholders in the food industry. The implementation requires the formulation of strategic policies, ranging from national to individual production levels. The relevant bodies include government, food certification bodies, food companies and stores, agribusinesses, and individual farmers. These bodies are described in detail in the following sections.

At the national level, the South African government could integrate environmental sustainability labelling into the current food labelling regulations. The government could use any of the above-mentioned footprint labelling approaches and designs to convey environmental sustainability information to consumers. The South African Food Labelling Regulations, R429/2014, can be amended to include environmental sustainability labelling, given the current consumer consciousness about the impact of food production on the environment. However, in order to append environmental sustainability labelling to current food labelling regulations, there is the need for the government to establish a reliable set of sustainability benchmarks, ethics, practices and standards which would be understood and accepted by various actors in the food industry. In order to compare different food products based on environmental sustainability, a pool of environmental sustainability data should be estimated using reliable estimation approaches. For example, if farmers are to be given premiums for sustainable food production, there is the need for well-defined sustainability practices to be prescribed for different food production areas. Additionally, quantitative data will be needed concerning different production areas, catchment areas, product varieties and provincial food product suppliers before appraisals can be made based on environmental sustainability attributes. This will require a strict inspection and certification processes to ensure that consumers are not given false information. This will also build consumers' confidence in environmentally sustainable food products.

Registered food certification bodies (e.g. South African Certification and Auditing Services (SACAS), SGS South Africa, and TNV-South Africa) are accountable for local and international food certification assessments, examinations, inspections, the implementation and safeguarding of food quality, food safety, environmental sustainability and satisfying customer demand. These registered certification bodies could be authorised by government to incorporate footprint labelling into their existing labelling design and see to it that the standards are complied with. The labelling designs and calculation methods highlighted above can be officially adopted by government for a labelling regulation. If the government were to adopt these labelling designs and calculation methods as a regulation, then food companies, agribusinesses, grocery shops, commercial farmers and private producers would be formally instructed to implement them as part of their food labelling designs. There should also be constant monitoring and inspection to ensure that the standards are met and that the relevant people comply with the authorised standards adopted by the government.

Big agribusinesses and food companies (e.g. Tiger Brands, Pioneer Food Groups, Tongaat-Hulett, and AFGRI) could also undertake an extensive implementation of footprint labelling for large varieties of foods, non-food products, and production systems. However, it must be emphasised that the implementation of footprint labelling for such large varieties of products demands further research that would aid in the creation of a detailed and reliable database. This could be costly, but if customers are willing to pay premiums for environmentally sustainable products, then agribusinesses and food companies would invest in environmental sustainability labelling. The willingness of customers to pay for sustainability labelling hinges significantly on awareness creation and educational campaigns aimed at enhancing subjective and objective knowledge on environmental sustainability. The demographic targeting of consumer segments and segment-specific educational campaigns are other policy alternatives that could be employed by these big companies to convey environmental sustainability or ecological footprint messages to various consumer segments. Additionally, footprint labelling at this level would require suppliers and retailers to these big companies to provide reliable environmental footprint labelling on products.

Small agribusinesses and food companies that have small varieties of products and production systems could easily incorporate footprint labelling into their existing labelling systems. Grocery shops, such as Woolworths Food, which already serve segments of customers with organic and environmental sustainability interests could implement water and carbon footprint sustainability labelling and attain some benefits. Furthermore, small agribusinesses and food companies that have direct linkages with local farmers would be able to rely on the sustainable practice adoption index in designing labels that directly show the local farmers' sustainability practices. This will be less costly and simple in terms of implementation and certification.

Detailed and large research initiatives for database establishment may not be needed at this level.

Lastly, footprint labelling could be adopted by individual farmers and producers. Farmers who adopt environmentally sustainable practices could link up with large and small agribusinesses and food companies that cater for segments of customers with environmental concerns and are interested in environmentally sustainable food products. Footprint labelling can result in the creation of niche markets for environmentally sustainable products. This will, in turn, draw new consumers into those segments. Nonetheless, the estimation of footprint ranges and indexes should be in line with the standards and calculation methods accepted by the appropriate food labelling regulatory body. At this level, care must be taken to ensure uniform quality and certification, since individual producers are widespread and vary in their operations.

In summary, it is worth noting that irrespective of the level at which footprint labelling is implemented; there must be reliable, feasible and consistent footprint estimation approaches taken that consider different food products, production systems, and sectors, as well as the economic aspects of footprint labelling. It must also be emphasised that for customers to understand footprint labelling, the footprint messages on labels must be presented in simple and common language that will be easier and simpler for people to read and understand. For instance, since consumers are already familiar with the star system for the labelling of products, it will be easier, simpler and more understandable when used to convey information on sustainability indicators, such as water and carbon footprints.

7.6 CHAPTER CONCLUSIONS

There has been growing awareness and consciousness among consumers about footprint labelling in recent years. However, uncertainties exist as to how to convey footprint labelling information to consumers in a manner that will be easily understood. Food producers and manufacturers are also interested in knowing how to incorporate footprint labelling into their existing labelling designs so as to take advantage of the increasing awareness and consumer consciousness and attract new customers, and possibly establish niche markets for environmentally sustainable products. This chapter has presented three footprint calculation approaches and four labelling design frameworks for water and carbon footprint labels. The estimation approaches and designs differ in term of calculations and levels of information presented on each design. The calculation methods and labelling designs offer agribusinesses and food companies alternative ways of conveying footprint information to customers.

The calculation methods highlighted above will assist in providing vital information for formulating sustainability strategies and creating awareness about unsustainable practices. The successful application of such labelling designs will assist customers in making their purchasing decision, particularly when choosing or comparing different products in terms of environmental sustainability. The integration of environmental sustainability labelling such as for water and carbon footprints on food products will enhance consumers' subjective and objective knowledge on environmental sustainability. This will, in turn, change consumers' attitudes and behaviour towards environmental sustainability, while minimising the increasing pressure on water resources, the atmosphere, and agri-food production systems. When footprint labelling designs are implemented, this will help in identifying possible markets for sustainable food products, as well as assisting farmers who produce environmentally sustainable products.

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CHAPTER 8

SUMMARY, CONCLUSION AND RECOMMENDATIONS

8.1 SUMMARY

8.1.1 BACKGROUND AND MOTIVATION

The environmental impacts of human activities and climate changes on water resources and the environment constitute a major issue of concern (Hoekstra et al., 2011; ISO, 2006). The food and agricultural sector has received particular attention in recent years because the sector is known to be a major consumer of the available scarce water resources, utilising about 86 % of all global freshwater (IWMI, 2007). The sector is also found to contribute to about 30–35% of the global GHG emissions (Foley et al., 2011). The current water scarcity situation in South Africa poses a threat to human survival and sustainable development in South Africa (DEA, 2015). South Africa is considered as one of the semi-arid regions in Africa and is rated as the 30th driest country in the world (DWA, 2013). More than 60 % of the available fresh water in South Africa is consumed by irrigated agriculture. Currently, the water required by the various sectors of the economy exceeds the quantity of water available in different catchment areas across the country (DWA, 2013). Irrigated agriculture utilises about 40 % of the utilisable runoff (Backeberg and Reinders, 2009). The livestock sector requires vast quantities of water for feed production, and it accounts for about 98 % of all the water used along the value chain (Owusu-Sekyere et al., 2016).

In terms of GHG emissions, South Africa is rated as the 12th country in the world with largest CO_2 emissions and contributes to almost half of all the GHG emissions in Africa (Carbon Tax Policy Paper, 2013). In an attempt to minimise the large carbon emissions across sectors, the government issued the Carbon Tax Policy Paper in 2013 which aims at reducing GHG emissions and facilitating the transition to a green economy. Addressing this challenge requires a thorough assessment of the various sectors of production to identify the major emission areas and the possible mitigation strategies that could be adopted to reduce emissions. One of the main sectors that require thorough assessment is the food and agricultural sector. The livestock sector contributes about 18 % of anthropogenic GHG emissions (Rotz et al., 2013). Gerber et al. (2010) revealed that the dairy sector contributes to 4.0 % of global GHG emissions.

Despite the high water usage in the livestock industry, its contribution to the economy cannot be ignored. The dairy industry contributes 14 % to the gross value of animal production, and 7 % to the gross value of agricultural production in South Africa (DAFF, 2014). The industry has great economic prospects and significantly absorbs about 4000 milk producers, who in turn provide employment to about 60 000 farm workers. Additionally, about 40 000 workers are absorbed indirectly along the dairy value chain (DAFF, 2012). This clearly shows that the South African dairy industry is very important from a socio-economic point of view. Given the significant contribution of the industry, the integration of water and energy (carbon) footprint assessments could potentially help sustainability policy decision-making, as they enable multiple issues to be dealt with simultaneously and help to avoid additional costs that would be incurred if sustainability assessments were to be conducted for water and carbon separately. Therefore, the combination of water and carbon footprint assessments in the food and agricultural sector has emerged as an important sustainability measure (Ridoutt et al., 2014).

From a policy and marketing perspective, governments, policymakers and agribusinesses are interested in knowing how water and carbon footprint labelling could be used to build sustainability attitudes and behaviour in South Africa. Additionally, private food companies seek to know whether there are sections of consumers who are willing to patronise environmentally sustainable products. An understanding of consumers' preference attitudes and behaviour towards environmental sustainability attributes provides vital information for formulating sustainability policies and marketing strategies (Hoekstra et al., 2011; Leach et al., 2016). Such information assists in minimising the increasing pressure on the environment, water resources and agri-food production systems.

8.1.2 PROBLEM STATEMENT AND OBJECTIVES

In recent years, assessments of the water and carbon footprints of products in the agricultural sector have received some attention in recent literature, globally (Amarasinghe et al., 2010; Huang et al., 2014; Ridoutt et al., 2014; Zonderland-Thomassen et al., 2014). In the African context, assessments of water footprints of crops and livestock products have also received some attention (Jordaan and Grové, 2012; Mekonnen and Hoekstra, 2010c, Scheepers, 2015; Scheepers and Jordaan, 2016; Owusu-Sekyere et al., 2016). The growing body of literature has been limited to the quantification of water footprint indicators only. No multiple footprint indicator assessment has been done in the African region. In particular, no multiple footprint indicator assessment has been done for the South African dairy industry for ensuring that there is harmonisation between sustainable water use and GHG emissions. No known study has evaluated water and carbon footprints in the dairy industry. The existing studies that have focused on multiple footprint indicator assessments of carbon, water and land use for beef cattle and sheep production systems are mainly based in developed countries (Bernardi et al., 2012; Ewing et al., 2012; Galli et al., 2012; Ridoutt et al., 2014; Rotz et al., 2013; Zonderland-Thomassen et al., 2014), with little or no such investigation being done for the semi-arid and arid regions of Southern Africa.

Moreover, the economic productivity of water utilised in the dairy industry has not been explored in South Africa. Furthermore, the impact of water and carbon footprint sustainability indicators or information on consumers' behaviour and welfare has not been explored. Prior to this study, there was no knowledge on how consumers might react to changes in sustainability, attributes, products and policies. Therefore, the current knowledge is insufficient for understanding whether, how, and why consumers, water users and managers might shift to more sustainable consumption and economically efficient production and consumption patterns in South Africa. Understanding consumers' sustainability behaviour patterns would help in identifying consumers' preferences and choices, and also aid in identifying possible markets for sustainable food products. Hence, the current environmental impacts related to water scarcity and carbon emissions in South Africa require in-depth and comprehensive information on water and carbon footprints to effectively guide South African policy and decision makers in formulating appropriate policies to guide freshwater use and reduce GHG emissions.

Therefore, the main objective of the study was to conduct a multiple footprint indicator assessment of the dairy industry and to assess the impact of carbon and water footprint sustainability attributes on consumers' behaviour and welfare in South Africa. A multiple footprint indicator assessment of the complete value chain of milk produced in South Africa was evaluated to obtain the water and carbon footprints of milk production. The final value of the water used, economic productivity, and carbon emitted during milk production were explored, and finally, the welfare implications of water and carbon footprint sustainability policy changes were assessed. This was the first step taken towards formulating an integration of multiple footprint indicator assessments that establishes harmonisations and benchmarks for the economical and environmentally sustainable use of freshwater and for managing GHG emissions in South Africa. This study also represents the first step in establishing benchmarks for the assessment of consumers' preferences, willingness to pay, and welfare measures arising from water and carbon footprint sustainability assessments. The main objective of the study was achieved through the following specific objectives:

Objective 1: to assess the water footprint and economic water productivity of feed crops and dairy products in order to determine the water use efficiency of South Africa. The focus of the study was placed principally on dairy products produced and processed in South Africa, as well as on feed crops used in the dairy sector.

Objective 2: to assess the carbon footprint (cradle to farm gate) for the dairy industry in South Africa in order to raise awareness about GHG emission and to design strategies to reduce carbon emission in the dairy industry.

Objective 3: to model consumers' heterogeneous preferences and willingness to pay for water and carbon footprint information and to quantify the welfare implications of water and carbon footprints sustainability policies on consumers in South Africa. This helps in understanding consumers' sustainability behaviour and the segment of South African consumers whose welfare is improved or reduced by sustainability policy changes. The findings provide benchmarks for policymakers in formulating effective and efficient sustainability policies.

8.1.3 LITERATURE REVIEW AND CHOICE OF CONCEPTUAL MODELS

A detailed and relevant review of literature was conducted on multiple footprint indicator assessments of the global and South African dairy industry. The global water scarcity situation and the state of water in South Africa were reviewed. Secondly, a literature review was conducted on the assessment of water footprints and the economic water productivity of dairy products. Detailed theoretical discussions on the concept of water footprints and economic water productivity, as well as methods for assessing water footprints and economic water productivity, were set out. A detailed review of the literature on carbon footprint assessment in the dairy industry was conducted, together with a comprehensive review of GHG emissions and the dairy industry, global GHG emission trends and challenges in the future, and methods of assessing carbon footprints. Detailed reviews of the LCA methodology, sources of GHG emissions, and the application of LCA methodology to South African dairy products were conducted. Furthermore, the relevant literature on consumers' preferences and welfare measurements was reviewed, with particular attention being given to consumers' awareness of sustainability attributes, consumers' preferences, and willingness to pay for sustainability attributes. Finally, the methods for estimating consumers' preferences and willingness to pay for sustainability attributes, and methods of estimating consumers' welfare measures were reviewed.

From a global perspective, the dairy industry has been an integral part of agricultural production for many years. Milk production on the global scale varies from one region to another, and from continent to continent. Milk output varies from one production system to another. The dairy industry not only contributes to milk supply, but also contributes to the global meat supply. It further acts as a key contributor to the global dietary protein needs of people. The dairy industry has grown from small-scale subsistence farming to large-scale commercial production, with substantial increases being experienced in global milk production and numbers of dairy cows. Milk production in the African region has improved significantly over the years. Despite this improvement in dairy output, production is affected primarily by climate variations. Therefore, stakeholders in the dairy industry require strategies and policy alternatives, such as breeding climate-resistant dairy cows with high milk-yielding potential, to help sustain and enhance the dairy industry's contribution to the global economy. The dairy industry plays a significant role in the South African economy. From a socio-economic perspective, the dairy industry contributes to the gross domestic product of the country, to reduction of unemployment by employing many people along the dairy value chain, and to the social and welfare improvement of people working in the industry and the country at large. Notwithstanding these significant contributions from the industry, it is uses significant amounts of water in producing feed and forage crops for feeding livestock. Hence, there is a need to incorporate efficient and sustainable water use policies in the production decisions of dairy farmers in the country.

Water footprint and economic water productivity assessments along the dairy chain are receiving much attention because water scarcity and its sustainability have become major issues of policy concern to governments, organisations, policymakers, water users and water managers. Water is one of the scarce global resources. It is estimated that about four billion people across the globe face severe water scarcity. Food and agricultural production has been found to be a major user of fresh water resources, globally. South Africa is one of the arid countries in the world. Agricultural production remains the highest user of the available water resources in South Africa. There is increasing pressure on the actors and water users in the food and agricultural sector to use water in a sustainable and economically efficient manner. Therefore, water footprint assessments have been embraced as constituting a useful tool for assessing water use in the agricultural sector. However, the inclusion of the economic aspect of water utilisation has received little attention. The review of concepts of water footprint reveals that the Global Water Footprint Standard of the Water Footprint Network, as described by Hoekstra et al. (2011), gives an all-inclusive indicator of freshwater use relative to the LCA.

The inclusion of the economic aspect of water utilisation adds more insight to the estimation of a total water footprint. Two steps are followed in the estimation of economic water productivities. Firstly, there is the need to estimate physical water productivities. Secondly, the economic water productivities are estimated by multiplying the physical water productivities by the value added to water along the value chain of the product. Methods such as the consumptive water-use-based volumetric water footprint method, the stress-weighted water LCA method, the adapted LCA water footprint method, and the hydrological water balance method, are well known in literature for estimating water footprints. The consumptive water-use-based volumetric water footprint methodology was used in this study because it accounts for the blue, green, and grey water footprints, with clear distinction being made between the sources of water.

In terms of carbon emissions and carbon footprint estimation, the review of literature showed that South Africa's contribution towards minimising global warming is insufficient. The existing emission policies in South Africa are not sufficient for significantly reducing carbon emission to the expected BAU levels. The agricultural sector is one of the sectors with a significant contribution to GHG emissions. This sector accounts for about 30–35% of global GHG emissions. The dairy sector alone contributes 4.0 % of global emissions. There is a fear that the pressure on the environment will increase in the future, with GHG emissions expected to increase due to increases in global demands for animal products. This increase in demand for animal products is attributed to the increase in world's population and shifts in consumers' dietary patterns. In view of the importance of the dairy sector, the global climate crisis, and food challenges, there is the need to gain a better understanding of the dairy sector's overall contribution to GHG emissions, to identify effective approaches for reducing emissions, and to identify where in the food chain to target these efforts. The LCA approach has been widely employed in assessing carbon footprints. The LCA has four phases, namely goal and scope definition, inventory analysis, impact assessment, and interpretation.

From a consumption point of view, the review of literature pertaining to consumers' preferences, willingness to pay, and welfare effects of water and carbon footprint sustainability information showed that it is very relevant to study consumers' behaviour and attitudes towards environmental sustainability. This can potentially assist in explaining how environmentally sustainable attributes and information would change the sustainability behaviour of consumers and producers, as well as the welfare implications of their changed behaviour. However, it was found during the review of literature that the existing research on environmental sustainability assessments in South Africa has ignored consumers' preferences, willingness to pay, and welfare measures in examining sustainability attributes.

Prior to this study, the then current knowledge was inadequate for gaining an understanding of how South African consumers would react to changes in water and carbon footprint sustainability attributes and policy changes. The methods for assessing consumers' preferences and willingness to pay for product attributes were reviewed. It was found that the preferences and willingness to pay for such sustainability attributes trace back to McFadden's standard statistical framework and Lancaster's characteristic methodology for explaining consumer behaviour and choices. The methods for assessing consumers' preferences and willingness to pay for sustainability attributes can be categorised into revealed and stated preferences approaches. The revealed preference approach is applicable when there is existing data on the product or service of study, whereas the stated preference approach is used when there is no existing data on the product or subject of study. The stated preference approach was used in this study because there was no existing data that would justify the use of the revealed preferences approach. The multi-attribute choice experiment was found to be an appropriate experimental strategy for soliciting details of consumers' choices of sustainability attributes. The review of the methods for assessing welfare estimates revealed that the compensating surplus estimation procedure was appropriate for estimating the welfare effects of sustainability attribute changes.

8.2 CONCLUSIONS

8.2.1 ASSESSMENT OF WATER FOOTPRINT AND ECONOMIC WATER PRODUCTIVITY OF DAIRY PRODUCTS AND FEED PRODUCTS

The objective of this chapter was to assess the water footprint and economic water productivity of dairy products and feed products in order to determine the water use efficiency of the dairy industry in South Africa. This objective was sub-categorised into two sections and each section was written as an article. The first article evaluated the water footprint and economic water productivities of dairy products in South Africa. A summary and the conclusions of this article are provided in the next section.

8.2.1.1 THE EVALUATION OF WATER FOOTPRINT AND ECONOMIC WATER PRODUCTIVITIES OF DAIRY PRODUCTS IN SOUTH AFRICA

A summary of the findings on this topic are provided to buttress the conclusions. The findings show that the average blue water footprint of dairy products in South Africa is lower, relative to the global average blue water footprint of dairy products considered in this study. South Africa's green water footprints for the dairy products considered in this study are higher than the global average green water footprints are. The grey water footprints for the dairy products in South Africa are lower than the global estimates for the same dairy products are. The findings imply that blue and grey water usage in the dairy industry of South Africa is lower, compared with the global estimates reported by Mekonnen and Hoekstra (2010) for the period 1996–2005. Nonetheless, the green water use along the dairy industry chain in South Africa is higher, compared with other parts of the world. Despite the low blue and grey water footprints, the total water footprints of all the dairy products considered in the study for the period 19962005 in South Africa are higher than the global average total water footprints of the same products are.

In terms of dairy products, butter had the highest total water footprint in South Africa. This is followed by the various cheese products, whether as grated or not grated, powdered or not powdered, blue-veined and cheese of all kinds. The high water footprints of all these products could be attributed to the product or value fractions employed (Mekonnen and Hoekstra, 2012). Dairy products with low water footprints include whey and milk (non-concentrated and unsweetened) not exceeding 1 % fat, respectively, followed by milk (non-concentrated and unsweetened) and cream with more than 6 % fat. The water footprints of whey and milk (non-concentrated and unsweetened) not exceeding 1 % fat in South Africa are about 64, 31 and 8 % lower than those of Morocco, Tunisia and Kenya, respectively, for the same time period (1996–2005) (Mekonnen and Hoekstra, 2010).

