DEVELOPING DAIRY CLIMATE SMART BUSINESS MODELS BY CALCULATING THE CARBON FOOTPRINT OF DAIRY FARMS IN ZIMBABWE

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September, 2021

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A Research thesis submitted to Van Hall Larenstein University of Applied Sciences in partial fulfilment of the requirements for the degree of Master in Agricultural Production Chain Management (APCM) with specialisation in livestock chains.

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This research has been carried out as part of the project "Promoting dairy impact models in Africa through living labs by alumni of Netherlands knowledge institutions" of the professorship of Robert Baars "Climate Smart Dairy Value Chains''

September 2021

Van Hall Larenstein University of Applied Sciences, Velp.

The Netherlands

Dedication

This Master Thesis is dedicated to my beloved daughter Darleen and my parents Timothy and Agnes Hore for praying, encouraging and always giving me the zeal to achieve more.

Acknowledgements
I would like to give honour and glory to the Almighty God for opening this opportunity and guiding me through the whole course.

My gratitude and much appreciation goes to my supervisor Marco Verschuur for his hard work, dedication and guidance throughout the project. This course would not have been successful if it was not for the financial support from Nuffic Fellowship Program and Van Hall Larenstein University of Applied Sciences for my tuition fees, accommodation, living allowances and data collection.

I would also like to acknowledge the contribution of my colleagues at Henderson Research Institute in Mazowe Zimbabwe for assisting me in data collection. Moreover, I am humbled by small-scale and commercial dairy farmers who provided information for the success of this research, thank you.

Finally, I would like to acknowledge my daughter Darleen and young sister Tandiwe for enduring during my whole year absence and for your prayers and encouragements.

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List of Acronyms

UNCCC	United Nations Conference on Climate Change
GHG	Greenhouse Gases
CH_4	Methane
N_2O	Nitrous oxide
NH_3	Ammonia
CO_2	Carbon dioxide
VHL	Van Hall Larenstein University of Applied Sciences
GDP	Gross Domestic Product
ZADF	Zimbabwe Association of Dairy Farmers
LCA	Life Cycle Assesssment
ERA	Environmental Risk Assessment
FAO	Food and Agriculture Organisation
CSA	Climate Smart Agriculture
SMMTs	Sustainable Manure Management Technologies
FPCM	Fat and Protein Corrected Milk
ILRI	International Livestock Research Institute
GWP	Global Warming Potential
AFOLU	Agriculture, Forestry and Other Land Uses
TMR	Total Mixed Ration
PMR	Partially Mixed Ration
DZL	Dairiboard Zimbabwe Limited
AN	Ammonium Nitrate
CD	Compound D
N	Nitrogen

Abstract

Greenhouse gas emissions from dairy farming have been a topic of concern all over the world with some countries having taken pilot studies in quantifying the emissions in their farms. This study was done to calculate and compare the carbon footprint in small and large-scale dairy farms in Zimbabwe. A sample of 24 farmers, thus 12 small-scale and 12 large-scale farmers were interviewed in Mashonaland Central and Mashonaland East provinces of Zimbabwe. The objective of the study was to quantify the carbon footprint per kg of milk for small- scale and commercial dairy farms then develop dairy business models for sustainable climate smart dairy in Zimbabwe. Data was collected from farmers using a fully structured questionnaire and analysis for comparison of means between the two groups was done using Statistical Package for Social Science (SPSS). Life Cycle Assessment computation tool developed by VHL staff was used to calculate the carbon footprint per farm. Canvas business model was used to identify current business models and come up with new inclusive climate smart business models.

The average herd size was 249.6 and 25.6 for large and small-scale dairy farms respectively. Average milk production was 4889 and 2837 litres per cow per year for the two farming systems. On climate smart dairy practices there was poor management of manure in both production systems. However, farmers practiced growing of fodder crops with 42% large-scale and 25% small-scale already cultivating Katambora Rhodes grass on their farms. Feeding of concentrates and straight feeds as supplement feeding was another climate smart practice identified of which 92% large-scale and 75% small-scale of the farmers interviewed were feeding their animals with dairy meal some were using concentrates, cotton seed cake, soya bean meal and sunflower meal. Another interesting result was the feeding of crop residues and by-products to animals; maize stover, maize bran, wheat straw, soya bean straw, brewery waste, molasses, orange peels and poultry waste were among the identified list used as feed to dairy animals. Of these maize stover (58% and 50%) and brewery waste (67% and 17%) large and small-scale farms respectively were commonly used. Hay and silage making were the major feed preservation methods identified in the farms interviewed.