For both sole grazing (extensive) and mixed systems (intensive and extensive) of dairy production, the study shows that the blue water footprints for all the dairy products produced under sole grazing systems, are higher than the blue water footprints under the mixed production system are, with the exception of whey (whether or not concentrated or sweetened). The difference in water footprints could be attributed to variability in milk yields between the two systems of production. The milk output from the mixed system of production is higher than that of the sole grazing system is. Green water utilisation for the grazing system in South Africa is higher than that of the mixed production system for all the dairy products is. Additionally, the total water footprints of all the dairy products produced under the grazing system alone are higher than the total water footprints of the same products produced under mixed production systems are. The high green water footprints under the grazing or extensive system of production could be attributed to the preponderance of indirect water usage for forage production and low milk yields associated with the extensive system of raising dairy cattle in South Africa (Scholtz et al., 2014). The low milk yield from this system can be attributed to poor pasture and forage output, as well as the inability of cows to consume sufficient metabolisable energy inputs required for high milk production.

Regarding the dairy products, the highest total water footprints are associated with butter, for both grazing and mixed systems of production. This is followed by cheese products, (whether grated or not grated, powdered or not powdered, blue-veined) and cheese of all kinds, for both systems of production, respectively. Additionally, milk powder with fat content not above 1.5 %, and milk and cream powder (unsweetened) exceeding 1.5 % fat were found to be the next products with high total water footprints, for both grazing and mixed systems of production. On the other hand, whey (whether or not concentrated or sweetened), yoghurt (concentrated and unsweetened) and other dairy products containing some milk components (sweetened) were among the dairy products with low water footprints, for both grazing and mixed systems of production.

In terms of water productivities, whey, yogurt (concentrated and unsweetened), milk (unsweetened and unconcentrated) with fat content greater than 1 % but not higher than 6 % fat, and milk (unsweetened and unconcentrated) with fat content higher than 1 % had high physical water productivities, respectively, for both systems of production. Under the grazing system of production, milk and cream (unsweetened) and whey had the highest economic water productivities of 0.74 and 0.59 US dollars per cubic metre of water used to produce one kilogram of these dairy products, respectively, followed by yogurt (concentrated and unsweetened) and buttermilk (curdled milk and cream), respectively. Low economic water productivities were related with milk (unsweetened) and cream powder with fat content exceeding 1.5 %, milk and cream (sweetened), milk and cream powder (sweetened) with fat contents higher than 1.5 %, and milk powder with fat content not above 1.5 %, respectively. For the mixed system of production, milk and cream (unsweetened), and whey had high economic water productivities, respectively. These were followed by cheese (fresh unfermented and curd), buttermilk (curdled milk and cream), and yoghurt (concentrated and unsweetened), respectively. Milk and cream powder (unsweetened) with more than 1.5 % fat content has the lowest economic water productivity of 0.13 US$/m^3. These are trailed by milk and cream (sweetened), and milk and cream (unconcentrated and unsweetened) with a fat content higher than 6 %, respectively. Generally, the economic water productivities for all the dairy products under the mixed system of production are higher than those of the grazing system are.

When comparing the water footprints of the dairy products between the periods 1996–2005 and 2006–2013, the study revealed that water usage in the production of most of dairy products considered in the study has reduced, with the exception of milk (unconcentrated and unsweetened) with fat content not higher than 1 %, and the same product with fat content exceeding 1 % but not higher than 6 %. The reductions in water usage for the dairy products differ from product to product. This provides the rationale for the introduction of awareness creation and campaigns for sustainable water management that are aimed at imparting water-saving attitudes among South Africans, since water use behaviour in the dairy industry has improved, with actors becoming conscious of the present water scarcity situation.

Based on these findings, the study generally concludes that South Africa’s total water footprints of the selected dairy products are higher than the global average total water footprints are. However, the study concludes that South Africa’s average blue and grey water footprints for all the dairy products are lower than the global average blue and grey water footprints were in the period 1996–2005. Furthermore, the study concludes that South African dairy producers utilise more green water in their dairy production. Concerning the dairy products, the study concludes that butter and cheese products (whether grated or not grated, powdered or not powdered, blue-veined) and cheese of all kinds had the highest total water footprints in South Africa for the periods 1996–2005 and 2006–2013. It is also concluded that the total water footprints of all the dairy products produced solely under grazing systems are higher than the total water footprints of the same products produced under the mixed production systems were for the 2006–2013 period. It is also concluded that blue water footprints under the grazing system are higher, relative to the blue water footprints under the mixed production system are. It is also concluded that the water footprints for most of the dairy products in the period 2006–2013 have reduced, compared with the 1996–2005 estimates.

Regarding water productivities, the study concluded that the economic water productivities for all the dairy products under the mixed system of production are higher than those of the grazing systems are. Among the dairy products, the study concludes that dairy products such as milk and cream (unsweetened), whey, cheese (fresh unfermented and curd), buttermilk (curdled milk and cream) and yoghurt (concentrated and unsweetened) had the highest economic water productivities, respectively. Milk and cream powder (unsweetened) with fat content above 1.5 %, milk and cream (sweetened), and milk and cream (unconcentrated and unsweetened) with a fat content higher than 6 % had the lowest economic water productivities. Since there are low blue water footprints and high economic water productivities under the mixed production system, the study concludes that this system seems to be a better alternative, compared with the sole grazing system.

8.2.1.2 THE EVALUATION OF ECONOMIC WATER PRODUCTIVITIES ALONG THE DAIRY VALUE CHAIN IN SOUTH AFRICA

The conclusion of the second article, which evaluated the economic water productivities along the dairy value chain in South Africa and the implications for sustainable and economically efficient water-use policies in the dairy industry, are outlined in this section. Prior to the conclusions, a summary of the findings on which the conclusions are made, is provided in this section. An assessment of the economic productivity of water along the dairy value chain, starting from feed production to the final product, was conducted. The study's findings provide significant economic and efficient water use implications for actors along the dairy value chain. Based on the results on water use along the dairy value chain, the study concludes that feed production for feeding dairy cows is the highest user of fresh water along the dairy value chain.

However, the study concludes that the water footprints of feed products differ from one feed product to another. Therefore, there is a need to undertake a water footprint assessment of the different feed products to identify the ones that are higher users of fresh water resources. Regarding blue water consumption in the dairy industry, the study reveals that feed products, such as lucerne hay, maize silage and sorghum silage, are higher users of blue water resources. Nevertheless, relying on the water footprint estimates alone to judge these products will be inappropriate. There is a need to undertake an assessment of the contributions of the feed products to milk production. The study evaluated the contributions of the different feed products to milk yield. The findings reveal that yellow maize meal, high protein concentrate, and lucerne hay are the highest contributors to milk output, respectively.

Notwithstanding the fact that feed production utilises the highest proportion of water along the dairy value chain, the study concludes that the production of the feed products considered in this study is economically efficient with regard to costs and water use. This is based on an assessment of the value addition and economic water productivities of the selected feed products. From an economic point of view, the findings suggest that the revenue attained from producing the feed crops, and the value added to water along the dairy value chain, exceed the costs incurred. Accordingly, the study concludes that dairy livestock farmers and producers are economically efficient in their production. The study concludes that high protein concentrate, yellow maize meal, lucerne hay, and sorghum and maize silages have high economic values, respectively.

Furthermore, the study asserts that the value added to milk as it moves along the value chain differs from stage to stage. The highest value is added at the processing level, followed by the retail level and the farm gate, respectively. Moreover, the estimates suggest that milk production at each stage along the value chain is economically efficient in terms of costs and water use. In terms of marketing, the findings show that more value is added to milk and water when packaged in smaller sizes. Hence, the study concludes that the type of packaging adopted for processed dairy products along value chain has an impact on value addition and economic water productivity estimates.

8.2.2 ASSESSMENT OF CARBON FOOTPRINT ALONG THE DAIRY VALUE CHAIN IN SOUTH AFRICA

An assessment of the carbon footprint (from cradle to farm gate) for milk produced and processed in South Africa was conducted. This was done to raise awareness about GHG emissions and to design strategies for reducing carbon emissions in the dairy industry. This assessment helped to identify the major emission areas and the possible mitigation strategies that could be implemented to reduce GHG emissions. The LCA methodology was employed in this assessment. A summary of the findings shows that the total carbon footprint of milk with 4 % fat and 3.3 % proteins produced and processed in South Africa is 2.72 kg CO_2e per kg. The study concludes that the carbon footprint of milk produced under the mixed system in South Africa is higher than global average for the same system of production is. Nonetheless, this carbon footprint estimate is in line with the carbon footprint of milk produced under a grassland system (Gerber et al., 2010).

Methane accounted for 57.9 % of the total carbon footprint, followed by nitrous oxide (31.6 %) and carbon dioxide (10.5 %), respectively, in South Africa. About 98.73 % of the methane emissions emanated from enteric fermentation. More than half of the direct nitrous oxide emissions emitted from excreta and manure management. Fertiliser production and application alone accounted for about 78 % of the total carbon dioxide emitted along the milk product chain. By reasonably varying one parameter, holding all the others constant, the total carbon footprint could considerably increase by 17.28 %.

Based on the study's findings, it is concluded that methane has the highest impact of the GHG in the dairy industry of South Africa. The study also concludes that about 98.73 % of the total methane emission is attributed to enteric fermentation. It is further concluded that the impact of methane on GHG emission in milk production in South Africa is higher, relative to developed countries. Besides methane, the study concludes that nitrous oxide is the next largest contributor to the total carbon footprint of milk in South Africa, with direct emissions from excreta and manure management being the largest contributors to total nitrous oxide emissions. Carbon dioxide (CO_2) emissions contributed the least to the total carbon footprint of milk in South Africa.

Finally, the study concludes from the sensitivity analysis that changes in a parameter can significantly influence the total carbon footprint estimates. More specifically, specific parameters such as the country-specific methane emission factor, the emission factor for methane from enteric fermentation, the emission factor for direct nitrous oxide emission, and dry matter intake, respectively, impact on the estimated carbon footprint.

8.2.3 MODELLING CONSUMERS' HETEROGENEOUS PREFERENCES AND WILLINGNESS TO PAY FOR WATER AND CARBON FOOTPRINT INFORMATION AND QUANTIFICATION OF WELFARE IMPLICATIONS OF WATER AND CARBON FOOTPRINTS SUSTAINABILITY POLICIES ON CONSUMERS IN SOUTH AFRICA

The consumers' choices of environmentally sustainable products are very important to sustainable food product marketing and sustainability policies. Therefore, this subsection presents insights on consumers' heterogeneous preferences and willingness to pay for water and carbon footprint information. Secondly, the welfare implications of water and carbon footprints sustainability policies on consumers were assessed. These are important for gaining better understanding of consumers' sustainability behaviour and how environmentally sustainable policies impact on the welfare of consumers. This chapter was written in two articles. The first article focuses on consumers' stated preferences for water and carbon footprint-labelled food products, from the viewpoints of the low- and high-income consumer classes. The second article focused on the compensating welfare estimates of water and carbon footprint sustainability policy changes in South Africa.

8.2.3.1 CONSUMERS' STATED PREFERENCES FOR WATER AND CARBON FOOTPRINT-LABELLED FOOD PRODUCTS: INSIGHTS FROM LOW- AND HIGH-INCOME CLASSES

An assessment of the preferences for water and carbon footprint sustainability attributes from the viewpoints of different income categories in South Africa was conducted. The impacts of socio-economic characteristics, awareness, trust and environmental sustainability knowledge levels on consumers' choices of water and carbon footprint-labelled food products were determined. A latent class modelling technique and attribute-based choice experimental data from beef and milk consumers were used. The study concludes, based on the findings, which preference heterogeneity exists for water usage and carbon emission along the value chain of beef and milk among the low- and high-income respondents in South Africa. Moreover, heterogeneity in preferences exists for beef and milk products without water and carbon footprint labelling information. It is important to also conclude that the heterogeneity in preferences revealed for the sustainability attributes was better explained at the segment level, rather than the individual level. Consumers' preferences for environmentally sustainable food products differ considerably between the low- and high-income groups in South Africa.

It is imperative to point out that different latent consumer classes exist for both product categories among low- and high-income respondents. The low-income respondents comprised four distinct consumer classes, named as water sustainability advocates, carbon reduction advocates, keen environmentalists, and environmental neutrals. The high-income class consists of three distinct consumer segments, named keen environmentalists, environmental cynics, and environmental neutrals. This proves the existence of greater diversity within the low-income group in terms of preferences for environmentally sustainable attributes, relative to high-income respondents. Nonetheless, there are more keen environmentalists among the high-income group, compared with the low-income group.

In terms of important determinants, the study proves that consumers' trust in food labelling regulatory bodies, awareness, and knowledge of environmental sustainability, as well as traditional socio-economic factors, have substantial impacts on their choices of environmentally sustainable food products. The study highlights the significance of the inclusion of awareness creation and knowledge building on environmental sustainability to communal and municipal policy. It is relevant to mention that consumers' knowledge of environmental sustainability is somewhat low.

8.2.3.2 COMPENSATING WELFARE ESTIMATES OF WATER AND CARBON FOOTPRINT SUSTAINABILITY POLICY CHANGES IN SOUTH AFRICA

The application of environmentally sustainable policies in the food and agricultural sector requires an understanding of consumers' preferences for environmentally sustainable food products and the welfare implications of consumers' choices. The study adopted a compensating surplus welfare estimation approach which reveals that there are varying welfare effects arising from water and carbon footprint sustainability policies, from one class to another. The study further proves that there are pertinent segmental equity issues that need to be addressed when designing environmental sustainability policies. The study concludes that willingness to pay for different levels of water usage and carbon emissions varies across different classes. Three classes of consumers were identified with different welfare implications. For both segments one and two, the study concludes that respondents are willing to pay higher amounts for low water footprint levels, compared with low carbon footprint levels. Therefore, the study proves that preferences for a low water footprint are higher than those for a low carbon footprint are.

The compensating welfare estimates disclose that the introduction of water and carbon footprint sustainability policy scenarios will have a negative impact on the welfare of respondents in segments one and two, given their utilities and willingness to pay estimates. Welfare improvement will be attained when respondents are compensated for choosing products with low water and carbon footprint values. In general, the welfare losses vary from one class to another, with class one members suffering the highest welfare loss. Consequently, there are imperative segmental equity issues that need to be taken into consideration when designing environmental sustainability strategies to change consumers' behaviour, with the aim of minimising the environmental impact.

8.2.4 CONCEPTUAL MODEL FOR ASSESSING CONSUMERS' HETEROGENEOUS PREFERENCES FOR ENVIRONMENTAL SUSTAINABILITY ATTRIBUTES IN SOUTH AFRICA

In this chapter, a detailed conceptual model is explored that depicts relevant factors that need to be considered in order to fully understand consumers' preferences and choice of environmentally sustainable products in South Africa. The conceptual model has revealed different consumer segments and explained their behaviour based on their segmental characteristics, using a discrete choice experiment and latent class modelling technique. From the conceptual model, different consumer segments are found within the different income groups in South Africa. This further confirms the existence of heterogeneous preferences for environmentally sustainable products in South Africa, as found in the previous chapter. Generally, the model depicts that consumers' preference attitudes towards environmentally sustainable products are not homogeneous in nature, but rather heterogeneous. The identified consumers segments revealed by the conceptual model were described in terms of their characteristics.

The study indicates that preferences for water and carbon footprints attributes significantly hinge on important socio-economic characteristics such as consumer's age, gender, marital status, household size, education, income, and location. The practical implication for marketers and policymakers is that the socio-economic targeting of consumer segments based on these factors could help shift consumers' attention towards environmentally sustainable choices and consumption patterns.

Beside socio-economic factors, the awareness and consciousness of consumers regarding the current and future climate changes and their impact on the environment are important variables to be considered when assessing consumers' preferences for environmentally sustainable products. These factors impact significantly on consumer preferences across different classes. In terms of knowledge, the study concludes that it is very relevant to include the subjective and objective knowledge of people in the assessment of preferences for environmentally sustainable products. The need for an environmental knowledge assessment hinges on the fact that the concepts of water and carbon footprints are relatively new to most consumers. In this study, subjective and objective knowledge assessment tools or instruments have been developed to assist future researchers in measuring subjective and objective knowledge indexes for water and carbon footprints.

Additionally, it is concluded that consumers' ethical concerns and beliefs about environmental sustainability are important factors that need to be considered in the estimation of consumers' preferences and choices of environmentally sustainable products in South Africa. Human values and trust in sustainability information and labels should also be taken into consideration in such empirical assessments of consumers' preferences for environmentally sustainable products. The study further reveals that consumers' attitudes towards environmental sustainability play a significant role in their choices of sustainable food products. An individual's emotional engagement with current climatic variations and trust intents should be considered and taken into consideration in an assessment of ethical and sustainable product choice making.

8.2.5 FRAMEWORK FOR ENVIRONMENTAL FOOTPRINT LABELLING IN SOUTH AFRICA

There has been growing awareness and consciousness among consumers about footprint labelling in recent years. Food producers and manufacturers are also interested in knowing how to incorporate footprint labelling into their existing labelling designs so as to take advantage of the increasing awareness and consumer consciousness to attract new customers, and possibly establish niche markets for environmentally sustainable products. A framework for environmental footprint labelling has been developed and discussed in South Africa. Specifically, methods for estimating and conveying footprint information on food products in South Africa are outlined. Different labelling designs for assisting agribusinesses and food companies in conveying footprint information on food products are developed, and their practical implications are discussed. The study has presented three footprint calculation approaches and four labelling design frameworks for water and carbon footprint labels. The study concludes that the estimation approaches and designs for footprint labelling differ in term of calculations and levels of information presented in each design.

The study concludes that estimation methods, such footprint mass, sustainability index, and fractional footprint valuation, can be adopted for estimating and conveying information on footprint labels on food products. These three calculation methods can be presented in four labelling designs. These design methods are the drops labelling design, the traffic light labelling design, the stars labelling design, and the nutritional labelling design. The successful application and implementation of these calculation methods and labelling designs could potentially assist customers in making their purchasing decisions, particularly when choosing or comparing different products in terms of environmental sustainability.

8.2.6 GENERAL CONCLUSIONS

Based on the specific conclusions drawn from the various sections of the study, it is generally concluded that the sustainability assessment of food and non-food products in different sectors should not be limited to a single indicator assessment, but rather that multiple sustainability indicators should be assessed together in a holistic and integrated manner. For instance, projects that focus on sustainability assessments, such as water footprints, can include carbon footprint assessments. Thus, the study concludes that the combination of different sustainability and footprint indicators in a single assessment is very insightful and feasible. The study concludes that a multiple footprint indicators assessment that combines water and carbon footprints is necessary and should be adopted because policies for reducing GHG emissions along a particular product cycle may require higher water utilisation. Furthermore, environmental policies and programmes designed to improve water quality and efficient water utilisation might involve significant energy consumption, which could potentially result in higher GHG emissions. Therefore, the study points to the need to consider sustainability assessment in a holistic approach by considering different ecological footprints in a single assessment in South Africa.

Finally, the study concludes that the concurrent assessment or integrated approach of sustainability assessment is imperative for providing insightful ecological policy recommendations and to escape any possible undesirable impacts that might arise from narrowing sustainability assessment to a single indicator. The integration of water and energy (carbon) footprint assessments can possibly assist policymakers and governments by providing them with insights into multiple ecological issues, simultaneously. In economic terms, the study concludes that the integration of water and carbon footprint assessments can possibly minimise costs, as the extra costs that would have been incurred in doing separate assessments are avoided.

8.3 RECOMMENDATIONS

A number of recommendations and suggestions emanate from the findings of this study. These recommendations and suggestions have important implications for water users (livestock producers, small-, medium- and large-scale businesses), policymakers and future researchers. The recommendations from the study are categorised into three. The first set of recommendations is addressed to water users to assist them in making their sustainable production choices. The second set of recommendations is addressed to policymakers in order to assist in successfully implementing sustainability policies. The last set provides recommendations for future research to assist researchers in executing appropriate and meaningful research on environmental sustainability.

8.3.1 RECOMMENDATIONS FOR LIVESTOCK PRODUCERS, SMALL-, MEDIUM- AND LARGE-SCALE AGRIBUSINESSES

1. For livestock producers, the study recommends that feed conversion efficiencies of animals kept on both sole grazing and mixed systems of production should be improved. The improvement in feed conversion efficiency will lead to low water footprint estimates (Bosire et al., 2015). Hence, the study suggests that dairy livestock producers should review their pasture and rangeland management strategies to increase feed availability

and quality, with the aim of increasing dairy output, which in turn will reduce water footprints.

2. In terms of production systems, the study recommends that livestock producers operating under the sole grazing and mixed systems should breed animals with better growth rates and milk yields per cow in order to enhance dairy output. This will reduce water footprints and enhance water productivities. Low milk yields result in higher water footprint estimates. Therefore, production systems with low milk yields directly result in high water footprint values.

3. For dairy processors, the study recommends including product water footprint assessments in their production decisions in order to identify products with high water footprint estimates. This is relevant in the sense that high water footprints of products raise major concerns regarding water sustainability and also increase production costs (i.e. blue water consumption). Dairy processors should consider investing in technologies that minimise water usage and increase dairy product outputs, especially for products such as butter and cheese.

4. For dairy farmers, farm management options that could potentially boost water productivities of livestock production entail the enhancement of livestock output, improvement in the feed efficiency of cows, animal health improvement and investment in water saving technologies. Moreover, the adoption of forage and pasture management practices that circumvent land degradation and reduce the quantity of water needed for field and forage crops is potentially relevant.

5. Dairy livestock producers should pay particular attention to feed products such as yellow maize meal, high protein concentrate and lucerne hay when formulating ration for dairy cows, with the aim of attaining high value addition and economic water productivities, in view of the high milk yields associated with the use of these feed products. The high milk yield associated with the use of these feed products can reduce water footprint estimates. Yellow maize meal, high protein concentrate and lucerne hay appear to be very economical in terms of water and to give a high contribution to milk yield, with positive value addition.

6. For producers and marketers of livestock feed, the study revealed that the value added to the feed products along the dairy value chain varies from product to product, and as such

and in order for them to attain more profit, they should consider an assessment of value additions from the various feed products.

7. Maize silage has low economic water productivity and somewhat low contribution to milk yield, and as such, the study suggests that dairy farmers and livestock producers should substitute it with a better option, such as triticale silage which is known to offer a high contribution to milk yield and is economically productive in terms of water use. This provides the rationale for profit-maximising dairy farmers with sustainable and efficient water use objectives to reconsider their dairy livestock feed formulation by incorporating more of the feed products with good contributions to milk output and economic water productivities.

8. The findings on consumers' behaviour and choice of environmentally sustainable products in South Africa indicate heterogeneous behaviour. Therefore, the study suggests that agribusinesses should consider identifying sustainable products and consumer segmentations as a feasible marketing strategy. This can be practically implemented by designing water and carbon footprint labels for products.

9. Generally, the findings suggest that some consumers potentially prefer beef and milk products labelled with low water usage and carbon emissions information. Therefore, producers and agribusinesses could create niche markets for environmentally sustainable food products, provided that the low water and carbon footprint information or labels can be assured.

10. Given the diversified segments of consumers identified in the study, the study recommends that it will be efficient for food producers to design different environmental marketing strategies for different consumer segments.

11. In the low-income- and high-income-dominated communities and markets, the environmental and ecological footprint labels can be presented in the local language that is understood by the majority or all of the residents in the areas. This can potentially make environmental sustainability labelling information easier and simpler for the majority of the people to understand, rather than presenting footprint messages in a technical language that is difficult to understand. Thus, it is expedient for footprint messages to be conveyed to consumers in plain labelling statements that are easy to understand.

12. From a marketing point of view, the study suggests that building consumers' trust in ecological or sustainability labelling regulatory bodies is a relevant marketing strategy that can potentially be adopted by agribusinesses to promote environmentally sustainable products. Food companies and agribusinesses can take action based on the identified segments of consumers who prefer environmentally sustainable food products and their segment characteristics.

13. Food companies and agribusinesses can obtain price premiums for environmentally sustainable labelled food products that are identified through footprint labelling.

14. The demographic targeting of consumer segments, awareness creation and segment-specific educational campaigns aimed at enhancing subjective and objective knowledge of environmental sustainability are important tools for food companies and agribusinesses in promoting and marketing environmentally sustainable food products.

15. Large agribusinesses and food companies (e.g. Tiger Brands, Pioneer Food Groups, Tongaat-Hulett, and AFGRI) can also undertake an extensive implementation of footprint labelling for large varieties of food foodstuffs, non-food products, and production systems. Nonetheless, it must be emphasised that the implementation of footprint labelling for such large varieties products demands further research that would aid in the creation of a detailed and reliable database. This can be costly, but if customers are willing to pay premiums for environmentally sustainable products, then agribusinesses and food companies could invest in such environmentally sustainable labelling.

16. Small agribusinesses and food companies that have small varieties of products and production systems can easily incorporate footprint labelling into their existing labelling systems. Grocery shops such as Woolworths Foods which already provide segments of its customers with organic and environmental sustainability interests can implement water and carbon footprint sustainability labelling without much difficulty and attain some benefits.

17. Small agribusinesses and food companies that have direct linkages with local farmers can rely on the sustainable practice adoption index to design labels that directly show the local farmers' sustainability practices. This will be less costly and simple in terms of implementation and certification. Detailed and large research for database establishment may not be needed at this level.

18. Footprint labelling can be adopted by individual farmers or producers. Farmers adopting environmentally sustainable practices can link up with large and small agribusinesses and food companies that have segments of their customers with environmental concerns and are interested in environmentally sustainable food products. Footprint labelling can result in the creation of niche markets for environmentally sustainable products. This will in turn draw in new consumer segments. Nonetheless, the estimation of footprint ranges and indexes should be made in line with the standards and calculation methods accepted by the appropriate food labelling regulatory bodies.

19. It is vital to highlight the point that, irrespective of the level at which footprint labelling is implemented, there must be reliable, feasible and consistent footprint estimation approaches taken that consider different food products, production systems and sectors, as well as the economic aspects of footprint labelling. Since consumers are already familiar with the stars method of labelling of products, the study suggests that it will be easier, simpler and more understandable when used to convey information on sustainability indicators such as water and carbon footprints. Additionally, footprint labelling at this level will require suppliers and retailers of these big companies to provide reliable environmental footprint labelling on products.

8.3.2 RECOMMENDATIONS FOR POLICY MAKERS

1. Policies are required to be put in place to ensure that feed products, such as butter and cheese products, which have large high water footprints can be given particular attention. An alternate policy option would be the importation of such products (butter and cheese) with high water footprints from countries with sufficient water resources and where the same products are produced with minimal water usage.

2. Given the different profitability and economic water productivities of products in the dairy industry, the study suggests that policymakers, water users and managers along the dairy value chain should not rely on water footprint estimates alone to judge the dairy industry; rather, the

3. The necessity to provide resource use information to consumer, apart from the market price, quality and safety information and the physically observable features of the product, to guide product choices and indirectly the use of source and sinks. The market price of the final product is the culmination of information contributions of buyers and sellers all

along the supply chain with intimate knowledge of production and utility considerations. However, the market price of the final product may not reflect the true value of water as markets may be distorted, especially when agricultural water prices are determined by water allocation authorities. The cost of carbon emitted into the atmosphere is an even better example of an externality not captured in private cost structures and in the final product price. The crucial question is if those externalities can be internalized more effectively by facilitating product choice at the shop shelf to favour products with low water and or carbon footprint. The mere provision of a water footprint or carbon footprint measured on micro level, without taking the broader picture into account, will certainly jeopardize the efforts to attain more effective use of sources and sinks.

The dairy sector itself provides a good example. During the past few decades, South African milk production relocated to a large extent to the eastern and southern coastal areas where the total availability and seasonal distribution of water (mainly runoff water from coastal mountains) allow cheaper roughage production as the main feed source for milk production. This relocation was/is driven mainly by financial considerations and availability of water for feed production. Thus, considering the fact that water utilization for feed production accounts for about 98% of all the used along the production cycle. Many inland factory type dairy operations based mainly on transporting total mixed ration to cows confined in small areas could not compete with cheaper grazing based milk production. As grazing based systems provide roughage as the dominant feed component, less grain-based supplements are required. Dairy farms in the coastal areas use more water for the irrigation of pastures, but agricultural and especially non-agricultural competition for water is less than in the more densely populated and drier inland parts of South Africa. The coastal areas with limited cold units are less suitable for the production of high value fruits crops.

The Tsitsikamma area as one of the major milk producing areas in South Africa is a very good case in point. Dairy production offers a high value use of water than say pasture based beef or mutton production with the same water. If the water is not used for irrigation agriculture-more specifically dairy, it will merely run into the sea. To put a water footprint symbol or count on a dairy product will motivate consumers to prefer milk from total mixed ration based dairy farm in the drought stricken western part of Western Caper or other inland Metropolis of Southern Africa will clearly be ineffective. This implies that the “where from” considerations cannot be separated from the “how much” consideration. This implies that dairy supply chains using water footprint information as a selling point, try to maximize profit from a micro perspective will be contra-productive if the aim is to facilitate better resource use decision making from a broader perspective.

4. Policy makers and municipal authorities should consider educating people on the prospective benefits of saving water, the consequences of wasting water, the cost of water, and the water scarcity situation, including threats posed by climate change, across different consumer segments in their local or dominant language.

5. Food policymakers should take into account welfare measures in their sustainability policy frameworks. This can potentially help to identify the segments of consumers whose welfare will be impacted on positively or negatively by environmentally sustainable food policy changes.

6. The successful implementation of water and carbon footprint policies will require a compromise to be made between environmental sustainability and improvements in the welfare of the general public. If the aim is to maximise the welfare of consumers and to sustain the environment, then the cost of producing environmentally sustainable products should not be transferred to consumers. This cost can be absorbed by the government whose aim is to sustain the environment. In other words, farmers or producers can be compensated for producing environmentally sustainable products.

7. Policy options are needed to enhance consumers' subjective and objective knowledge of environmental sustainability. Important policy options needed to achieve this include the demographic targeting of consumers, awareness creation, and segment-specific educational campaigns on sustainable water usage and carbon reduction. This provides the rationale for state departments, such as the Department of Water and Sanitation, the Department of Environmental Affairs, and the Water Research Commission, to increase their awareness and educational campaigns on climate changes, water scarcity, cost of unsustainable water usage, and negative effects of unsustainable practices on the environment. This will go a long way towards changing the attitudes of the public about environmental sustainability.

8. Policies are required to integrate environmental sustainability information labelling, such as for water and carbon footprints, on food products and this can potentially enhance consumers' subjective and objective knowledge on environmental sustainability. This can in turn change consumers' attitudes and behaviour towards environmental sustainability,

while minimising the increasing pressure on water resources, the atmosphere, and agri-food production systems. When footprint labelling designs are implemented, it can potentially help in identifying possible markets for sustainable food products, as well as assisting farmers who produce environmentally sustainable products.

9. Registered food certification bodies, such as South African Certification and Auditing Services (SACAS), SGS South Africa, and TNV-South Africa, that are accountable for local and international food certification assessments, examinations, inspections, implementation and safeguarding the food quality, food safety, environmental sustainability and satisfying customer demand can be authorised or motivated by government to require the incorporation of water and carbon footprint information labelling into the existing required labelling designs. These registered certification bodies should ensure that sustainable practices and standards are complied with. The labelling designs and calculation methods outlined in this study could be officially adopted by policymakers and governments as a labelling regulation.

10. Policies are required to formally ensure that food companies, agribusinesses, grocery shops, commercial farmers and private producers incorporate environmental sustainability labelling designs and calculation methods as part of their food labelling designs. There should also be constant monitoring and inspection to ensure that the standards are met and that the relevant people comply with the authorised standards adopted and with the sustainability benchmarks that will be adopted by the government.

11. Policymakers should consider the identification of different consumer segments and possibly design segment-specific water and carbon footprint labelling information and educational campaigns to initiate change towards achieving environmental sustainability.

12. Policies are required to ensure that farmers and producers adopt local water saving technologies that are practical and cost efficient. The investment in water saving technologies, and the adoption of field and forage crops with lower water consumption requirements can potentially help sustain water.

13. Policies are required to incentivise farmers to produce environmentally friendly products. Policy options include granting subsidy payments or price premiums to farmers who produce in an environmentally friendly and sustainable manner.

14. Training and guidance on environmentally sustainable practices are vital to the successful adoption and implementation of environmentally sustainable practices.

15. Policymakers should strive for the establishment of country- and regional-specific benchmarks for the water footprint and carbon emission factors to be used for calculating and assessing water consumption and carbon emissions at local levels and across different industries.

8.3.3 SUGGESTIONS FOR FUTURE RESEARCH

1. Considering the role played by data availability in sustainability assessments, future research is needed to ensure the availability of consistent, reliable and frequent livestock survey data at provincial and national levels in South Africa. This can potentially safeguard the precision of future studies that focus on productivities and efficient uses of resources in different livestock production systems.

2. Further research is required for water and carbon footprint assessments for dairy production under the systems and products not considered in this study in order to gain a detailed understanding and overview of the overall water use and carbon emissions in the livestock industry.

3. Future research should consider the assessment of water footprints and economic water productivities for different meat production systems in South Africa, since this study only focused on dairy products.

4. Future research is necessary to develop country-specific water and carbon footprint benchmarks for different product categories and production systems to serve as a reference and assist in establishing water and carbon reduction targets in South Africa.

5. The study further suggests that future research on estimations of ecological footprints such as water should not be limited to the quantification of the footprint indicators alone. Rather, researchers should take into account economic water productivities and the monetary value added to the product along its value chain since this provides meaningful and significant economic implications.

6. The role played by key parameters in the estimation of GHG emissions in different livestock production systems need to be investigated across different provinces. This will help to attain more accurate and consistent carbon footprint estimates at national and regional levels in the future. Thus, it is imperative to expand the existing knowledge on the key practices, activities and parameters that affect key contributors to carbon footprints, such as methane and nitrous oxide, not excluding carbon dioxide. Hence, future carbon footprint assessments should consider the use of the Life Cycle Assessment (LCA) approach which gives detailed information on key parameters and impact assessments.

7. Future research is needed to establish country- and regional-specific emission factors to be used as benchmarks for calculating carbon footprints at local levels. A carbon footprint assessment using the Life Cycle Assessment (LCA) is an expedient tool for evaluating the possible impact of food production and products on climate variation, particularly in developing countries.

8. The question that needs more discussions and further research is if complex resource use issues can really be communicated via environmental impact labelling to allow wiser resource use decisions. The carbon market is even less developed than the water market. Sensitivity with regards to the contribution of agriculture to global warming is of great importance. But care is needed how this should be quantified and used. The strong point of agriculture compared to other sectors is the ability of growing plants to sequester carbon during the growing of crops-even annual crops. Thus, at least agriculture can claim c cyclical pattern, to a greater or lesser extent. The calculation of the carbon footprint should include the positive sequestration component. Since this study focused on dairy production, the positive sequestration component was not accounted for and as such the study suggests that future research should consider the positive sequestration component of agriculture.

9. Future research should consider carbon footprint assessments for the sole grazing system of livestock production in order to ascertain whether the carbon footprint of this system is higher than that of the total mixed ration (TMR) system is. This research is necessary since the dairy outputs from the two feeding systems vary (Ercole, 2013). Therefore, such comparisons can potentially assist dairy producers and agribusinesses in deciding on which system of dairy production should be adopted, if their objective is to produce in sustainable and environmentally friendly ways.

10. Future research is necessary to investigate and establish uncertainty ranges for different parameters, as well as the application of clear of data input and estimation procedures in South Africa where little has been done in establishing country-specific emission factors.

11. The findings on consumers' preferences for potentially sustainable products were obtained from consumers who purchase products from formal markets. It is suggested that future research should consider consumers who purchase products from the informal markets to ascertain if the behaviour of consumers reported in this study is robust, compared with the behaviour of consumers in the informal markets in the context of environmental sustainability.

12. Moreover, this study has focused only on beef and milk. Hence, future research could consider examining other food and non-food products to determine if the preferences for carbon and water footprint attributes reported in this study are vigorous, as compared with other food and non-food products.

13. Finally, the stated preference choice experimental approach and the questionnaire method employed in this study may have some components of self-selection, which might lead to biased results (Grebitus et al., 2016). This potential limitation was minimised by obtaining large samples for both categories of respondents as well as cheap talks. Nonetheless, future research could consider the employment of honesty priming, Baysian truth serum, and inferred valuations.

14. Future studies on preferences for environmentally sustainable products should not be limited to willingness to pay estimates only; rather, compensating surplus estimates should also be computed for efficient and effective policy purposes.

15. Future research on consumers' behaviour and choice of environmentally sustainable products in South Africa should consider using modelling techniques that account for heterogeneity, especially models that identify different consumer segments. Such models include the random parameter logit, latent class and attribute non-attendant models.

16. Given that the heterogeneous preferences for environmentally sustainable products were better explained at segment levels, relative to the individual level, future research on consumers' preferences and willingness to pay should test the levels where heterogeneity is better explained before choosing an appropriate model.

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APPENDIX A

QUESTIONNAIRE FOR CONSUMERS SURVEY

LETTER OF INTRODUCTION

I am a PhD Student at the University of the Free State, in the Department of Agricultural Economics. I am carrying out a research project on **environmental sustainability and willingness to pay for sustainable water and carbon footprint information**. The objective of this study is to assess consumers' awareness, attitude and willingness to pay sustainable meat products. Specifically, the study focuses on carbon reduction and efficient water use (Carbon and Water Footprints) information in the livestock sector. Water is scarce in many provinces in South Africa and hence, there is the need to understand consumers' behavior towards sustainable water use as well as environmental sustainability. This will guide policy makers in coming out with strategies to minimize environmental effects and pressure on scarce water resources in South Africa.

I kindly request that you complete the attached questionnaire as objectively as possible. Confidentiality of the information you provide will be strictly maintained, please do not write your name on the questionnaire.

The questionnaire will take you about 15 minutes to complete. Select the best answer to each particular question, and where indicated, briefly state your opinion.

Thank you very much for your understanding, cooperation and valuable information!

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QUESTIONNAIRES ON ENVIRONMENTAL SUSTAINABILITY AND WILLINGNESS TO PAY FOR SUSTAINABILITY INFORMATION

Name of the interviewer……………………………

Date of interview……………………

Respondent identity………………………….

Market/shop…………………………

Questionnaire Number……………. …………….

SECTION A:

PERSONAL AND HOUSEHOLD CHARACTERISTICS

1. What is your age category? Less than 25 years [ ] 25 - 34 years [ ] 35 - 44 years [ ] 45 - 54 years [ ] 55 - 64 years [ ] More than 64 years [ ]
2. Gender: Male [ ] Female [ ]
3. What is your highest level of education attained? Primary [ ] Matric [ ] Undergraduate [ ] Honours [ ] Masters [ ] Doctorate [ ]
4. Household size…………………………
5. Race: Black [ ] White [ ] Coloured [ ]
6. Marital status: Single [ ] Married [ ] Widowed [ ] Separated [ ]
7. Which occupational category applies to you? Government work [ ] Private work [ ] Unemployed [ ] Pensioner [ ]
8. Are you a farmer? Yes [ ] No [ ]
9. Monthly income: R0 -R1783 [ ] R1783 –R2979 [ ] R2979-R5135 [ ] R5135 –R11840[ ] Above R11840 [ ]

SECTION B:

AWARENESS AND KNOWLEDGE ON ENVIRONMENTAL SUSTAINABILITY (WATER AND CARBON FOOTPRINTS)

1. Are you aware of the changing climate (climate change)? Yes [ ] No [ ]
2. Are you aware that water is a scarce resource in South Africa? Yes [ ] No [ ]
3. If Yes, where did you hear about the water scarcity? Radio [ ] Television [ ] Magazines [ ] Newspapers [ ] Friends [ ] Personal observation [ ] Posters [ ] Other (Please specify) …………………………………………………….
4. Are you aware that the water scarcity situation is expected to be worse in the future? Yes [ ] No [ ]
5. Do you know that some provinces in South Africa are water scarce? Yes [ ] No [ ]

6. Are you aware that water for farming or food production is scarce in South Africa? Yes [ ] No [ ]
7. Are you aware that some crops or food production uses more water than others? Yes [ ] No [ ]
8. Please rate the following statements on using the following scales (1=strongly disagree, 2= disagree, 3=Neutral, 4= Agree, 5=Strongly agree)

Water Footprint Knowledge	1	2	3	4	5
10. I know pretty much about water footprint of a product					
11. I know how to judge the water footprint of a product					
12. I think I know enough about water footprint to feel pretty confident when purchasing food products.					
13. I do not feel very knowledgeable about water footprint of products					
14. Among my circle of friends, I'm one of the “experts” in water footprint					
15. Compared to most other people, I know less about water footprint.					
16. I have heard of most of the campaigns to reduce water wastage.					
17. When it comes to water footprint, I really don't know a lot.					
18. I can tell if a product is water efficient and worth the price or not.					

9. Please rate the following statements on using the following scales (1=strongly disagree, 2= disagree, 3=Neutral, 4= Agree, 5=Strongly agree)

Carbon Footprint Knowledge	1	2	3	4	5
4. I know pretty much about carbon footprints					
5. I know how to judge the carbon footprint of a product					
6. I think I know enough about carbon footprint to feel pretty confident when purchasing food products.					
7. I do not feel very knowledgeable about carbon footprint					
8. Among my circle of friends, I'm one of the “experts” in carbon footprint					
9. Compared to most other people, I know less about carbon footprint					
10. I have heard of most of the new campaigns to reduce greenhouse gas emissions(GHG)					

11. When it comes to carbon footprint, I really don't know a lot.					
12. I can tell if a product is produced with less carbon emissions and worth its price or not.					