Enteric fermentation was the primary producer of CH_4 emissions producing 0.92 and 1.8 CO_2 eq/kg FPCM for large and small-scale farms respectively. The second category was emissions from off-farm feed production, by-products and concentrates which emitted 0.27 and 0.53 CO_2 eq/kg FPCM. Manure and fertilizer application, fodder and fertilizer production were other sources of greenhouse gases in dairy farms. The carbon footprint of milk in small-scale dairy farms was 2.97 while for large-scale farms was 1.30 CO_2 eq/kg FPCM. The analyses showed that emissions CO_2 eq/kg were higher in small-scale farms than large-scale farms. New business models were developed which focused on productivity, sustainability and resilience while addressing environmental issues to achieve climate smartness in dairy farming.

Key words: Carbon footprint, Greenhouse gas, Climate smart practice, Dairy business model

CHAPTER ONE: INTRODUCTION

1.1 Background

Greenhouse gas emissions from the agricultural sector comprise mostly of methane gas (CH_4) from mainly enteric fermentation and manure, Carbon dioxide (CO_2) and nitrous oxide (N_2O) from manure and N_2O from fertilisation of crops and pastures through a process of nitrification and de-nitrification (Rotz C. A., 2018). These gases are emitted from livestock, crop, agricultural processing and industrial systems such as feed production. The contribution of livestock to climate change through these GHG emissions is of paramount importance (York et al., 2017). Livestock have been reported to contribute 44% of anthropogenic CH_4, 53% of anthropogenic N_2O and 5% of anthropogenic CO_2 emissions globally (Rojas-Downing et al., 2017). In Zimbabwe alone, the livestock sector has been reported to contribute more than 60% of agricultural GHG emissions (Svinurai, et al., 2018). Of these, enteric fermentation has been ranked as the second highest GHG emitter after the energy sector (Svinurai, et al., 2018). Globally, the beef and dairy sub-sectors jointly contribute more than 70% of global greenhouse gas emissions from agriculture (Gerber, et al., 2013) the majority of which are from the dairy farms.

Under the Paris agreement, Zimbabwe has set a target of reducing the GHG emission by 33% (UNFCCC, 2015). There are a number of strategies that the country needs to adopt in order to meet this target and mitigate the effects of the GHG emissions. In order to successfully implement reduction approaches, the country needs to know the quantity of GHG emissions that are produced per farm. Gerber et al., 2013 stated that there is a huge difference in emission quantities between production systems, hence the need to verify these findings by calculating and comparing the carbon footprint of small- scale and commercial dairy farms.

The commissioner to this project is Agricultural Research and Innovation Development Directorate, Department of Livestock Research under the Ministry of Lands, Agriculture, Water and Rural Resettlement in Zimbabwe. The mandate of the department is to generate appropriate and sustainable management technologies to support livestock productivity and production in intensive, semi-intensive and extensive systems in the different agro ecological regions. In line with this mandate the project aims to address gaps in knowledge which hinder efficiency of interventions in achieving greenhouse gas emissions reductions in the dairy sector. In their study on Enteric methane emissions and their response to agro-ecological and livestock production systems dynamics in Zimbabwe (Svinurai et al., 2017) recommended further research on direct measurements and modelling of emissions from livestock breeds in Zimbabwe. Hence this research becomes instrumental in addressing that gap. This work is also done in collaboration with Van Hall Larenstein University of Applied Sciences (VHL) alumni who are going to cover other provinces of the country. The commissioner needs an inventory of the carbon footprint in-order to advise farmers on sustainable climate smart business models as well as influence policy in the fight of reducing GHG emissions in the country as part of the Zimbabwean table of Pan African Food Systems Development Forum.