SECTION C:
ATTITUDE AND PERCEPTION TOWARDS ENVIRONMENTAL SUSTAINABILITY

1. Do you usually read product information on labels before you purchase any products?
   Yes [ ] No [ ]
   If yes, do you look out for environmental sustainability information? Yes [ ] No [ ]
2. How frequently does the need to reduce water usage/wastage affect what you do, for example by choosing to use less water or to turn off the pipe or report water leakages to the appropriate authorities when you can? Frequently [ ] Sometimes [ ] Rarely [ ] Never [ ]

3. How frequently does the need to reduce carbon emissions affect what you do, for example by choosing to drive less or to turn lights off when you can? Frequently [ ] Sometimes [ ] Rarely [ ] Never [ ]

4. Please use the following scales (1=strongly disagree, 2= disagree, 3=Neutral, 4= Agree, 5=Strongly agree) to answer the following perception statements on regarding environmental sustainability

Perception statements	scale
The environment is a low priority for me compared with a lot of other things in my life	
It takes too much time and effort to do things that are environmentally friendly	
I am environmentally friendly in most things that I do	
Most people in the South Africa today need to change their way of life so that future generations can continue to enjoy good quality of life and environment	
Most people in the South Africa today need to change their way of using water so that future generations can continue to enjoy good water	
Scientists will find a solution to global warming without people having to make big changes to their lifestyle	
Companies that are environmentally sustainable are more likely to be profitable over the long run	
Acting sustainably is only worthwhile if it reduces costs	

The Government should be leaders in sustainability and the environment	
Communities can significantly benefit from sustainable development	

SECTION D: PRE-SURVEY INFORMATION

Attribute	Meaning
Water footprint	Refers to the quantity of fresh water used in the production, storage and distribute either beef or milk. Specifically, the water used to produce feed, water intake by live animals, water used at the processing level and all volumes of water used until the product reached the market. The lower the water usage, the better for the environment.
Carbon footprint	The amount of greenhouse gases emitted along the entire product (beef and milk) life cycle. The lower the carbon emitted, the better for the environment

SECTION E.
WILLINGNESS TO PAY FOR WATER AND CARBON FOOTPRINT INDICATORS ON BEEF

1. How frequently do you typically purchase Beef Products? Once per month [ ] 2-3 times per month [ ] 4 or more times per month [ ] Once per week [ ] 2-3 times per week [ ]
2. Are you willing to pay a premium for beef production that uses less water in order to sustain water availability? Yes [ ] No [ ]
3. If yes, how much more are you willing to pay for such beef products? Less than 5% [ ] 5% more [ ] 15% more [ ] 20% more [ ] 25% more [ ]
4. Are you willing to pay a premium for beef production that reduces greenhouse gas emissions (GHG) in order to sustain the environment? Yes [ ] No [ ]
5. If yes, how much more are you willing to pay for such beef products? Less than 5% [ ] 5% more [ ] 15% more [ ] 20% more [ ] 25% more [ ]

SECTION F: CHOICE EXPERIMENTAL SURVEY

6. Please place an "X" in the box below the option that you would choose from each of the following choice scenarios for **Beef Rump Steak**:

Choice set 1

Attribute	Alternative A	Alternative B	None
Beef type	Organic beef	Non organic beef	
Carbon (CO_2) Equivalent	26.37 kgCO_2e	27.00kgCO_2e	
Volume of water required	17387L/kg	15415L/kg	
Price	R185/1kg	159.99/1kg	
I would buy	☐	☐	☐

Choice set 2

Attribute	Alternative A	Alternative B	None
Beef type	Organic beef	Non organic beef	
Carbon (CO_2) Equivalent	22.93 kgCO_2e	26.37kgCO_2e	
Volume of water required	17300L/kg	15414L/kg	
Price	R179.99/1kg	159.99/1kg	
I would buy	☐	☐	☐

Choice set 3

Attribute	Alternative A	Alternative B	None
Beef type	Organic beef	Non organic beef	
Carbon (CO_2) Equivalent	27.00 kgCO_2e	22.93 kgCO_2e	
Volume of water required	15414L/kg	15300L/kg	
Price	R179.99/1kg	R185/1kg	
I would buy	☐	☐	☐

7. Please place an "X" in the box below the option that you would choose from each of the following choice scenarios for **Milk**:

Choice set 1

Attribute	Alternative A	Alternative B	None
Milk type	Fat free organic milk	Fresh full cream milk	
Carbon (CO_2) Equivalent	1.3kgCO_2e	1.9kgCO_2e	
Volume of water required	1025L/kg	1020L/kg	
Price	R20.00/1L	11.98/1L	
I would buy	☐	☐	☐

Choice set 2

Attribute	Alternative A	Alternative B	None
Milk type	Fat free organic milk	Fresh full cream milk	
Carbon (CO_2) Equivalent	1.5kgCO_2e	1.9kgCO_2e	
Volume of water required	1020L/kg	1030L/kg	
Price	R17.45/1L	R20.00/1L	
I would buy	☐	☐	☐

Choice set 3

Attribute	Alternative A	Alternative B	None
Milk type	Fat free organic milk	Fresh full cream milk	
Carbon (CO_2) Equivalent	1.3kgCO_2e	1.5kgCO_2e	
Volume of water required	1025L/kg	1030L/kg	
Price	11.98/1L	R17.45/1L	
I would buy	☐	☐	☐

8. Please place an "X" in the box below the option that you would choose from each of the following choice scenarios for **Yoghurt**:

Choice set 1

Attribute	Alternative A	Alternative B	None
Yoghurt type	Low fat organic yoghurt	Low fat cream yoghurt	
WFP label	Yes	Not Assured	
CF label	Yes	No	
Price	R35/1kg	29.95/1kg	
I would buy	☐	☐	☐

Choice set 2

Attribute	Alternative A	Alternative B	None
Yoghurt type	Low fat organic yoghurt	Low fat cream yoghurt	
WFP label	Assured	Not Assured	
CF label	No	Yes	
Price	R32.95/1kg	R35/1kg	
I would buy	☐	☐	☐

Choice set 3

Attribute	Alternative A	Alternative B	None
Yoghurt type	Low fat organic yoghurt	Low fat cream yoghurt	
WFP label	Not Assured	Assured	
CF label	No	Yes	
Price	R32.95/1kg	29.95/1kg	
I would buy	☐	☐	☐

Thank you very much for your valuable contribution!!

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Evaluation of water footprint and economic water productivities of dairy products of South Africa

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ABSTRACT

Assessment of water footprint sustainability indicators and economic water productivities is regarded as a cornerstone of the world's sustainability goal and the reduction of the fresh water scarcity risk. These assessments are gaining much prominence because about four billion people face severe water scarcity, globally. Attaining sustainable and economically efficient water use goals requires a thorough assessment of all the existing sectors that use water. This paper examined the water footprint and economic water productivities of dairy products in South Africa for the periods 1996–2005 and 2006–2013 using the water footprint network assessment methodology. We found the total water footprints of all the selected dairy products in South Africa to be higher than the global averages are. During the period of 1996–2005, South African dairy producers utilized more green water in their dairy production. The production of butter and cheese products, whether grated or not grated, powdered or not powdered, blue-veined and cheese of all kinds had the highest total water footprints among all the dairy products in South Africa. Dairy production under a sole grazing system has high water footprints and low economic water productivities, relative to mixed production systems, for the period 2006–2013. With blue water becoming scarcer in South Africa, it is time for dairy livestock producers to shift their production to a system that is highly productive and has low water footprints. The water footprints of most of the dairy products for period 2006–2013 have reduced by varying amounts, relative to 1996–2005, which shows that water users along the dairy industry chains are managing water cautiously. Our findings have revealed dairy products that have high economic water productivities, and suggest that profit maximising and environmentally sustainable dairy producers and water users should integrate both blue water sustainability and economic water productivity indicators in their production decisions.

1. Introduction

In recent years, ecological and environmental sustainability assessments have been gaining much prominence, globally. The global water scarcity phenomenon has become a major issue of distress to governments, policy-makers, water users and water managers as well as private and non-governmental organisations and professional bodies interested in environmental and sustainability issues. It is estimated that about four billion people across the globe face severe water scarcity (Mekonnen and Hoekstra, 2016). An assessment of water sustainability indicators across various sectors of the global economy identified that, the greatest share of the world's freshwater is utilized in food production (IWMI, 2007). About 86% of all the freshwater resources in the world are consumed in food production (IWMI, 2007). This implies that the relative importance of water to food production and human survival cannot be overlooked. As a result of that, researchers and policy makers in recent years are interested in the study of sustainable and economical water utilization in the food sector.

Water footprint assessment is one of the ways of assessing water utilization in the food sector. The water footprint assessment gives an account of the quantity of fresh water utilized in the production of a particular food commodity (Hoekstra et al., 2011). Accounting for green (rainwater), blue (surface and groundwater) and grey (related to assimilating water pollutant) water consumption along the whole product value chain. Sustainability assessment of how water is utilized for food production reveals how producers along the food production chain behave with regards to the blue water available to them; as to whether they are using the available water resources sustainably or not. An important pillar of fresh water allocation is economic water productivity, which quantifies the value obtained by producers per unit of water used in producing a particular product (Hoekstra, 2014). The economic water productivities are calculated after the estimation of

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physical water productivities.

Water footprint sustainability assessments of livestock production systems and products have received some attention in recent years in countries such as Ireland (Murphy et al., 2013), Australia (Ridoutt et al., 2014) and China (Huang et al., 2014). Regarding dairy products, water footprint of assessments of milk and milk products have received much attention in developed countries such as Germany (Drastig et al., 2010), Argentina (Manazza and Iglesias, 2012), New Zealand (Zonderland-Thomassen et al., 2014) and in India (Amarasinghe et al., 2010). Animals and animal products' water footprints across the globe have also been explored based on global averages (Mekonnen and Hoekstra, 2012).

These assessments employed different methods such as the water footprint assessment methodology (Drastig et al., 2010; Mekonnen and Hoekstra, 2012), and life cycle assessment methodology including direct and virtual water consumption (Manazza and Iglesias, 2012; Murphy et al., 2013; Huang et al., 2014; Ridoutt et al., 2014; Zonderland-Thomassen et al., 2014). Most of these studies have focused on developed countries (Drastig et al., 2010; Huang et al., 2014; Murphy et al., 2013; Ridoutt et al., 2014; Zonderland-Thomassen et al., 2014), with little emphasis placed on water-scarce African countries including South Africa. Existing studies that focus on assessing water utilization in the agricultural sector in South Africa are limited to the work of Jordaan and Grové (2012) who assessed the cumulative value added to water along the value chain of small-scale raisin and vegetables in order to determine the point along the value chain where most value is added to water.

Scheepers and Jordaan (2016) recently examined the blue and green water utilization for producing lucerne, used as feed for dairy cows. Owusu-Sekyere et al. (2016) recently quantified water utilization for milk production and processing in South Africa. However, this study focused only on milk with 4% fat and 3.3% protein. At the national level, information on water footprints of some dairy products was available from work of Mekonnen and Hoekstra (2012). However, these studies are limited to the quantification of water footprint indicators only, without accounting for economic water productivities, which is a strong pillar of fresh water allocation.

Nonetheless, some authors have assessed economic water productivities of products in the food sector. For instance, in Tunisia, assessments of some key crops were done to ascertain how productive the country is, in terms of water and land utilization (Chouchane et al., 2015) Schyns and Hoekstra (2014) conducted similar studies for some predominant crops produced in Morocco. Mekonnen and Hoekstra (2014) further assessed water conservation through trade in Kenya. Zoumides et al. (2014) conducted an economic water productivity assessment for crop production in Cyprus. All these studies focused on economic water productivities of crops, but with no similar studies being done on livestock products.

This study aims to assess the water footprint and economic water productivity of primary and derived dairy products for different production systems and periods in South Africa. This contributes to the limited knowledge on economic water productivities in the livestock sector and, to the best of our knowledge, this will be the first step taken towards assessing economic water productivities for dairy products in the dairy industry, particularly in Africa. Findings from this study can potentially assist water and environmental sustainability policy makers to understand whether, how and why consumers, water users and dairy producers along the dairy value chain might shift their consumption and production patterns to more sustainable and economically efficient ones. Insights from this study can further contribute to the current debate on the economic dimension of water footprint assessment.

2. Materials and methods

2.1. The study area

The study was conducted in South Africa. South Africa is one of the driest areas in the world and is ranked 30th in terms of freshwater water scarcity (DWA, 2013). The mean rainfall of the country is about 450 mm (DWA, 2013). According to DAFF (2012), approximately 80% of South Africa's agricultural land is suitable for livestock farming. The main source of water supply in the country is surface water (DWA, 2013). Ground water is widely used in rural and arid areas. A significant volume of water originates from return flows from major urban and industrial developments to streams. South Africa irrigates 1.5% of its total landmass to produce 30% of the total crops produced (DWA, 2013). Backeberg (2005) recounted that irrigated agriculture in South Africa utilizes about 40% of the utilizable runoff whiles agricultural production in general use more than 60% of the available water (DWA, 2013). In the dairy industry sector, large quantities of water are utilized for feed production. About 98% of all the water used along the dairy value chain in South Africa goes into feed production (Owusu-Sekyere et al., 2016).

The South African dairy industry is handled by Milk South Africa (Milk SA) and South African Milk Processors' Organisation (SAMPRO). These bodies consist of dairy farmers, producers and processors, who produce different dairy products for the local and international market. Dairy producers in South Africa do not import composite animal feeds (DAFF, 2015). However, some quantities of feed ingredients such as soya oilcake, yellow maize and fish meal are imported. It must be emphasised that there was no import of fish meal over the past ten years in the dairy industry (DAFF, 2015). There are three main systems of feeding dairy cows. These include: (i) Semi-intensive farm-based ration obtained from available crops, pastures and crop residues with minimal rations purchased. (ii) An intensive, zero-grazing dairy system using a total mixed ration. (iii) A traditional, extensive or dual-purpose system (Milk SA, 2014).

About 56% of dairy cows in South Africa rely on pasture, 38% rely on total mixed ration (TMR) and 6% rely on mixed or dual purpose system (Ercole, 2013; Milk SA, 2014). Table 1 presents production differences between the grazing (pasture) and mixed ration systems of feeding dairy cows for 300 days lactation period. This survey was done as part of a scheme towards dairy cattle improvement in the South African dairy industry. Average milk yield for total mixed ration is higher that grazing system, with a significant mean difference of 1463 kg of milk per cow for 300 days lactation period. In terms of fat content, the survey revealed that the butter fat content per kilogram for the mixed system is significantly higher than that of the grazing system.

Table 1
Mean production differences between grazing and mixed systems of dairy feeding.
Source: Dairy Cattle Improvement Scheme (Milk SA).

System	Milk (kg)	Butter fat (kg)	Protein (kg)	Butter fat (%)	Protein (%)
Mixed	7411 (1489)	310(61)	256(50)	4.26(0.36)	3.48(0.21)
Grazing	5949(1285)	245(50)	203(42)	4.23(0.33)	3.46(0.22)
Mean difference	1463***	65**	53**	0.04	0.02

Values in brackets are standard deviations.
**Indicates significant mean difference at 95% confidence interval.

This is indicated by the significant mean difference of 65 at 5% level. Additionally, the protein content of mixed system of feeding dairy cows is higher than that of the grazing system, as shown by the significantly positive mean difference of 53.

2.2. Data sources and description

The paper used secondary data from 1996 to 2013. An overview of the data inputs, sources and duration are described in this section. Mekonnen and Hoekstra (2012) provided data on water footprints of derived products from animals for different countries for the periods of 1996–2005. It must be emphasised that the data reported by these authors are weighted averages estimated at the global level for the stated period. The data pertaining to South Africa were extracted for the selected dairy products from grazing and mixed systems, for the stated period. The volumes of blue, green and grey water utilization in the dairy industry for the periods of 2006–2013 were obtained from the South African Milk Processors' Organisation (SAMPRO) and Milk South Africa (Milk SA). Milk SA was established in 2002 to oversee the South African dairy industry. These organisations consist of dairy producers and processors, who produce different dairy products for the local and international market. Data on producer prices of daily products and production quantities were obtained from SAMPRO and FAOSTAT (FAO, 2015).

Part of the data on feed production and water usage for feed crops used in the dairy industry were attained from the work of Van Rensburg et al. (2012). Data on crop water use, irrigation, evapotranspiration, drainage and rainfall for different catchment areas and irrigation schemes for feed and forage crops production were obtained from Van Rensburg et al. (2012). This information was utilized in the estimation of the feed and forage crops' water footprints. Data on feeding (composition and quantities) were obtained from commercial dairy producers and processors who have electronic feed calculation systems with good recordkeeping. This electronic feed calculation system keeps records of feed ration, moisture content, dry matter, the nutritional content of feed inputs and the complete ration for the lactating cows. The data obtained from different producers and production areas for the period of 2006–2013 were aggregated and used in the calculations of blue, green and grey water footprints of the primary and derived products.

2.3. Methodological and empirical framework

In the calculations of the water footprints, the paper adopted the terminologies and empirical procedures outlined by Hoekstra et al. (2011). The methodology outlined by these authors for quantifying water footprint has been adopted by researchers in recent years to distinctly quantify the proportion of the total water footprint that is blue, green or grey in a particular product value chain. Conceptually, the surface and groundwater utilized for producing any of the selected dairy products is quantified as the blue water footprint of that product. The rainwater utilized for producing any of the selected dairy products is also quantified as the green water footprint of that dairy product. Hoekstra et al. (2011) iterated that the green water footprint excludes the rainwater that runs off. The quantified amount of water used to fine-tune the water quality to its acceptable standard becomes the grey water footprint. Grey water footprint deals with water contamination.

The stepwise accumulative procedure was applied in our quantifications of water footprints of the dairy products since the focus was on a variety of dairy products (Hoekstra et al., 2011). The empirical specification employed by Chapagain and Hoekstra (2004) to calculate live animals' water footprints was employed to quantify the water footprint of live animals. The quantification of the service water footprint in our analysis was based on the procedure set out by Hoekstra et al. (2011). In calculating the water footprint of various feed crops and dairy products, the estimation procedures employed by Mekonnen and Hoekstra (2012) were followed.

Additionally, the water footprint estimates of dairy products reported by Mekonnen and Hoekstra (2012) for the period of 1996–2005 were utilized and compared with our estimates for 2006–2013 because we applied the same models, parameters, assumptions and guidelines used by the authors. Also, the dairy products and production systems considered in our study and that of Mekonnen and Hoekstra (2012) are the same. The proportion of imported feed ingredients that were incorporated into rations formulated for dairy animals was approximated to be about 1.5%. Hence, the weighted average water footprint based on the relative volumes of local production and imports were taken in the calculation of the water footprint of animal feed ingredients (Mekonnen and Hoekstra, 2012). For the different field and forage crops, their blue and green water footprints were calculated using the formula specified in equation (1):

$$WF_{proc,blue,green} = \left(\frac{CWU_{blue}}{Y_t}\right) + \left(\frac{CWU_{green}}{Y_t}\right) \tag{1}$$

where $WF_{proc,blue,green}$ represents the blue and green water footprint of a particular feed crop. The first part of equation (1) represents blue water footprint. CWU_{blue} denotes the blue component in feed crops water use and Y_t is the feed crop yield (Hoekstra et al., 2011). The second part of equation (1) represents the green water footprint. Similarly, CWU_{green} denotes the green component in feed crops water use (Hoekstra et al., 2011). The crop water use components of equations (1) is defined as the sum of the daily evapotranspiration over the complete growing period of the feed crops (Hoekstra et al., 2011). This is empirically specified in equation (2):

$$CWU_{blue,green} = 10 \times \sum_{d=1}^{lgp} ET_{blue,green} \tag{2}$$

$ET_{blue,green}$ represents the blue and green water evapotranspiration. The water depths are changed from millimetres to volumes per area by using the factor 10. The summation is done over the complete length of the growing period from day one to harvest (Hoekstra et al., 2011). The grey water footprints of the feed crops are calculated by taking the chemical application rate for the field per hectare (AR, kg/ha) and multiplied by the leaching-run-off fraction (α). The product is divided by the difference between the maximum acceptable concentration (c_{max}, kg/m^3) and the natural concentration of the pollutant considered (c_{nat}, kg/m^3). The result is then divided by the crop yield (Y, tonne/ha). This is expressed empirically in equation (3):

$$WF_{proc,grey} = \frac{(\alpha \times AR)/(c_{\max} - c_{nat})}{Y_t} \tag{3}$$

It is worth noting that the fresh water used in cleaning the processing facilities was recycled and later used for cleaning the cattle runs and the floor of the dairy parlour. The dairy processing water thus becomes grey water in the effluent pond and was accounted for according to the grey water methodology. The grey water emanating from the faeces and urine of the lactating cows was estimated with the use of an effluent sample analysis, and the volume measured as the flow into the effluent pond. In line with the stepwise accumulative procedure, the water footprint of the main product Υ is assumed to be produced from x inputs or feed crops. Let x inputs be numbered from i = 1…. x. Assuming that x inputs are used to produce y dairy products, let the different dairy output products be represented as Υ = 1….y. The dairy products' (Υ) water footprints are represented in equation (4):

$$WF_{prod}[\Upsilon] = \left(WF_{proc}[\Upsilon] + \sum_{i=1}^{x} \frac{WF_{prod}[i]}{f_{\Upsilon}[\Upsilon, i]}\right) * f_v[\Upsilon] \tag{4}$$

where $WF_{prod}[\Upsilon]$ denotes total water utilized in order to produce Υ. The water footprint of input i is represented by $WF_{prod}[i]$. $WF_{proc}[\Upsilon]$ is the processing water that was used to process x inputs to y output products. The product and value fractions are denoted by $f_p[\Upsilon, i]$ and $f_v[\Upsilon]$, respectively. Details regarding the product and value fraction are outlined in Hoekstra et al. (2011). After calculating the dairy products' footprints for different production regions, weighted averages were calculated in order to determine total, blue, green and grey water footprints at the national level. The calculation of the weighted averages follows the formula specified in equation (5):

$$WWF = \frac{\sum_{l=1}^{n} x_l \times w_l}{\sum_{l=1}^{n} w_l} \quad (5)$$

where the weighted average water footprint is denoted by WWF. x_l is the water footprint value of a given dairy product from production region l and w_l represents the weight assigned to the given dairy product from production region l. The weights were assigned in line with the contribution of the different regions to total dairy output. Given that $WF_{prod}[\Upsilon]$ is measured in cubic m^3/tonne, the physical water productivity (PWP) of a particular dairy output product Υ measured in kilograms per metre cubed and expressed in equation (6):

$$PWP = \frac{1}{WF_{prod}[\Upsilon]} * 1000 \quad (6)$$

After calculating the physical water productivity, economic water productivities are further calculated. The economic water productivity for a particular dairy output product is then attained by multiplying the physical water productivity by that particular dairy product's value per kilogram. The producer prices are expressed in price per kilogram of the output product Υ. We denote the price of Υ by Υ_{Price}. We express the economic water productivity (EWP) in equation (7):

$$EWP = PWP * \Upsilon_{Price} \quad (7)$$

The monetary value attained from every cubic meter of water used in producing any of the dairy products then becomes the economic water productivity of that product (Chouchane et al., 2015). Economic water productivities were estimated for all the dairy products considered in the study. The water footprints and water productivities of the selected products were separated for grazing and mixed systems of raising dairy cows in the study area because water utilization (Mekonnen and Hoekstra, 2012) and milk yields from these production systems differ (Scholtz et al., 2014).

3. Results and discussions

3.1. The water footprints of South African dairy products versus the global averages from the year 1996–2005

The water footprints of South African dairy products were compared the global averages for the period 1996–2005 to understand the water use pattern and how dairy producers are behaving in terms of water utilization (Table 2). The findings point out that the average blue water footprints for all the dairy products in South Africa are lower than the global average blue water footprints are. This implies that in terms of blue water usage, water users in the South African dairy industry are performing better, compared with the global blue water footprint indicators. Regarding green water utilization, the 1996–2005 estimates by Mekonnen and Hoekstra (2010) show that South Africa's green water footprints are higher than the global average green water footprints for the dairy products considered, suggesting that green water use along the dairy industry chain in South Africa is higher, compared with other parts of the world. However, the grey water footprints for the dairy products in South Africa are lower than the global estimates for the same dairy products.

Although South Africa's blue and grey water footprints were revealed to be lower, the 1996–2005 estimates indicate that the overall water footprints for the selected dairy products in South Africa are higher than the global average total water footprints are. The high total water footprint indicators for dairy products in South Africa are attributable to the higher green water footprints. This further indicates that the highest proportion of water utilized along the dairy chain in South Africa during the 1996–2005 periods was accumulated from the farm level, since green water was not utilized at the processing and marketing stage of the dairy value chain. This is supported by Owusu-Sekyere et al. (2016) who iterated that the largest proportion of water used along the dairy value chain in South Africa is green water.

The high green water footprints for South Africa could be attributed to low milk yield associated with sole grazing system of dairy production under which relies on rainfall for field and forage crops production for feeding livestock (Scholtz et al., 2014). The low milk output could be explained by the low yield of rain-fed field and forage crops largely used dairy producers in South Africa, compared to the global average. For both South Africa and the world, the highest total water footprint was found to be associated with the production of butter. This is followed by the various cheese products, whether as grated or not grated, powdered or not powdered, blue-veined and cheese of all kinds. The high water footprints of all these products are as a result of the conversion factors (product/value fractions) used (Mekonnen and Hoekstra, 2012).

The lowest water footprints among all the dairy products were associated with the production of whey and non-concentrated and unsweetened milk not exceeding one per cent fat, respectively. The next product with low water footprint was non-concentrated and unsweetened milk and cream with more than 6% fat. Comparing the water footprint estimates of South Africa for the period of 1996–2005 to other African countries where water footprint is gaining much prominence, the estimates show that the water footprints of butter and the assorted cheese products in South Africa are about 31 and 8% lower than that of Tunisia and Kenya, respectively for the same time period (Mekonnen and Hoekstra, 2010).

Similarly, the water footprint of whey and milk (non-concentrated and unsweetened) not exceeding one per cent fat in South Africa are about 64, 31 and 8% lower than that of Morocco, Tunisia and Kenya, respectively for the same time period (1996–2005) (Mekonnen and Hoekstra, 2010). Given that the South African estimates are higher than the global averages, but lower than these African countries, there is therefore the need for South Africa to have its country-specific benchmarks based on the country's available freshwater resources and for which the water footprints of products in that country can be related to. This benchmark will help South Africa by serving as a reference and assist in establishing water footprint reduction targets. This is in agreement with recent findings by Zhuo et al. (2016) in China.

3.2. Water footprints of dairy products under different dairy production systems in South Africa for the period 2006–2013

The average water footprints of the selected dairy products were estimated for sole grazing (extensive) and mixed systems (intensive and extensive) of production and the estimates are provided in Table 3. The estimates indicate that the blue water footprints for the selected dairy products produced under sole grazing system, is higher than the blue water footprints under the mixed production system, with the exception of whey (whether or not concentrated or sweetened), which had the same blue water footprints under the two production systems. This is concurs with the findings of Srairi et al. (2009) in an assessment of water productivities for dairy and meat cows kept under irrigation scheme in Morocco. The authors found that significant variability in milk and meat outputs placed substantial influence on water productivities.

Given the blue water scarcity situation in South Africa, it is vital for dairy livestock producers to decide whether to keep dairy animals solely on grazing or under the extensive system of production. Regarding green water use, the results show that green water footprints for the

Table 2
The average blue, green and grey water footprint of dairy products for the period 1996–2005 adapted from Mekonnen and Hoekstra (2012).

Product description	South Africa (m^3/tonne)				Global average (m^3/tonne)			
	Blue WF	Green WF	Grey WF	Total WF	Blue WF	Green WF	Grey WF	Total WF
Milk not concentrated and unsweetened not exceeding 1% fat	41	1019	40	1100	86	863	72	1021
Milk not concentrated & unsweetened exceeding1% not exceeding 6% fat	42	1053	41	1136	88	891	75	1056
Milk and cream not concentrated and unsweetened exceeding 6% fat	76	1896	74	2046	159	1605	134	1898
Milk powder not exceeding 1.5% fat	190	4739	185	5114	398	4011	336	4745
Milk and cream powder unsweetened exceeding 1.5% fat	190	4739	185	5114	398	4011	336	4745
Milk and cream powder sweetened exceeding 1.5% fat	200	4739	185	5124	408	4011	336	4755
Milk and cream unsweetened,	62	1576	63	1701	132	1334	112	1578
Milk and cream sweetened	81	1896	74	2051	164	1605	134	1903
Yogurt concentrated, unsweetened	48	1185	46	1279	99	1003	84	1186
Buttermilk, curdled milk & cream	64	1597	62	1723	134	1352	113	1599
Whey whether or not concentrated or sweetened	26	646	25	697	54	547	46	647
Products consisting of natural milk constituents sweetened	48	1185	46	1279	99	1003	84	1186
Butter	223	5546	217	5986	465	4695	393	5553
Cheese, fresh unfermented, and curd	128	3174	124	3426	266	2687	225	3178
Cheese, grated or powdered, of all kinds	218	5038	197	5453	439	4264	357	5060
Cheese processed, not grated or powdered	218	5038	197	5453	439	4264	357	5060
Cheese, blue-veined	218	5038	197	5453	439	4264	357	5060
Cheese (others)	218	5038	197	5453	439	4264	357	5060

grazing system are higher than that of mixed production system for all the dairy products. In terms of total water footprints, the results suggest that the total water footprints of all the dairy products produced under the grazing system alone are higher than the total water footprints of the same products produced under mixed production systems. The high green water footprints under the grazing or extensive system of production are as a result of the preponderance of indirect water usage for forage production. This might also be attributed to low milk yield associated with the extensive system of raising dairy cattle in South Africa (Scholtz et al., 2014). The low milk yield from this system can be attributed to poor pasture and forage output, mainly due to erratic rainfall. MacDonald et al. (2007) opined that low milk yield from cows kept on grazing system can be attributed to the inability of cows to eat sufficient metabolizable energy for high production owing to feed intake constraints.

Low milk yield affects water footprints estimates in the sense that lower yield from a particular production system directly increases the water footprint values of that particular system (Bosire et al., 2015). The high water footprints may also be attributed to low feed conversion efficiencies of animals kept on grazing system (Bosire et al., 2015). Therefore there is the need for dairy livestock producers to review their pastures and rangelands management strategies to increase feed availability and quality. This will increase dairy output, which in turn will reduce water footprints. For both grazing and mixed production systems, dairy livestock producers should breed animals with better growth rates and milk yield per cow, with the aim of enhancing feed conversion efficiency. This will reduce water footprints and enhance water productivities.

In terms of individual dairy products, the results reveal that the highest total water footprints are associated with butter for both grazing and mixed systems of production. Cheese products, whether grated or not grated, powdered or not powdered, blue-veined and cheese of all kinds recorded the next highest water footprints for both systems of production. Also, products such as milk powder with fat content not above 1.5%, milk and cream powder (unsweetened) exceeding 1.5% fat were found to have the third-highest total water footprints for both grazing and mixed systems of production.

The high water footprints of these products raise major concerns for sustainability policy-makers. Producers of these products should consider an investment in technologies that minimize water usage and

Table 3
The average blue, green and grey water footprint of dairy products for different production systems in South Africa (2006–2013).

Product description	Grazing system (m^3/tonne)				Mixed system (m^3/tonne)			
	Blue WF	Green WF	Grey WF	Total WF	Blue WF	Green WF	Grey WF	Total WF
Milk not concentrated and unsweetened not exceeding 1% fat	69	1289	40	1398	68	1180	39	1287
Milk not concentrated & unsweetened exceeding1% not exceeding 6% fat	70	1263	41	1374	69	1185	41	1295
Milk and cream not concentrated and unsweetened exceeding 6% fat	75	1914	74	2063	68	1583	73	1724
Milk powder not exceeding 1.5% fat	187	4784	185	5156	171	3369	183	3723
Milk and cream powder unsweetened exceeding 1.5% fat	187	4784	185	5156	171	3369	183	3723
Milk and cream powder sweetened exceeding 1.5% fat	197	4784	185	5166	181	3369	183	3733
Milk and cream unsweetened	62	1591	62	1715	57	1383	61	1501
Milk and cream sweetened	80	1914	74	2068	73	1583	73	1729
Yogurt concentrated, unsweetened	47	1196	46	1289	43	1137	46	1226
Buttermilk, curdled milk & cream	63	1612	62	1737	58	1396	62	1516
Whey whether or not concentrated or sweetened	25	625	25	675	25	599	23	647
Products consisting of natural milk constituents sweetened	47	1196	46	1289	43	1137	46	1226
Butter	219	5599	217	6035	200	3876	214	4290
Cheese, fresh unfermented, and curd	125	3204	124	3453	115	2386	123	2624
Cheese, grated or powdered, of all kinds	215	5086	197	5498	198	3557	195	3950
Cheese processed, not grated or powdered	215	5086	197	5498	198	3557	195	3950
Cheese, blue-veined	215	5086	197	5498	198	3557	195	3950
Cheese (others)	215	5086	197	5498	198	3557	195	3950

Authors' calculations, 2016.

Table 4
Physical and economic water productivities for different production systems in South Africa (2006–2013).

Product description	Grazing system			Mixed system		
	Total WF (m^3/tonne)	Physical Water productivity (kg/m^3)	Economic water productivity (US$/$m^3$)	Total WF (m^3/tonne)	Physical Water productivity (kg/m^3)	Economic water productivity (US$/$m^3$)
Milk not concentrated and unsweetened not exceeding 1% fat	1398	0.72	0.21	1287	0.77	0.23
Milk not concentrated & unsweetened exceeding 1% not exceeding 6% fat	1374	0.73	0.22	1295	0.78	0.23
Milk and cream not concentrated and unsweetened exceeding 6% fat	2063	0.48	0.15	1724	0.58	0.17
Milk powder not exceeding 1.5% fat	5156	0.19	0.14	3723	0.27	0.20
Milk and cream powder unsweetened exceeding 1.5% fat	5156	0.19	0.10	3723	0.27	0.13
Milk and cream powder sweetened exceeding 1.5% fat	5166	0.19	0.13	3733	0.27	0.18
Milk and cream unsweetened	1715	0.58	0.74	1501	0.66	0.85
Milk and cream sweetened	2068	0.48	0.13	1729	0.58	0.15
Yogurt concentrated, unsweetened	1289	0.78	0.42	1226	0.82	0.44
Buttermilk, curdled milk & cream	1737	0.58	0.39	1516	0.66	0.45
Whey	675	1.48	0.59	647	1.55	0.62
Butter	6035	0.17	0.19	4290	0.23	0.30
Cheese, fresh unfermented, and curd	3453	0.29	0.38	2624	0.38	0.51
Cheese, grated or powdered, of all kinds	5498	0.18	0.25	3950	0.25	0.34
Cheese processed, not grated or powdered	5498	0.18	0.23	3950	0.25	0.32
Cheese, blue-veined	5498	0.18	0.31	3950	0.25	0.43
Cheese (other)	5498	0.18	0.25	3950	0.25	0.34

Authors' calculations, 2016.

increase dairy product outputs, especially for butter and cheese processing. Another alternate will be the importation of such products with high water footprints from countries with enough water resources and where the same products are produced with minimal water usage. The results reveal that whey (whether or not concentrated or sweetened) has the lowest water footprints under both systems of production. Yoghurt (concentrated and unsweetened) and other dairy products containing some milk components (sweetened) were among the dairy products with low water footprints for both grazing and mixed systems of production.

3.3. The water productivities (physical and economic) of the selected dairy products in South Africa

Table 4 presents the water productivities of the dairy products for different production systems in South Africa. The water productivities were expressed in physical and economic terms. For both systems of production, the results show that whey, yogurt (concentrated and unsweetened), milk (unsweetened and unconcentrated) with fat content greater than 1 per cent but not higher than 6% fat and milk (unsweetened and unconcentrated) with fat content higher than 1 per cent have physical water productivities, respectively. However, it is worth noting that expressing water productivities in the physical context does not provide much insight when water utilization is assessed from an economic viewpoint (Pereira et al., 2009). Hence, it was imperative to focus on economic water productivities. Additionally, profit maximising firms are more interested in maximising the value attained from the quantity of water utilized in their production, in lieu of focusing on physical water productivities (Molden et al., 2010). This is because blue water is directly associated with production cost and as such; firms aim at gaining more value to cover the cost of water and other production inputs.

Under the grazing system of production, the results show that higher economic water productivities are associated with milk and cream (unsweetened) and whey, as 0.74 and 0.59 US dollars are attained per every cubic metre of water used to produce one kilogram of these dairy products, respectively. This is followed by yogurt (concentrated and unsweetened) and buttermilk (curdled milk and cream), respectively. Milk (unsweetened) and cream powder with fat content exceeding 1.5%, milk and cream (sweetened), milk and cream powder (sweetened) with fat contents higher than 1.5% and milk powder with fat content not above 1.5% have the lowest economic water productivities, respectively. Under the mixed system of production, the results show that milk and cream (unsweetened), and whey have high economic water productivities, respectively. This is followed by cheese (fresh unfermented and curd), buttermilk (curdled milk and cream) and yoghurt (concentrated and unsweetened), respectively.

On the other hand, milk and cream powder (unsweetened) with a fat content higher than 1.5% has the lowest economic water productivity of 0.13 US$/$m^3$. This is followed by milk and cream (sweetened) and milk and cream (unconcentrated and unsweetened) with a fat content higher than 6%, respectively. In general, the results show that economic water productivities for all the dairy products under the mixed system of production are higher than those of the grazing systems are. The difference in economic water productivities is the result of the difference in water use or footprints for the two systems. The higher water footprints observed for the grazing system resulted in low physical water productivities and hence the low economic water productivities. This provides the justification for stakeholders in the dairy sector to consider which system is economically efficient in terms of water use.

The contributions of different provinces to total dairy production in South Africa are presented in Fig. 1. The Western Cape province is the highest contributor to the total dairy production for the 2012/2013 production season. The Eastern Cape and KwaZulu-Natal provinces are the second-highest contributors to the total dairy production of the country, with 24% contributions each. Thirteen per cent of the country's dairy products come from the Free State province, with the North West and Mpumalanga provinces contributing 5% and 4%, respectively to the total dairy production of the country. The remaining provinces contribute 3% to the total dairy production. The high contributions from the Western and Eastern Cape provinces, as well as KwaZulu-Natal province, are probably attributable to the favourable climate and good pasture regimes for livestock production.

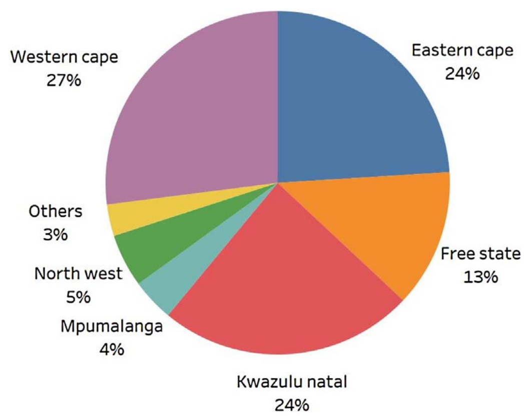

Fig. 1. Contributions of different provinces to total dairy production in South Africa.

4.1. Average water use behaviour in dairy production between the period 1996–2005 and 2006–2013

Table 5 presents the estimates of average water footprints of the dairy products calculated for the periods 1996–2005 and 2006–2013 in South Africa. The 1996–2005 estimates by Mekonnen and Hoekstra (2010) were compared to our 2006–2013 estimates because the same models, parameters, assumptions and guidelines as outlined in the water footprint assessment manual were employed in both estimations. Also, the analyses for the two time periods were conducted for the same dairy products and production systems and as such the estimates are comparable. This comparison is critically important to understand the degree of sustainability with which freshwater is used in the dairy industry in recent years. This will accurately and effectively inform water managers and water users towards the sustainable use of freshwater in dairy production.

Comparing the water footprint of the dairy products between the periods of 1996–2005 and 2006–2013, it was revealed that the production of milk (unconcentrated and unsweetened) with fat content not higher than 1% recorded the highest increase in water usage. This is followed by the same product with fat content exceeding 1% but not higher than 6%. The implication from these findings is that the water usage in the production of these dairy products has increased. This can be ascribed to our qualitative information which revealed that some of these unsweetened and unconcentrated milk products are produced by dairy producers who are not processors and as such their capacity to recycle blue water is limited compare with the other products which are mainly produced by dairy processing companies with good water recycling systems in recent years.

The production of the remaining dairy products saw significant improvements in terms of water saving, comparing the water footprints between the two periods. For instance, the highest reduction in water usage was associated with the production of butter. Similarly, there were somehow moderate reductions in water use for the production of cheese products, which were found to be among the dairy products with high water consumption. Between the periods of 1996–2005 and 2006–2013, the production of dairy products such as milk powder with fat content not above 1.5%, unsweetened milk and cream powder with fat content higher than 1.5%, as well as milk and cream powder (sweetened) with above 1.5% fat content, saw reductions in water usage of about 13%.

The remaining dairy products also recorded some reductions in water use between the two periods, which is a good indication that water users in the dairy industry recognise the need for water management and saving strategies to sustain their business and the environment in the long run. The reductions in water footprints for the dairy products vary from product to product. This provides the rationale for awareness creation and campaigns on sustainable water management aimed at imparting water-saving attitudes among South Africans because our findings indicate that water use behaviour in the dairy industry has improved since actors along the dairy value chain have become conscious of the water scarcity situation in the country.

Our study is not without limitations; firstly, our analysis focused only on dairy production under the grazing and mixed production system due to unavailability of data for other production systems such as the intensive, zero-grazing and traditional dual-purpose dairy system. Secondly, the study focused only on dairy outputs without considering meat output. Thirdly, we acknowledge the lack of consistency in input variables and data sources. For instance, the data extracted from Mekonnen and Hoekstra (2012) are averages of a global assessment and as such using it in the context of a national assessment has pros and cons.

Facilitating consist, reliable and frequent livestock surveys at provincial and national levels in South Africa would be essential to safeguard precision of future studies that focus on productivities and efficient use of resources in different livestock production systems. Similar

Table 5
Comparison of the average water footprints of the dairy products for the periods 1996–2005 (Mekonnen and Hoekstra, 2012) and 2006–2013 in South Africa (authors' calculations, 2016).

Product description	Water footprint in m^3/tonne (2006–2013)	Water footprint in m^3/tonne (1996–2005)	Mean difference (m^3/tonne)	Percentage change
Milk not concentrated and unsweetened not exceeding 1% fat	1343	1100	243	22
Milk not concentrated & unsweetened exceeding1% not exceeding 6% fat	1335	1136	199	17
Milk and cream not concentrated and unsweetened exceeding 6% fat	1894	2046	−153	−7
Milk powder not exceeding 1.5% fat	4440	5114	−675	−13
Milk and cream powder unsweetened exceeding 1.5% fat	4440	5114	−675	−13
Milk and cream powder sweetened exceeding 1.5% fat	4450	5124	−675	−13
Milk and cream unsweetened	1608	1701	−93	−5
Milk and cream sweetened	1899	2051	−153	−7
Yogurt concentrated, unsweetened	1258	1279	−22	−2
Buttermilk, curdled milk & cream	1627	1723	−97	−6
Whey whether or not concentrated or sweetened	661	697	−36	−5
Products consisting of natural milk constituents sweetened	1258	1279	−22	−2
Butter	5163	5986	−824	−14
Cheese, fresh unfermented, and curd	3039	3426	−388	−11
Cheese, grated or powdered, of all kinds	4724	5453	−729	−13
Cheese processed, not grated or powdered	4724	5453	−729	−13
Cheese, blue-veined	4724	5453	−729	−13
Cheese (Other)	4724	5453	−729	−13

studies should be conducted for dairy production under the systems not considered in this study when data is available. Future research in South Africa should consider the development of country-specific water footprint benchmarks for different product categories and production systems to serve as a reference and assist in establishing water footprint reduction targets. Additionally, future studies should consider water footprints and economic water productivities for different meat production systems in South Africa.

5. Conclusions

Generally, it is concluded that South Africa's total water footprints for the dairy products considered in this study are higher than the global average total water footprints in the period 1996–2005 are. Nonetheless, it can be concluded that South Africa's average blue water footprints for all the dairy products considered are lower than the global average blue water footprints in the period 1996–2005. Additionally, it can be concluded that during the period of 1996–2005, South African dairy producers were utilizing more green water in their dairy production. We suggest that current dairy producers should make efficient use of green water.

Regarding the dairy products, we conclude that butter and cheese products (whether grated or not grated, powdered or not powdered, blue-veined) and cheese of all kinds had the highest total water footprints in South Africa for both periods. In the 2006–2013 period, we conclude that the total water footprints for all the dairy products produced solely under grazing systems are higher than the total water footprints of the same products produced under the mixed production systems. We also conclude that blue water footprints under the grazing system are higher, relative to the blue water footprints under the mixed production system. We also conclude that the water footprints for most of the dairy products in the 2006–2013 period have reduced compared with the 1996–2005 estimates.