1.2 Problem statement

Dairy farming contributes large amounts of greenhouse gas emissions into the environment (Romano et al., 2021) e.g., in Europe, it contributes 28-30% of the total GHG emissions. The production of these GHG contributes to climate change which has been associated with a lot of negative impacts. These have been forecasted to lead to a reduction in agricultural output through extreme climate parameters and other related phenomena. Climate change has been reported to result in low productivity due to erratic rains, high temperatures and persistent droughts leading to low forage production, increased incidences of diseases and ticks. This inevitably affect the dairy sub-sector negatively in-terms of production and sustainability. Zimbabwe does not have an inventory of the carbon footprint per kg of milk for both small-scale and commercial dairy farms. Hence the need to calculate the carbon footprint of small-scale and commercial dairy farms in Mashonaland Central and Mashonaland East as pilot areas. Availability of carbon footprint inventory will facilitate development of sustainable dairy business model for climate smart dairy in Zimbabwe.

1.3 Research Objective

To quantify carbon footprint per kg of milk for small- scale and commercial dairy farms then develop dairy business models for sustainable climate smart dairy in Zimbabwe.

1.4 Research Questions

1. **What are the differences in carbon footprint per farm between small scale and commercial dairy farms?**

    i. What is the farm level milk production of dairy animals in both small-scale and commercial dairy farms?

    ii. What are the GHG emissions from enteric fermentation on small and large scale farms?

    iii. What are the GHG emissions from manure and fertiliser applications in both small and large-scale farms?

    iv. What are the GHG emissions on farm machinery, feed transport and manufacturing?

2. What are possible climate smart dairy business models for the small scale and commercial dairy farmers?

i. What are the climate smart dairy farming practices currently practised at the dairy farms to reduce emissions?

ii. What are the current dairy business models being practised by the dairy farmers in Mashonaland Central and Mashonaland East provinces?

1.5 Conceptual Framework

CHAPTER TWO: LITERATURE REVIEW

2.1 Definition of Terms and Concepts

Carbon Footprint- The carbon footprint (CF) of milk is the sum of the net GHGs emitted throughout the lifecycle of milk within a set system boundary and in relation to a defined amount of milk with specified composition (National Dairy Development Board, 2017).

Life Cycle Assessment - (Finnveden, et al., 2009) defined LCA as a tool which is used to assess the environmental impacts and resources used throughout a product's life cycle, from acquiring raw material, production, and use up to waste management.

Fat and Protein Corrected Milk (FPCM) – Is defined as the mass of greenhouse gas emissions expressed as kg carbon dioxide equivalent per mass of FPCM expressed as kg (FAO and ILRI, 2016).

Methane (CH_4) – Is a greenhouse gas with a global warming potential (GWP) of 25.15 (FAO and ILRI, 2016)

Nitrous oxide (N_2O) – Is a greenhouse gas with a global warming potential (GWP) of 298 (FAO and ILRI, 2016).

Business Model- A business model is a conceptual structure that supports the viability of the business and explains who the business serves to, what it offers, how it offers it, and how it achieves its goals (Pahwa, 2021).

Small- scale dairy farmer- (Paraffin, et al., 2018) defined small- scale dairy farming as an economic activity of rearing less than 7 milking dairy on a piece of land which is usually less than a hectare.

Large scale dairy farmer- owns large farms with high producing (> 5000 kg/lactation) pure exotic cows and their crosses (Ngongoni, et al., 2006).

Greenhouse gas – is defined as any gas that has the property of absorbing infrared radiation which is net heat energy emitted from Earth’s surface and reradiating it back to Earth’s surface, thus contributing to the greenhouse effect (Mann, 2019).

Climate Smart Agriculture- Climate smart agriculture is defined by (FAO, 2010b) as sustainable agriculture that increases productivity, resilience, reduces greenhouse gases, and enhances achievement of national food security and poverty reduction

Cost benefit Analysis- is a way to compare the costs and benefits of an intervention, where both are expressed in monetary units.