Regarding water productivities, we conclude that the economic water productivities for all the dairy products under the mixed system of production are higher than those of the grazing systems are. Among the dairy products, we conclude that dairy products such as milk and cream (unsweetened), whey, cheese (fresh unfermented and curd), buttermilk (curdled milk and cream) and yoghurt (concentrated and unsweetened) had the highest economic water productivities, respectively. Milk and cream powder (unsweetened) with fat content above 1.5%, milk and cream (sweetened) and milk and cream (unconcentrated and unsweetened) with a fat content higher than 6% had the lowest economic water productivity.

Given that there are low blue water footprints and high economic water productivities in the mixed production system, this system appears to be a better alternative, relative to the sole grazing system. Farm management options to boost water productivities under the various systems of livestock production include increasing dairy output, improving feed conversion efficiency of cows, animal health improvement, investment in water saving technologies and adoption of pasture management practices that increase forage availability and quality. Additionally, forage and pasture management practices that circumvent land degradation to reduce the quantity of water needed for field and forage crops.

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Economic Water Productivities Along the Dairy Value Chain in South Africa: Implications for Sustainable and Economically Efficient Water-use Policies in the Dairy Industry

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A B S T R A C T

The global water scarcity situation is a major issue of concern to sustainable development and requires detailed assessment of water footprints and water productivities in all sectors of the economy. This paper has analysed economic water productivities along the dairy value chain in South Africa. The findings reveal that the value added to milk and water as it moves along the value chain varies from stage to stage; with the highest value being attained at the processing level, followed by the retail and farm gate levels, respectively. Milk production in South Africa is economically efficient in terms of water use. Feed production accounts for about 98.02% of the total water footprint of milk with 3.3% protein and 4% fat. Feed production is economically efficient in terms of cost and water use. Value addition to milk and economic productivity of water are influenced by packaging design. Not all economically water productive feed products are significant contributors to milk yield. Future ecological footprint assessments should take into account the value added to output products and economic water productivities along the products' value chain, rather than relying only on water footprint estimates.

1. Introduction

The global water scarcity phenomenon has become a major issue of concern to governments, organisations, policy-makers, water-users and water managers. A significant proportion (two-thirds) of the world's population faces difficulties in getting freshwater (Mekonnen and Hoekstra, 2016). The pressure on freshwater resources arises as a result of population growth, climate change, pollution of existing water resources, urbanisation, among other things (Jefferies et al., 2012). In many parts of the word, quantities of water supply do not meet the quantity demanded by the various sectors of the economies. Food production has been identified as the major user of the available scarce water resources; accounting for about 86% of all global water use (IWMI, 2007). However, given the fact that food production is vital for human survival and the essential role that water plays in food production, there is the need to design strategies and methods to make efficient use of water in all sectors, particularly in agriculture which uses most of the world's water. Based on this, two internationally accepted concepts of water footprint have been developed; the water footprint concept as described by Hoekstra et al. (2011) and the Life Cycle Assessment (LCA) as described in the ISO standards. The water footprint (WF) approach introduced by Hoekstra (2003) is gaining prominence because it gives a comprehensive assessment of freshwater use, and quantifies and maps water consumption and pollution in relation to production or consumption. The concept of water footprint in the Life Cycle Assessment approach (LCA) has also been applied in many studies (Ridoutt et al., 2014; Zonderland-Thomassen et al., 2014).

Various authors have assessed water footprints of products in the agricultural sector. Ridoutt et al. (2014) and Zonderland-Thomassen et al. (2014) assessed the water footprint of beef cattle and sheep production systems in Australia and New Zealand, respectively. In China, water availability footprint of milk and milk products from large-scale farms has been assessed by Huang et al. (2014). Matlock et al. (2012) examined the potential water use, water stress, and eutrophication impacts from US dairy activities. Environmental impacts associated with freshwater consumption along the life cycle of animal products was analysed by De Boer et al. (2013) in the Netherlands. Amarasinghe et al. (2010) assessed water footprints of milk production in India. Water footprint analyses of milk production in Germany and Argentina have been examined by Drastig et al. (2010) and Manazza and Iglesias (2012), respectively.

The growing body of literature is limited to quantification of water footprint indicators and, to some extent, the environmental impact. The economic aspect of water footprint indicators has received little attention, particularly in the semi-arid and arid regions of southern Africa. Meanwhile, Hoekstra et al. (2011), and Pérez-Urdiales and García-

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Valiñas (2016) indicated that economic water efficiency and water-efficient technologies are very important to ecologically sustainable environmental policies. Existing studies on economic water productivities are limited to that of Chouchane et al. (2015) who assessed the economic water and land productivities related to crop production for irrigated and rain-fed agriculture in Tunisia. Similar assessments have been done for case studies in Morocco and Kenya (Mekonnen and Hoekstra, 2014; Schyns and Hoekstra, 2014). Zoumides et al. (2014) also included economic water productivity when assessing the water footprint of crop production and supply utilization in Cyprus. It is clear that the focus has been on economic water productivities of crops, with no similar research being done in the livestock sector. To the best of our knowledge, no known study has evaluated the economic productivity of water along the dairy value chain. Therefore, current knowledge is insufficient to understand whether, how and why water users and managers along the dairy value chain might shift to more sustainable and economically efficient production patterns.

The present paper contributes to filling this gap in knowledge by assessing the economic water productivity along the dairy value chain in South Africa. We estimated economic water productivity for milk and important feed crops because evidence shows that a significant proportion of water usage in the dairy sector goes into feed production. This will be the first step towards an assessment of economic water productivities for feed crops and dairy products, particularly in Africa. The economic water productivity is the value of the marginal product of the agri-food product with respect to water (Chouchane et al., 2015; Molden, 2007; Playan and Matoes, 2006). The economic productivity gives an indication of the income that is generated per cubic metre of water used. The economic water productivity is calculated in two steps. First, the physical water productivity (in kg/m^3 of water) is calculated by dividing the yield (kg) by the water footprints (m^3) of the product. In the second step, the economic productivities (US\$/m^3 of water) of the product are calculated by multiplying the physical water productivity (kg/m^3) of each product by their monetary value (US\$//kg).

2. Methodology

2.1. Conceptual and Empirical Framework

The concept of the Global Water Footprint Standard of the Water Footprint Network was employed in this study. The water footprint network approach adopted gives a distinction between green, blue and grey water used along the value chain (Berger and Finkbeiner, 2010; Hoekstra et al., 2011). The calculations of blue, green and grey water footprints of the feed crops and milk followed the terminologies and procedures set out in The Water Footprint Assessment Manual (Hoekstra et al., 2011). The blue water footprint ($WF_{proc,blue}$, m^3/tonne) is estimated as the blue component in crop water use (CWU_{blue},m^3/ha), divided by the crop yield (Y, tonne/ha) in relation to the feed crops. This is specified as:

$$WF_{proc,blue} = \frac{CWU_{blue}}{Y} \quad (\text{volume/mass}) \tag{1}$$

The green water footprint (WF_{green}, m^3/tonne) is calculated in a similar manner as the blue water footprint. The green water used for feed crop production and natural vegetation for pastoral grazing constitute the total green water footprint considered along dairy value chain because we found that no green water is used at the processing and retailing stages of the dairy value chain. The final calculated green water footprint is an indicator of the total amount of rainwater that was evapotranspired by the crop and incorporated into the crop.

$$WF_{proc,green} = \frac{CWU_{green}}{Y} \quad (\text{volume/mass}) \tag{2}$$

The crop water use component of Eqs. (1) and (2) is defined as the sum of the daily evapotranspiration (ET, mm/day) over the complete growing period of the feed crop (Hoekstra et al., 2011). This is expressed as:

$$CWU_{blue,green} = 10 \times \sum_{d=1}^{\text{lgp}} ET_{blue,green}(volume/area) \tag{3}$$

The blue and green water evapotranspiration is denoted by $ET_{blue,green}$. The water depths are converted from millimetres to volumes per area (m^3/ha) by using the factor 10. Summation is done over the complete length of the growing period (lgp) from day one to harvest (Hoekstra et al., 2011). Grey water footprints ($WF_{proc,grey}$, m^3/tonne) of the feed crops are estimated by taking the chemical application rate for the field per hectare (AR, kg/ha) and multiplied by the leaching-run-off fraction (α). The product is divided by the difference between the maximum acceptable concentration (c_{max}, kg/m^3) and the natural concentration of the pollutant considered (c_{nat}, kg/m^3). The result is then divided by the crop yield (Y, tonne/ha). This is expressed empirically as:

$$WF_{proc,grey} = \frac{(\alpha \times AR)/(c_{\max} - c_{nat})}{Y} \quad [\text{volume/mass}] \tag{4}$$

In the study area, fresh water used in cleaning the processing facilities was recycled and later used for cleaning the cattle runs and the floor of the dairy parlour. The dairy processing water thus becomes grey water in the effluent pond and was accounted for according to the grey water methodology. The grey water emanating from the faeces and urine of the lactating cows was estimated with the use of an effluent sample analysis, and the volume measured as the flow into the effluent pond. After estimating the blue, green and grey water footprints, they were summed up to obtain the total water footprint.

After calculating the water footprint of the feed crops, we calculated the marginal water productivities for the feed crops. In estimating the water productivities for the feed crops, a distinction was made between crop yield from rainfall and that of irrigation. Once such distinction is made, water productivities can be discussed in terms of green and blue water. The blue water productivity is described as the incremental yield attained due to irrigation divided by the blue water footprint or the volume of blue water consumed (Hoekstra, 2013). This is expressed as:

$$WP_{blue} = \frac{Yt_{blue}}{ET_{blue}} \tag{5}$$

where Yt_{blue} is the crop yield under irrigation, and ET_{blue} is the evapotranspiration of blue water. Green water productivity, on the other hand, can be defined as the crop yield obtained from rainfall only, without irrigation, divided by the total green water used by the crop (Hoekstra, 2013). This is specified as:

$$WP_{green} = \frac{Yt_{green}}{ET_{green}} \tag{6}$$

where Yt_{green} is the crop yield under rain fed conditions only, and ET_{green} is the evapotranspiration of green water that would have occurred without irrigation. Crop yield under rain fed conditions only (Yt_{green}), according to Chouchane et al. (2015) and Doorenbos and Kassam (1979) can be calculated as:

$$\left(1 - \frac{Y_a}{Y_m}\right) = RF_y\left(1 - \frac{ET_a}{CWR}\right) \tag{7}$$

where RF_y is a yield response factor, Y_a is the actual crop yield in kg per hectare, and Y_m is the maximum yield attainable at optimum water level. ET_a denotes the actual crop evapotranspiration measured in millimetres per period, whereas CWR is the crop water requirement in millimetres per period. The total water productivity then becomes the sum of blue and green water productivities for the feed crops:

$$Total\ WP = WP_{green} + WP_{blue} \quad (8)$$

Regarding the primary product (milk), the chain-summation approach was used to estimate the water footprint since our focus was only on milk and not a variety of derived dairy products (Hoekstra et al., 2011). The water footprint of milk consists of direct and indirect water footprints (Mekonnen and Hoekstra, 2010a). The water footprint for the output product (processed milk with 3.3% and 4% fat) is denoted by $WF[\Upsilon]$. The output product (Υ) is produced from x inputs. Let x inputs be numbered from $i = 1\dots\ x$. Assuming that x inputs are used to produce only Υ dairy product. The output product's (Υ) water footprint is represented as:

$$WF_{prod}[\Upsilon] = \frac{\sum_{i=1}^{x} WF_{proc}[i]}{P[\Upsilon]} \quad (m^3/tonne) \quad (9)$$

where $WF_{prod}[\Upsilon]$ denotes the total water utilized in order to produce Υ. The water footprint of input i is represented by $WF_{prod}[i]$ and $P[\Upsilon]$ is the production quantity of product Υ. Given that $WF_{prod}[\Upsilon]$ is measured in m^3 per tonne; the physical water productivity (*PWP*) of the output product Υ is expressed in kilograms per cubic metre (kg/m^3) and specified as:

$$PWP(kg/m^3) = \frac{1}{WF_{prod}[\Upsilon](m^3/tonne)} * 1000 \quad (10)$$

After calculating the physical water productivity, the economic water productivity for the output product Υ is then attained by multiplying the physical water productivity by the monetary value added to Υ per kilogram. Various authors in recent literature have used producer prices as a proxy for value added in estimating economic water productivities due to difficulties in getting data for estimating value added to the products investigated (Chouchane et al., 2015; Schyns and Hoekstra, 2014; Zoumides et al., 2014). However, this paper adds some novelty in our economic water productivity estimates by moving a step further to calculate the value added to milk along the dairy value chain as well as some important feed products for our productivity estimates. As the main product moves along the value chain, value is added at each stage. Hence, we estimated the value added to milk at the farm gate, processing or wholesale and retail levels in order to ascertain the point along the dairy value chain where most value is added. The value added to the out product (Υ) was estimated by deducting the cost per kilogram of Υ from the sales revenue obtained from selling one kilogram of Υ at each stage of the value chain (Crafford et al., 2004). Thus, the value added to the output product (Υ) is the total revenue from the product minus the cost of all intermediate inputs employed in the production of Υ. We denote the value added to Υ at a particular stage of the value chain as $VAD_{ivc}[\Upsilon]$ and expressed empirically as:

$$VAD_{ivc}[\Upsilon] = Re_{ivc}(\Upsilon) - Co_{ivc}(\Upsilon) \quad ZAR/kg \quad (11)$$

where $Re_{ivc}(\Upsilon)$ is the sales revenue obtained from selling one kilogram of Υ at each stage of the value chain and $Co_{ivc}(\Upsilon)$ is the cost of all intermediate inputs employed to produce a kilogram of Υ. $Co_{ivc}(\Upsilon)$ consists of the cost of water usage, capital, land, labour, feed, taxes, veterinary, transport, packaging, fuel, repairs and maintenance, etc. The total value added ($TVAD[\Upsilon]_{vc}$) along the complete value chain was calculated by summing the value added at each stage of the value chain. This is specified as:

$$TVAD_{vc}[\Upsilon] = \sum_{i=1}^{3} VAD_{ivc} \quad ZAR/kg \quad (12)$$

The value added to water as the product moves along the value chain can be expressed as the ratio of the value added to the output product (Υ) at each stage of the value chain over the quantity of water utilized at the respective stages (Crafford et al., 2004). Given the value added to the output product (Υ) along the value chain, marginal contribution from water MVAD[water] is specified as:

$$MVAD[water]_{vc} = \frac{VAD_{ivc}}{WU_{ivc}} \quad (13)$$

VAD_{ivc} denotes value added to the product at i stage of the value chain and WU_{ivc} is the quantity of water used at i stage of the value chain. We then expressed the economic water productivity as:

$$EWP\left(ZAR/m^3\right) = PWP\left(kg/m^3\right) * VAD(ZAR/kg) \quad (14)$$

The economic water productivity (*EWP*) is expressed in ZAR[1]/m^3. The procedure for estimating the physical and economic water productivities for the output product was applied to estimate the physical and economic water productivities for the feed crops.

2.2. Data

Both primary and secondary data pertaining to the South African dairy sector were used. Primary data on cost and revenue expenditures on feed products and raw milk were obtained from dairy agribusiness companies who form part of the South African Milk Processors' Organisation (SAMPRO), and Milk South Africa (Milk SA). Milk SA was established in 2002 to oversee the South African dairy industry. These organisations consist of dairy producers and processors, who produce different dairy products for the local and international market. These companies consist of both commercial dairy and processing plants where milk is processed and bottled. Data on price consisted of producer, wholesale and retail prices. Secondary data on feed production, inputs cost, water usage for feed crops and servicing water used in the dairy industry were attained from SAMPRO, Milk SA and Van Rensburg et al. (2012). Van Rensburg et al. (2012) assessed water utilization for important field and forage crops. The dairy producers considered have feed calculation systems with electronic recordkeeping and as such accurate data on feed composition and the quantities fed to animals were available. The data obtained were aggregated and average values were used in further calculations. The electronic feed calculator records information on quantities of the various feed products and ingredients in feed ration, moisture content, dry matter, nutritional values of the inputs and the complete ration for the lactating cows. Data obtained from these sources were used to calculate the volumes of blue, green and grey water utilized in milk production. Our estimated water footprints for feed crops such as maize, soy and sun flower were compared to the estimates obtained by Mekonnen and Hoekstra (2010a) for South Africa. Secondary data on prices of feed crops were obtained from Bureau of Food and Agricultural Policy and Southern Africa (BFAP).

3. Results and Discussion

3.1. Water Footprint, Marginal and Economic Water Productivities of Feed Products

Table 1 presents the water footprints of key feed products included in a balance ration formulated for dairy cows. We estimated blue, green and grey water footprints for these feed stuffs in order to ascertain which of them uses more water. The results show that high protein concentrates (HPC) and yellow maize meal had the highest total water footprints, while oats silage had the lowest. Among all the feed crops,

[1] Average exchange rate for December 2015: US$1; ZAR 15.05.

Table 1
Water footprint of main feed products in a complete ration for dairy cows.
Source: Author's calculations, 2015.

Feed products	Blue WF (m^3/year)	Green WF (m^3/year)	Grey WF (m^3/year)	Total WF (m^3/year)
Lucerne hay	217,942	263,165	99,682	580,788
Oats Silage	103,587	23,397	9965	136,948
Sorghum Silage	122,421	107,529	18,031	247,981
Maize Silage	188,961	179,215	28,872	397,047
Yellow maize meal	0	2,256,175	195,969	2,452,143
HPC	74,643	2,512,770	47,560	2,634,972
Soybean cake	53,400	1,662,502	8797	1,724,698
Sun flower cake	21,207	850,268	38,800	910,274

HPC: High Protein Concentrate.

lucerne hay and maize silage had the highest blue water footprints. In terms of green water, high protein concentrate and yellow maize meal had the highest footprints, respectively. In all instances, the grey water footprint was lower than both blue and green water footprints, with the exception of yellow maize meal and sun flower cake. Additionally, maize meal and lucerne hay recorded the highest grey water footprints.

Prior to the estimation of economic water productivities of the feed products, their dry matter contribution and marginal water productivities were calculated for a balance ration providing an average of 26.32 kg of dry matter per day for dairy cows and the results are presented in Table 2. It must be emphasised that water productivities were estimated for the main feed stuffs and ingredients. Out of the 26.32 kg of dry matter (DM) supplied, 28.42% representing 7.48 kg was provided by yellow maize meal. High protein concentrate (HPC) contributed 18.47% (4.86 kg) to the total dry matter. Lucerne hay and maize silage contributed 16.03% and 14.78%, respectively to the dry matter. Sorghum and oat silage also contributed 9.80% and 3.99% of the total daily dry matter, respectively. This result implies that yellow maize meal, high protein concentrate and lucerne hay are very important contributors to dry matter for dairy cows, not excluding the other feed stuffs. In order to arrive at meaningful conclusions, we estimated the marginal contribution of the individual feed products to the total milk output. The total average milk yield per year for the dairy farms considered for this study was 13,197 t. The results reveal that yellow maize meal is the highest contributor to yearly milk yield. Similarly, we found that high protein concentrate and lucerne hay are the second- and third-highest contributors to the yearly milk yield, respectively. Maize silage contributed 14.78% of the total yearly milk output, with the lowest contribution coming from oat silage. Soybean and sun flower cakes are incorporated into HPC and not fed to the animals separately, so we did not estimate separate contributions to dry matter for these feed ingredients.

After estimating the contribution to yield from the individual feed crops, water productivities of the feed products were estimated by dividing their contribution to yield by their respective water footprints. The results are presented in the last column of Table 2. The findings show that feed products such as sorghum silage, maize silage, oats silage and lucerne hay have high marginal water productivities. However, expressing water productivities in physical terms is not sufficient to meaningfully explain the economic benefits of water-use. Hence, we estimated economic water productivities which give insight to the economic benefits of water usage in the feed production sector. The results are presented in Table 3. The value added to the feed crops and ingredients were estimated for economic and policy purposes. In terms of value addition, the results show that more value is added to high protein concentrate and yellow maize meal, as ZAR 6.91 and ZAR 4.39 are attained from these feed products, respectively. This is followed by lucerne hay, sorghum and maize silages, respectively. The least value added is associated with oats silage. The results generally suggest that the production of all the feed products considered is economically efficient since the monetary value attained from them is positive. However, the value added varies from product to product.

The results in Table 3 further revealed that sorghum silage and lucerne hay are the top two feed products which have high economic water productivities; as every cubic metre of water used in producing sorghum silage and lucerne hay results in ZAR 8.72 and ZAR 6.82, respectively. This is followed by yellow maize meal and high protein concentrate (HPC); as every cubic metre of water used in their production yields about ZAR 6.71 and ZAR 6.43, respectively. Maize silage had the least economic water productivities. The above results provide vital information for livestock feed producers and water users along the dairy value chain as to which feed crops or products are economically efficient to produce in terms of water use and profitability. Notwithstanding this, the contribution to dry matter and milk yield should be taken into consideration in order to attain higher proceeds. For instance, the total economic water productivity estimates and contributions to milk output indicate that feed products such as yellow maize meal, high protein concentrate and lucerne hay are very economical in terms of water and have high contributions to milk yield. Hence, profit-maximising dairy farmers and feed manufacturers with sustainable and efficient water-use objectives can focus more on such feed products which are good contributors to milk yield and have high economic water productivities.

Despite the high economic water productivity of sorghum silage, our findings indicate that its contribution to milk yield is low, relative to feed products such as maize meal, HPC and lucerne hay. This implies that not all economically active feed products are significant contributors to milk output. Similarly, maize silage has low economic water productivity and somewhat low contribution to milk output. Therefore, dairy farmers can replace it with feed products such as triticale silage

Table 2
Dry matter contribution and marginal water productivities of main animal feed products in a complete ration for dairy cows.
Source: Author's calculations, 2015.

Feed products	Total WF (m^3/year)	Kilogram of dry matter per day	Percentage contribution to milk output[a]	Actual contribution to yearly milk output (tonnes)	Marginal water productivities (kg/m^3)
Lucerne hay	580,788	4.22	16.04	2117	3.64
Oats Silage	136,948	1.05	3.99	527	3.84
Sorghum Silage	247,981	2.58	9.80	1293	5.22
Maize Silage	397,047	3.89	14.78	1950	4.91
Maize meal	2,452,143	7.48	28.42	3750	1.53
HPC	2,634,972	4.86	18.47	2437	0.93
Other ingredients	1,409,485	2.24	8.50	1122	0.80
Total	7,859,363	26.32	100	13,197	20.87

[a] Average dry matter to milk yield ratio for South Africa: 1 kg DM: 3.8 output Mekonnen and Hoekstra (2010b).

Table 3
Value addition and economic water productivity of main feed products.
Source: Author's calculations, 2015.

Feed products	Marginal water productivities (kg/m^3)	Value added (ZAR/kg)	Economic water productivities (ZAR/m^3)
Lucerne hay	3.64	ZAR 1.88	6.84
Oats Silage	3.84	ZAR 1.37	5.22
Sorghum Silage	5.22	ZAR 1.67	8.72
Maize Silage	4.91	ZAR 1.66	3.25
Yellow maize meal	1.53	ZAR 4.39	6.71
HPC	0.93	ZAR 6.91	6.43

Average exchange rate for December 2015: US$1; ZAR 15.05.

which is known to have high contribution to milk output and economic water productivities (Cosentino et al., 2015).

3.2. Water Footprint and Physical Water Productivity of Milk Produced and Processed in South Africa

Table 4 presents the water footprint and physical water productivities of milk produced and processed in South Africa. The results show that the total yearly water footprint for producing 13,196.58 t of milk with 3.3% protein and 4% fat is 1024.95 cubic meters per tonne. Based on this figure, we estimated the physical water productivity of milk along the complete dairy value chain to be 0.98 kg per cubic meter. Precisely, green water footprint constitutes 862.20 cubic meters per tonne whereas blue and grey water footprints constitute 96.99 and 65.76 cubic meters per tonne, respectively. This suggests that green water (84.12%) forms the largest constituent of the total water footprint of milk, followed by blue water (9.46%) and grey water (6.42%) footprints, respectively. In terms of physical water productivities, the results indicate that 10.31 kg of milk is attained from every cubic meter of blue water used, whereas 1.56 kg of milk is obtained from every cubic meter of green water utilized. The results further show that about 80.92% of the total yearly water footprint in the dairy industry in South Africa is attributed to feeding lactating cows only, whereas 17.10% is utilized for feeding non-lactating cows. This indicates that about 98.02% of the total water footprints along the dairy value chain go into feeding of animals. This concurs with the findings of Mekonnen and Hoekstra (2010b) who opined that more than 95% of the water footprints of animal products relates to water used for feed production. The remaining amount constitutes the water consumed by the live animals and servicing water used at the processing stage.

3.3. Value Additions and Economic Water Productivities of Milk at Different Stages and for Different Packaging Designs

For dairy producers with profit maximization and water sustainability objectives, the value generated from their production inputs and economic water productivities are very important to their production decisions. For instance, inputs such as blue water use is directly associated with production costs and may be limiting dairy production (Chouchane et al., 2015). This implies that particular attention should be paid to activities that result in higher value addition and economic water productivities, while focusing on making rational and efficient use of water in order to be economically productive along the dairy value chain. Hence, we have estimated the value added to milk as it moves along the dairy value chain in order to determine the point along the dairy value chain where most value is added. Given the value added along the value chain, we conducted sensitivity analysis for economic water productivities of milk at different stages of the value chain and for different packaging sizes. We considered one litre and three litres packaging sizes with different sales revenue per kilogram. The results are presented in Table 5. The results show that a total value of ZAR 12.11 is added to a kilogram of milk when packaged in 1 l bottle, relative to ZAR 9.04 per kilogram of milk when packaged in 3 l bottle. This implies that more value is attained when milk is packaged in smaller sizes.

Along the value chain, our results show that more value is added to milk at the processing or whole sale level irrespective of the packaging size, as indicated by the amounts of ZAR 5.84 and ZAR 4.01 per kilogram of milk for one and three litres packages, respectively and relative to the other stages along the value chain. The second highest value is added at the retail level where ZAR 4.70 and ZAR 3.46 per kilogram of milk were added to one litre and three litres packaging sizes, respectively. At the

Table 4
Water footprint and physical water productivity of milk in South Africa.
Source: author's calculations, 2015.

Parameters	Yield (tonne/year)	Blue WF (m^3/year)	Green WF (m^3/year)	Grey WF (m^3/year)	Total WF (m^3/year)
Drinking water					
Lactating cows		31,153.12			31,153.12
Non-lactating animals		15,556.67			15,556.67
Feed production water					
Lactating cows		707,552.50	5,342,213.00	400,040.00	6,449,805.50
Non-lactating animals			1,362,837.00		1,362,837.00
Total yearly water usage		754,262.29	6,705,050.00	400,040.00	7,812,642.50
Yearly Milk Production	7776.69				
Total yearly production WF		96.99 m^3/t	862.20 m^3/t	51.44 m^3/t	1010.63 m^3/t
Service water					
Service		–	–	188,960.50	188,960.50
Yearly milk processed	13,196.58				
Total yearly servicing water		0 m^3/t	0 m^3/t	14.32 m^3/t	14.32 m^3/t
Total water footprint		96.99m^3/t	862.20 m^3/t	65.76 m^3/t	1024.95 m^3/t
Physical water productivity		10.31 kg/m^3	1.56 kg/m^3	15.21 kg/m^3	0.98 kg/m^3

Table 5
Value additions to milk as it moves along the value chain and economic water productivities of milk at different stages and different packaging sizes.
Source: Author's calculations, 2015: 1 l of milk = 1.033 kg.

Stage of value chain	Value addition (ZAR/kg)		Economic water productivity (ZAR/m^3)	
	1 Litre packaging	3 Litres packaging	1 Litre packaging	3 Litres packaging
Farm gate	1.57	1.57	1.55	1.55
Processing/whole sale	5.84	4.01	5.72	3.93
Retail	4.70	3.46	4.61	3.39
Total	12.11	9.04	11.88	8.87
Total physical water productivity (farm gate)				0.99 kg/m^3
Total physical water productivity (wholesale and retail levels)				0.98 kg/m^3

Average exchange rate for December 2015: US$1; ZAR 15.05.

farm gate level, we found that an amount of ZAR 1.57 each was added to milk for both packaging sizes considered. It worth noting that the value added to milk at the retail level for one litre packaging size is higher than the value added to the three litres packaging size at the processing or wholesale level. Generally, the results indicate that milk production is economically efficient since the revenue attained at each stage of the value chain exceeds the cost incurred.

Regarding economic productivity of water, the results show that the economic water productivity of milk packaged in one litre bottle is ZAR 11.88 per cubic meter, whereas that of the three litres package is ZAR 8.87 per cubic meter. This means that every cubic metre of water used to produce one kilogram of milk with 3.3% protein and 4% fat, yields ZAR 11.88 and ZAR 8.87, when packaged in one litre and three litres respectively. The implication from this finding is that milk production in South Africa is economically efficient in terms of water usage since the value attained from every cubic meter of water used exceeds its cost. At the production stage where larger proportion of water is used, our results indicate that every cubic meter of water utilized results in ZAR 1.55. Water use is highly economical at the processing stage; as every cubic meter of water used in the production of a kilogram of milk with 3.3% protein and 4% fat, resulted in ZAR 5.72 and ZAR 3.93, respectively for one litre and three litres packaging sizes. At the retail level, every cubic meter of water utilized yielded ZAR 4.61 and ZAR 3.39, when milk is packaged in one litre and three litres respectively. The above results indicate that water use along the dairy value chain is very productive at the processing and retail levels. The type of packaging sizes used for selling the dairy product has a bearing on the value addition and economic water productivity estimates.

4. Conclusions

The current global water scarcity situation and the pressure on governments, organisations, policy-makers, water-users and water managers to develop sustainable and economically efficient water-use policies require rigorous assessment of water footprints and water productivities in all sectors of the economy that use water. Water footprint assessment in the agriculture and food sectors has emerged as a vital sustainability indicator. The present paper has contributed to earlier water footprint studies in South Africa and Africa as a whole by adding the economic aspect of water use along the dairy value chain. The study focused on the economic productivity of water along the dairy value chain, starting from feed production to the final product.

Our findings have important economic and efficient water use implications for actors along the dairy value chain. In terms of water use, we conclude that the highest proportion of water utilized along the dairy value chain goes into feed production. Different feed products have different water footprints. This suggests the need for water footprint assessment of different feed products to identify the ones that are higher users of the existing scarce water resources. Given the blue water scarcity situation in South Africa, our findings suggest that feed products such as lucerne hay, maize silage and sorghum silage are higher consumers of blue water resources. However, judging these products based on their water footprint estimates alone will be biased. Hence, our findings have highlighted the contributions of the feed products to milk output. Yellow maize meal, high protein concentrate and lucerne hay are the top three feed products with high contribution to milk output, respectively. Hence, dairy livestock producers should pay particular attention to these feed products when formulating ration for dairy cows, with the aim of attaining high milk yield, which in turn will lead to low water footprints, high value addition and economic water productivities.

Although feed production uses the highest proportion of water along the dairy value chain, our assessment of value addition and economic water productivities of the feed products proves that the production of the feed products are economically efficient in terms of cost and water use. The economic implication of this finding is that the revenue attained from producing the feed crops and the value added to water along the dairy value exceeds the cost incurred. Hence, we conclude that dairy livestock farmers or producers are economically efficient in their production. The findings further provide vital information for livestock feed producers and marketers on the feed products which are more profitable, as our results indicate that the value added to the feed products vary from product to product. High economic values are associated with high protein concentrate, yellow maize meal, lucerne hay, and sorghum and maize silages, respectively.

Of further importance from our study is the findings which point to the fact that not all economically water productive feed products are significant contributors to milk yield. Feed products such as yellow maize meal, high protein concentrate and lucerne hay appear to be very economical in terms of water and have high contribution to milk yield, with positive value addition. Maize silage has low economic water productivity and somewhat low contribution to milk yield and as such we suggest that dairy farmers can substitute it with a better option such as triticale silage which is known to have high contribution to milk yield and economically productive in terms of water use. This provide the rationale for profit-maximising dairy farmers with sustainable and efficient water use objectives to reconsider their dairy livestock feed formulation by incorporating more of the feed products with good contribution to milk output and economic water productivities.

We further conclude that the value added to milk as it moves along the value chain varies from stage to stage, with the highest value added at the processing level, followed by retail level and the farm gate, respectively. Albeit, our estimates suggest that milk production at each stage along the value chain is economically efficient in terms of cost and water use. From marketing point of view, our findings suggest that more value is added to milk and water when packaged in smaller sizes. This connote that the type of packaging design used at the processing level of the dairy value chain has an influence on value addition and economic water productivity estimates.

We generally recommend that future research on estimations of ecological footprints and economic productivities of ecological indicators such as water should not focus only on quantifying the footprint indicators. Rather, researchers should take into account economic water productivities and the monetary value added to the product along its value chain since it gives meaningful economic implications. In order to be sustainable and economically productive in water use, all water users and managers along the dairy value chain can rely on such context-specific and concrete research outcomes to reduce the pressure of animal feed production on fresh water use in the livestock sector, while maintaining milk yield and profitability. The findings provide detailed insights into profitability and economically productive water-use in the dairy industry. We suggest that policy makers, water users and managers along the dairy value chain should not rely on water footprint estimates alone to judge the industry.

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Water Footprint of Milk Produced and Processed in South Africa: Implications for Policy-Makers and Stakeholders along the Dairy Value Chain

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Abstract: The current water scarcity situation in South Africa is a threat to sustainable development. The present paper has assessed the water footprint of milk produced and processed in South Africa using the procedures outlined in the water footprint assessment manual. The results show that 1352 m^3 of water is required to produce one tonne of milk with 4% fat and 3.3% protein in South Africa. The water used in producing feed for lactating cows alone accounts for 86.35% of the total water footprint of milk. The water footprint of feed ration for lactating cows is about 85% higher than that of non-lactating cows. Green water footprint accounts for more than 86% of the total water footprint of feed ration for lactating cows. Green and blue water footprints are the highest contributors to the total water footprint milk production in South Africa. Water used for feed production for both lactating and non-lactating cows accounts for about 99% of the total water footprint of milk production in South Africa. Particular attention should be given to feed crops with low water footprints and high contribution to dry matter to provide balanced ration with low water footprint. Water users, managers and livestock producers should pay attention to green and blue water consumption activities along the milk value chain and design strategies to minimize them. Corn, sorghum and lucerne production under irrigation in the greater Orange River basin is sustainable, whereas oats production for silage in the same catchment area is not sustainable. Our findings provide the rationale for dairy producers and water users in the dairy industry to get an understanding of the degree of sustainability of their input and output combinations, production choices, and policy interventions, in terms of water use.

Keywords: dairy value chain; South Africa; milk; water footprint; water scarcity; water sustainability

1. Introduction

The global water scarcity situation is a major issue of concern to sustainable development and requires detailed assessment of water footprints in all sectors of the economy [1]. Water footprint assessment in the food and agricultural sector has been recognized as an important sustainability indicator in recent years [2]. The water footprint concept takes into account the volume of fresh water used to produce a product and it is measured along the entire product value chain, right from production of inputs to the stage where the final product reaches the consumers [3]. The water footprint measured along the value chain of the product, according to Hoekstra et al. [3], is categorized into blue, green and grey. The blue water footprint refers to the surface and groundwater that is consumed (including water that has evaporated and the water that was incorporated into the product) along the value chain of a product. The green component of the water footprint refers to all the rainwater that does not become run-off, but is consumed by the crop [3]. The volume of freshwater required to reduce the pollutants to ambient levels is referred to as the grey water footprint. The concept of water footprint is also well grounded in the Life Cycle Assessment approach (LCA) [2] and the Water Footprint Assessment Manual described by Hoekstra et al. [3].

Water footprint assessment across the entire value chain of livestock products is gaining prominence because the livestock industry has crucial deficits in meeting the food needs of the increasing human population without exerting potential impacts on water resources [4]. For instance, assessments of the water footprint of beef cattle and sheep production systems in Australia and New Zealand have been done by Ridoutt et al. [2] and Zonderland-Thomassen et al. [5]. In China, the water availability footprint of milk and milk products from large-scale farms has been assessed by Huang et al. [6]. Analysis of potential water use, water stress, and eutrophication impacts from US dairy has been done by Matlock et al. [7]. The water footprints of milk in Germany, the Netherlands, India, and Argentina, among others, have been assessed [8–11]. In the African context, Bosire et al. [12] have recently assessed the trends and spatial variation in freshwater use for meat and milk in arid, semi-arid and humid production systems in Kenya using nation-wide data. The water footprint of livestock feed production is by far the greatest consumer of water along animal value chains, as it uses more than 95% of all the water used along the value chain [13,14]. Unfortunately, none of the studies in the growing body of literature on livestock and dairy products has focussed on the South African dairy industry. This has resulted in a literature gap regarding the water footprint of dairy products, particularly milk, in South Africa.

Although Mekonnen and Hoekstra [15] assessed the water footprint of dairy cattle in South Africa, their assessment was based on global averages. No South African case study was considered in the assessment and this raises doubt whether regional- or country-specific case study footprints will be the same as the global averages. Blue and green water footprints of lucerne for milk production in South Africa were recently assessed by Scheepers and Jordaan [16]. However, the focus of their study was on lucerne production for use as animal feed in the dairy industry and not on the dairy products. Hence, little information is available to guide and inform policy makers in policy formulation and integrated water resources management in the dairy sector at regional and national levels. Meanwhile, pressure is mounting on government and policy makers regarding allocation of water resources because fresh water is becoming increasingly scarce in South Africa [17].

South Africa is ranked as the 30th driest country in the world [17]. The agricultural sector, which includes the meat and dairy industry, uses up to 60% of the available water in South Africa [16]. Also, about 40% of the exploitable runoff is used for irrigating crops and pastures for feeding livestock [18]. This implies that the agricultural sector is a major user of freshwater in South Africa. However, given the relevance of agriculture and the essential role that water plays in agriculture, there is the need for water footprint and sustainability assessment in the agricultural sector. For instance, the livestock sector contributes about 40% to the gross value of agricultural production in South Africa [19]. The dairy industry alone contributes 14% to the gross value of animal production, and 7% of the gross value of agricultural production in South Africa [19]. This sector alone comprises of about 4000 milk producers. It further provides direct and indirect employment for about 100,000 people along the dairy value chain [19], emphasising the relevance of the industry to socio-economic development. Therefore, it is crucially essential to understand the degree of sustainability with which freshwater is used in dairy production. Such sustainability information will accurately and effectively inform water managers and water users towards the sustainable use of freshwater in dairy production, while sustaining the socio-economic benefits from the industry. Sustainability assessment in the dairy industry will reveal the water use behaviour from the view point of blue water availability in order to precisely understand whether the behaviour of water users in the industry is environmentally sustainable or not.

The present paper endeavours to fill the gap in the literature while contributing to the sustainability objective by assessing the water footprint of milk produced and processed in South Africa. Large water users along the milk production chain are identified for policy purposes.

2. Methodology

2.1. Conceptual Framework and Empirical Models

The study adopted the concept of water footprint as described in the Water Footprint Assessment Manual by Hoekstra et al. [3]. The water footprint indicates freshwater use (direct and indirect) of a consumer or product. Hoekstra et al. [3] stressed that the water footprint can be regarded as a comprehensive indicator of freshwater use and should be used along with the traditional and restricted measures of water withdrawal. The water footprint concept, as described in the Water Footprint Assessment Manual, has been widely adopted to estimate the water footprint of an individual, a product, community, business or a nation [20–22]. This method is preferred because it is multidimensional, revealing water consumption volumes by source and polluted volumes by type of pollution [23]. Some authors have also applied the Life Cycle Assessment approach (LCA) to assess water footprints of animal products [2,9,11]. However, the LCA concept does not account for rainwater used by crops and the grey water footprint [3].

In this paper, the focus is on the water footprint of milk production from cattle. Conceptually, the water footprint of milk is defined as the total volume of freshwater used to produce the milk [3]. The water footprint concept adopted in this study gives a distinction between the green, blue and grey water used in producing milk. This implies that the concept offers an all-inclusive and comprehensive indication of freshwater consumption and pollution. The chain-summation approach for estimating water footprint of a product as described by Hoekstra et al. [3] was used, since our focus is on milk and not a variety of products [3]. The water footprint of milk consists of different process water footprints. These processes are made up of direct and indirect water footprints. The direct water footprint relates to the service water and the water that the live animals drink, while the indirect water footprint is the water used for feed production [3]. The formula specified by Chapagain and Hoekstra [24] for calculating the water footprint of live animals was employed to calculate the water footprint of the cows. The service water refers to the water used for washing the animals, cleaning the farmyard, and all other water used in order to maintain the production environment [3]. Animal water footprints are usually expressed in terms of m^3/year/ animal or m^3/animal, when summed over the entire lifespan of the animal. The estimation of the water footprint for feed followed the method outlined in the work of Mekonnen and Hoekstra [13,21].

As indicated by Mekonnen and Hoekstra [13,21], the feed ingredients for formulating feed ration in a country comes from both domestic production and imported products. Therefore, we took the weighted average water footprint according to the relative volumes of domestic production and imports in the calculation of the water footprint of animal feed [13]. The equation for estimating water footprint of feed ingredient is specified in Mekonnen and Hoekstra [13]. After estimating the water footprint of the feed, it is worth noting that the composition and the volume of the feed need to be determined, given that feed consumption varies depending on breed of animal, the production system and the country. Total dry matter intake, feed conversion efficiency and milk output per cow were recorded using electronic feed calculators. Feed conversion efficiency (FCE) was recorded as the ratio of total feed intake per cow over milk output per cow. The milk yield per dairy cow was multiplied by the total number of dairy cows to obtain the total milk yield.

It must be emphasized that the blue, green and grey water footprints of some feed crops used in South Africa are estimated separately. Hence, the water footprints at the processing phase of the value chain are added to get the total water footprint. We assumed that the volume of water used at retail level for cleaning is negligible in relation to the complete value chain, and it will therefore not be included in this study. The final blue water footprint is then an indicator of the total amount of surface and ground water that has evaporated together with the water that was incorporated into the final product. No green water is used in the processing and retailing of dairy products, so the green water used for the feed production, including the natural vegetation for pastoral grazing, is the total green water footprint of the milk value chain in our study. Grey water from the production of feed ration for the lactating cows was estimated as a leaching requirement to maintain the good productive potential of the soil. No blue water originated from the processing plant, as the fresh water that was used for cleaning the facility was recycled and later used for cleaning the cattle runs and the floor of the dairy parlour. The service water thus becomes grey water in the effluent pond and was accounted for according to the grey water methodology [3]. The grey water emanating from the faeces and urine of the lactating cows was estimated with the use of an effluent sample analysis, and the volume was measured as the flow into the effluent pond. From the analysis, the electrical conductivity (EC) of the effluent pond was taken and multiplied by the total volume of the effluent, and the salts originating from the abstracted water were then subtracted to obtain the total salts added to the effluent at the facility. The volume of water required to assimilate this load to below the acceptable level is then the grey water for milk processing. The formulas for estimating the blue, green and grey water footprints are clearly outlined in the Water Footprint Assessment Manual by Hoekstra et al. [3].

2.2. Sustainability Assessment

Sustainability assessment of water use in milk production from cattle was done after calculating the volumetric water footprint of milk. This was done to ascertain whether water use in the catchment area for milk production is sustainable or not. The blue water footprint used in the dairy industry is regarded as unsustainable if the blue water footprint exceeds blue water availability in the milk-producing catchment area. It must be emphasised that the blue water footprint and blue water availability were determined for the particular catchment area at definite time periods due to seasonal changes in water use and run-off. Hoekstra et al. [25] expressed blue water availability in a catchment for a particular time period as the difference between the natural run-off in the catchment and environmental flow requirement. Refer to Hoekstra et al. [3] and Scheepers and Jordaan [16] for the equation regarding blue water availability.

The environmental flow requirement for a particular catchment area at a certain time period is not met when the blue water footprint surpasses the blue water availability in the catchment. The environmental flow requirement denotes the volume and timing of water flows needed to ensure freshwater ecosystems and human livelihoods. Failure to meet the environmental flow requirement indicates unsustainable water use. Hoekstra et al. [25] further revealed that the blue water footprint sustainability assessment can be estimated by means of an index known as the blue water scarcity index. Refer to Hoekstra et al. [3] for the empirical specification of blue water scarcity index.

The blue water availability is unsustainable if blue water scarcity index is greater than 1 for a particular catchment area for a specific time period [3]. A catchment area where blue water scarcity index is greater than 1 at a point in time is regarded a hotspot [3]. Such catchment areas need intervention to ensure sustainability of freshwater use at the relevant time period.

2.3. Data Description

Data used in this paper consists of both primary and secondary data. The data covers the entire dairy value chain, with a focus on milk sold at processing level. Secondary data on water usage for the production of feed crops were obtained from Van Rensburg et al. [26]. Once the feed crops are produced, they become important inputs for dairy production and the link between the feed crops and dairy value chains is made. Therefore, data on water used in the commercial dairy farm and dairy processor is needed. This data was collected through questionnaires and interviews with the managers of the various divisions at the case study agribusiness. The business consists of both a commercial dairy and a processing plant where milk is processed and bottled. Data associated with irrigation was taken from the Vaalharts Irrigation Scheme. Important feed crops are produced under this scheme. Detailed information on measuring sites and systems can be obtained from Van Rensburg et al. [26]. The data were recorded over four seasons (two winters and two summers).

Data on water usage were measured on a weekly basis at every measuring point. These weekly measurements enumerated rainfall, irrigation, soil water content, water table depth, and drainage from artificial drainage systems, if any, as well as electrical conductivity (EC) of the irrigation water, water table and drainage water. The rainfall and irrigation were measured with rain gauges placed on the surface of the soil, with a 6 m^2 cleared area around each rain gauge in order to prevent interference from the crop. Soil water content was measured with a calibrated neutron probe. The depth of the water table was measured manually by using an electronic device, while the volume of drainage water flowing from the artificial drainage systems was measured with a bucket and converted to $L \cdot min^{-1}$. Changes in irrigation, rainfall, soil water content, and drainage from artificial drainage systems were all measured, of which the latter mentioned also apply to the change in salt content of the soil, and salts added through rainfall and irrigation, as well as salts removed through the artificial drainage system. The net amount of salt applied through fertilisation (SF) was calculated as the difference between salt applied through fertilisers and salt removed by the crop.

Data on water used to produce milk were collected from the milk producers and Milk SA [27]. Farms considered in the study have feed calculating systems with electronic recordkeeping of the dry matter intake, feed conversion efficiency, and milk output per cow. The data recorded per animal was multiplied by the total number of animals to attain the aggregated data for the whole dairy farm. The data obtained were used in the calculations of the water footprint of feed ration. No further estimation was done to determine the dry matter intake (DMI) and feed conversion efficiency (FCE) for lactating cows since accurate data were available from the producers. The electronic feed calculator system also has information on quantities of the various inputs in the feed ration, their moisture content and nutritional values. The DMI guidelines of Stalker et al. [28] together with the average body weights set out by Bowling and Putnam [29] were used to determine the total feed consumption for the non-lactating cows. This method was used since the electronic feed calculator did not record information on non-lactating cows. We estimated DMI of all the non-lactating animals in order to get comprehensive information on water and feed intake. The total DMI was then multiplied by 385 m^3 as reported by Mekonnen and Hoekstra [20] in order to calculate the water footprint for the non-lactating cows fed mainly on grazing lands or pastures. Also, the guidelines suggested by Ensminger et al. [30] were used to generate data on water intake by the non-lactating animals on the case study dairy farm. The estimation of water intake by lactating cows was based on the Little and Shaw [31].

3. Results and Discussion

3.1. Water Usage in Feed Production for Dairy Cows

Table 1 presents the water use for feed production for lactating cows. The results show that the total water footprint for producing feed for 825 lactating cows is about 9.08 million·m^3 of water per year. The actual amount of green water used for feed production for the lactating cows is about 7.85 million·m^3 per year, 782,161 m^3 and 447,676 m^3 of blue and grey water were used per year, respectively for all the lactating cows. This implies that 8.61% of the total water footprint is blue water, 86.46% is green water and 4.93% is grey water. Specifically, the actual amounts of blue, green and grey water used for feed production for a lactating cow are 948 m^3, 9521 m^3 and 543 m^3 per year, respectively. This implies that feed production for lactating cows is largely dependent on green water, followed by the blue water and grey water, respectively. Among the feed crops, high protein concentrates (including soybean cake, canola cake and sunflower cake) and maize meal had the highest green water footprints of 2.51 million·m^3 and 2.25 million·m^3 per year, respectively. Lucerne and maize silage has the highest blue water footprints of 217,942 m^3 and 188,961 m^3 per year, respectively. Additionally, maize meal and lucerne silage recorded the highest grey water footprints respectively. Since green water is the largest contributor to the total water footprint for feed production for lactating cows, particular attention should be given to feeds such as maize meal, high protein concentrate feeds, soybean and sunflower oil cakes which have high green water footprints in order to minimize green water consumption in the feed industry. Also, since blue water is directly associated with production cost, particular attention should be paid to feeds such as lucerne, maize, sorghum and oat silages to make sure that they are efficiently and sustainably produced. The results further show that the formulation of high protein concentrates and maize meals contribute the highest to the total water footprint for feeding lactating cows per year, among all the feeds.

Table 1. Water use in feed production for lactating cows per year.

Product	Kg DM	%	Herd Total	Tonne	m^3/Tonne	Blue m^3/year	Green m^3/year	Grey m^3/year	Total WF m^3/year
Lucerne	1533	17.3	1,264,725	1265	459	217,942	263,165	99,682	580,789
Oats Silage	402	4.6	331,650	332	412	103,587	23,397	9965	136,949
Sorghum Silage	949	10.7	782,925	783	317	122,421	107,529	18,031	247,981
Maize Silage	1424	16.1	1,174,800	1175	338	188,961	179,215	28,872	397,048
Maize meal	2738	31.0	2,258,850	2259	1086	0	2,256,175	195,969	2,452,144
HPC	1789	20.3	1,475,925	1476	1785	74,643	2,512,770	47,560	2,634,973
Soy oilcake	–	–	–	–	–	53,400	1,662,502	8797	1,724,699
Sun flower oilcake		–	–	–	–	21,207	850,268	38,800	910,275
Total	8833	100	7,288,875	7290	4397	782,161	7,855,021	447,676	9,084,858

Note: Source: Authors' calculations, 2015; HPC: High Protein Concentrate.

The water used in feed production for non-lactating cows is explained in the following section.

Table 2 presents the yearly feed intake and water utilized in producing feed for non-lactating cows. The results indicate that the total water footprint of feed for all the non-lactating cows fed solely on grazing is about 1.36 million·m^3 per tonne per year, all of which contributes to the total water footprint. About 53.09% of the total water footprint for feeding non-lactating cows goes into feeding dry cows, 42.68% is utilized in feed production for heifers and only 4.23% goes into feeding bulls. This implies that, among non-lactating cows, feed production for dry cows utilizes more water compared with heifers and bulls.

Table 2. Yearly feed intake by the non-lactating cows on the case study farm.

Parameters	Number of Animals	Live Weight (Kg)	DMI				m^3/year
			% of BW	Kg	Total	Tonne	385 m^3/tonne
Dry cows	399	544.31	2.37%	12.90	5147.10	5.15	723,704
Heifers	886	–	–	–	–	–	–
0–6 months	220	62.14	1.50%	0.93	204.60	0.20	28,105
6–12 months	206	171.38	2.10%	3.60	741.6	0.74	103,989
12–18 months	238	259.68	2.15%	5.58	1328.04	1.33	186,898
18–24 months	156	332.48	2.20%	7.31	1140.36	1.14	160,199
24+ months	66	479.38	2.30%	11.03	727.98	0.73	102,583
Bulls	23	589.67	3.00%	17.69	406.87	0.41	57,615
Total	1308	2439.04	–	59.04	9696.55	9.70	1,363,093

Note: Source: Authors' calculations, 2015.

3.2. Water Intake by Cattle Herd and Service Water at the Processing Plants

The total water intake of the complete herd and the service water used at the processing plants of the dairy industries are presented in Table 3. The results show that the total water intake of the complete cattle herd is 46,688 m^3 of water per year. Out of this amount of water, lactating cows drink 31,350 m^3 per year, representing about 67.15% of the total water intake per year. About 18.29% and 0.89% of the total water intake by the complete herd is consumed by heifers and bulls respectively. The estimates imply that the water intake of lactating cows in the study area is about 104% higher than that of all the non-lactating cows, 391% and 267% higher than that of dry cows and heifers, respectively, suggesting that lactating cows are major consumers of the total water supplied to the complete herd.

The largest amount of service water is utilized in cleaning the milking tanks (10,950 m^3/year), followed by the milking apparatus and other uses. Overall, the total service water used at the processing facilities is 26,134 m^3 of water per year. All the freshwater used in cleaning the processing plant and parlour are reused to clean the excrement of the dairy cows off the floors of the dairy parlour, and as such was regarded as effluent (no evaporation is considered).

Table 3. Total yearly water intake by the complete cattle herd and service water used on the case study farm.

Parameters	Water Intake			Service Water	
	Number of Animals	m^3/animal/year	Total (m^3/year)	Cleaning and Sanitation	m^3/year
Total herd size	2133	–	–	Inline Pasturators	2190
Lactating cows	825	38	31,350	Cream Tank	584
Dry cows	399	16	6384	Milk Tanks	10,950
Heifers	886	–	–	Intake	730
0–6 months	220	5	1100	Fillers	2190
6–12 months	206	8	1648	Floors	2190
12–18 months	238	11	2618	Milking Apparatus	3650
18–24 months	156	14	2184	Other uses	3650
24+ months	66	15	990	–	–
Bulls	23	18	414	–	–
Total	2133	–	46,688	–	26,134
Average yearly production per cow (tonne)			9.426	–	

Note: Source: Authors' calculations, 2015.

Table 3 further shows that the average yearly milk production per cow per year is 9.426 tonnes. Given that the yearly dry matter intake of a lactating cow is 8.84 tonnes, the feed conversion efficiency is 1.07. This is too low according to findings from Hutjens [32], who opined that dairy feed conversion efficiency should range between 1.3 and 1.5. The low feed conversion efficiency may be attributed to errors in feeding management of the dairy cows or genetic factors, such as breed of cow as well as climatic factors such as heat stress.

3.3. Water Footprint of Milk

The water footprint of milk is presented in Table 4. The results reveal that 1352 m^3 of water is needed to produce a tonne of milk with an average fat content of 4% and a protein content of 3.3%. Specifically, the amount of water used for producing the tonne of milk with an average fat content of 4% and a protein content of 3.3% consists of 107 m^3 of blue water, 1185 m^3 of green water, and 60 m^3 of grey water. The results indicate that green water forms the largest component of the total water footprint of milk production from cattle, as it accounts for about 87.65% of the total water footprint. Blue water on the other hand, accounts for about 7.91% of the total water footprint of milk. Comparing the water footprint of feed ration for lactating cows and non-lactating cows, we found that the water footprint of feed ration for lactating cows is about 85% higher than that of non-lactating cows (bulls, dry cows and heifers). Also, the water footprint of feed for lactating cows alone accounts for about 87% of the total water footprint for feed production. This implies that feed ration formulation for lactating cows under zero grazing is a major user of fresh water resources relative to non-lactating cows kept mainly on grazing. The results further reveal that about 88.23% of the total water footprint of feed ration for the complete herd is green water, 7.49% is blue water and 4.28% grey water. This suggests that green water footprint is the main contributor to the high water footprint observed for feed production, particularly for lactating cows.

Figure 1 presents the contributions of the various components to the total dairy water footprint. The results reveal that the water used in producing feed for lactating cows alone accounts for 86.35% of the total water footprint of milk and that of non-lactating cows accounts for 12.96%. It is also shown that servicing water is only 0.25%, while drinking water accounts for 0.44% of the total water footprint of milk. The above results suggest that about 99% of the water used in milk production from cattle goes into feed production. This provides further support for previous findings of Mekonnen and Hoekstra [13] and Hoekstra [14] who also reported that more than 95% of the water footprints of animal products related to water used for feed production.

Table 4. Water footprint of milk.

Parameters	Yield (tonne/year)	Blue (m^3/year)	Green (m^3/year)	Grey (m^3/year)	Total (m^3/year)
Drinking Water					
Lactating cows	–	31,350	–	–	31,350
Non-lactating animals	–	15,338	–	–	15,338
Feed Production Water					
Lactating cows	–	782,161	7,855,021	447,676	9,084,858
Non-lactating animals	–	–	1,363,093	–	1,363,093
Total yearly Water Usage		828,849	9,218,114	447,676	10,494,639
Yearly Milk Production	7776.45	–	–	–	–
Total yearly Production Water		107 m^3/tonne	1185 m^3/tonne	58 m^3/tonne	1350 m^3/tonne
Service Water					
Service	–	–	–	26,134	26,134
Yearly Milk Processed	13,196.58	–	–	–	–
Total Yearly Servicing Water		0 m^3/tonne	0 m^3/tonne	2 m^3/tonne	2 m^3/tonne
Milk Water Footprint (m^3/tonne)		107 m^3/tonne	1185 m^3/tonne	60 m^3/tonne	1352 m^3/tonne

Note: Source: authors' calculations, 2015.

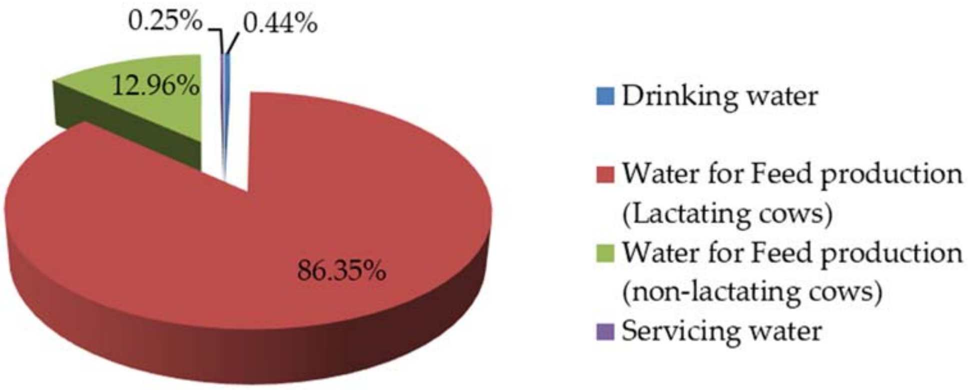

Figure 1. Contribution of the various components to the total dairy water footprint. Source: authors' calculations, 2015.

3.4. Sustainability Assessment

Figure 2 shows the blue water scarcity of the Orange River basin, in which Vaalharts and the case study dairy farm are located. Figure 2 reveals that from January to May, and in December, there is a water scarcity index (WS) of below 100%, since the blue water availability (WA) exceeds the blue water footprint (WF). During these months, there is low blue water scarcity with sufficient water available to satisfy the environmental flow requirements. However, in June and November, there is moderate blue water scarcity (100%–150%). This causes slight modification of the runoff and hence the environmental flow requirements are not met. In July there exists significant blue water scarcity (150%–200%) for which the runoff is significantly modified and does not meet the environmental flow requirements. August, September and October have water scarcity indices exceeding 300%. The blue water footprints exceed 40% of the natural runoff during these months; runoff is thus seriously modified and environmental flow requirements are not met. Therefore, it is clear that the Orange River basin experiences low blue water scarcity during January, February, March, April, May and December. Of the feed crops used by the dairy farms for feeding cattle, maize is grown under irrigation between November and February, and sorghum is planted in December and harvested at the end of February. Hence, maize and sorghum production under irrigation in the greater Orange River basin is considered sustainable since the production does not distort the natural runoff significantly and environmental flow requirements are met.

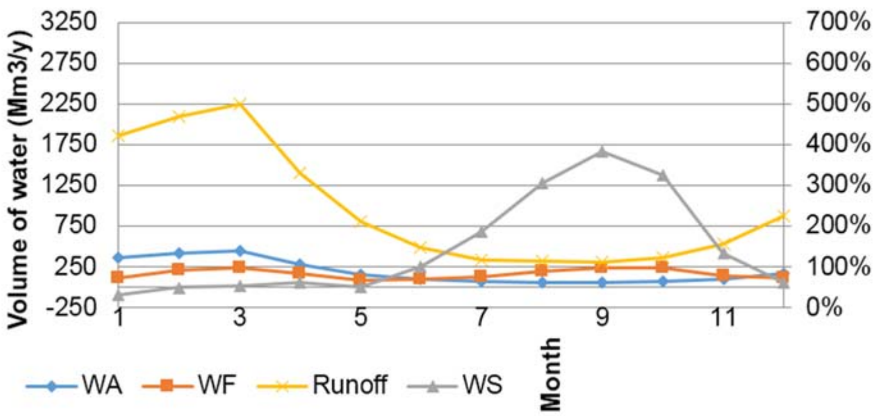

Figure 2. Monthly blue water scarcity of the Orange River basin. Source: Hoekstra and Mekonnen [33].

Lucerne production for feed has larger freshwater requirement since it falls in the summer months (December to February) when evapotranspiration is high. Therefore, lucerne production for livestock feed at Vaalharts is considered sustainable. Moderate blue water scarcity occurs in June and November, with significant blue water scarcity in July. Meanwhile, in August, September and October, there is severe water scarcity. The production of oats for silage takes place between June and October, depending on the planting date. June has moderate blue water scarcity; significant blue water scarcity in occurs in July; while August, September and October experience severe water scarcity. Therefore, oats production under irrigation in the Orange River basin is not sustainable from an environmental water flow requirement perspective and should, therefore, be reconsidered. More importantly, it is observed that the water scarcity index is greater than 100% in six of the 12 months of a year, which gives an indication that the Orange River basin is a hot spot. The major cause for concern to water users and managers is the fact that a large water scarcity index occurs in 4 of the 12 months in a year.

4. Conclusions

Given the emergence of water footprint assessment in various sectors of agriculture, the present paper has assessed the water footprint of milk produced and processed in South Africa using country-specific case studies. The study employed the concept of the water footprint described in the Water Footprint Assessment Manual. Based on the findings, it concluded that 1352 m^3 of water is required to produce one tonne of milk with an average fat content of 4% and a protein content of 3.3% in South Africa. Water footprint for feed production accounts for a significantly larger portion (99%) of the total water footprint of milk production from cattle in South Africa. It is worth noting that the water footprint of feed production for lactating cows alone accounts for about 87% of the total water footprint for feed production. Despite the significant amount of water used in feed production, we found that the feed conversion efficiency for lactating cows is too low. The low feed conversion efficiency leads to a higher water footprint of feed rations [12]. We therefore suggest that careful management of rangelands and pastures to improve feed availability and quality as well as breeding programs that aim at enhancing growth rates and milk yield per cow can improve feed conversion efficiency. This will in turn increase the efficiency and productivity of water in dairy production.

It is also concluded that the greatest portion of the total water footprint of feed for non-lactating animals goes into feeding dry cows. Therefore, in order to gain economic and water use efficiency, cattle farmers should aim at increasing output from dry cows to enhance feed conversion efficiency. Generally, we conclude that lactating and dry cows are the major consumers of fresh water along the milk production chain.

We conclude that the water footprint of feed production for lactating cows is largely dependent on green and blue water. Specifically, green and blue water accounts for 88.23% and 7.49% of the total water footprint of feed ration for the complete herd, respectively. Since our study focused on blue water scarcity assessment, we suggest that dairy livestock producers should pay particular attention to activities that lead to higher blue water footprint in feed ration formulation. For instance, particular attention should be given to feeds such as lucerne, maize, sorghum and oat silages should be carefully to make sure that they are efficiently and sustainably produced since they have high blue water footprints. Also, since blue water scarcity is a major issue of concern and, given the fact that blue water is directly associated with production cost, we suggest that dairy livestock producers should carefully evaluate the water footprint of the various feed crops and minimize or substitute the ones with high water footprints with lesser ones in order to be sustainable in terms of water use. However, the contribution of the various feed stuffs to dry matter and yield should not be overlooked. For instance, corn silage which is higher contributor to the blue water footprint can be replaced with triticale silage as it has been found to have low water footprints and high contribution to milk yield [34].

Although our findings reveal that lucerne, maize and sorghum have high blue water footprints, we conclude that their production under irrigation in the greater Orange River basin is sustainable. However, oats production for silage in the same catchment area is not sustainable. Hence, it is concluded that high water footprint of a product does not always mean that its production is unsustainable. This provides the rationale for livestock producers, policy makers and water users to get an understanding of the degree of sustainability of their input and output combinations, production choices, and policies interventions, in terms of water use. The large water scarcity index which occurs in 4 of the 12 months in a year in this particular catchment area should be of great concern to water users and policy makers in the area.

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