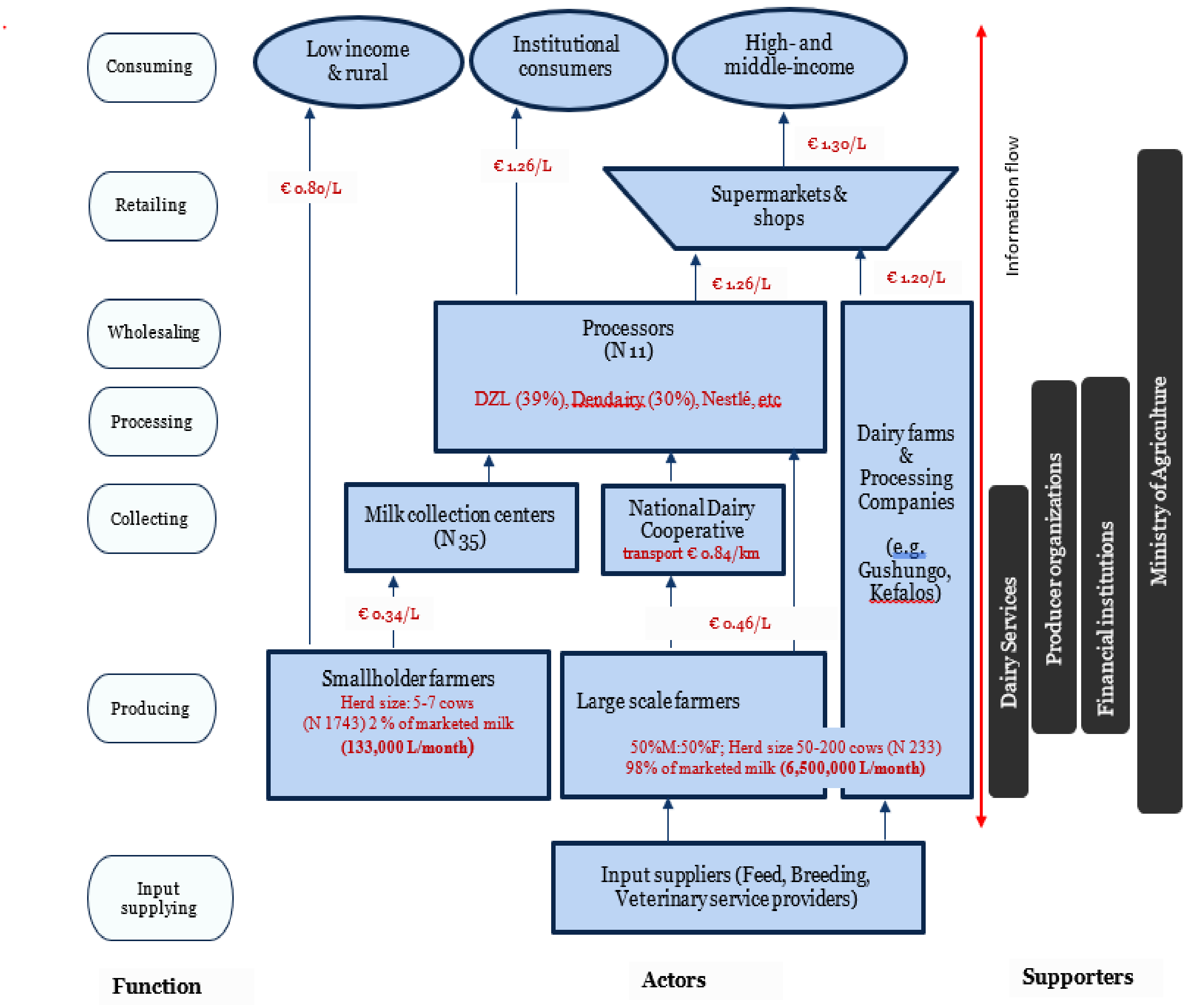
Gross Margin - Is the sales revenue a company retains after incurring the direct costs associated with producing the goods it sells, and the services it provides (Bloomenthal, 2021).

2.2 Dairy sector in Zimbabwe

2.2.1 Overview of the Dairy Sector

Zimbabwe traditionally had a relatively vibrant dairy industry comprising of commercial farmers and heavily subsidized small-scale farmers. The country currently produces about 60 per cent of the country's annual milk demand of 120 million litres; with the remaining 40 per cent being covered by importing (The Dairy Site, 2019). Recurrent droughts was one of the factors which was cited by (Chari, 2017) which caused a drop in the contribution of agriculture to the Gross Domestic Product (GDP) in Zimbabwe. The Dairy sector was singled out as significantly contribution to the fall as part of the agriculture sector, these are the negative effects of climate change hence the need for mitigation measures.

Figure 1: The Current Dairy Value Chain in Zimbabwe



2.2.2 Dairy Production Systems

2.2.2.1 Small-scale Dairy Farming

Small-scale dairy farmers in Zimbabwe practise mixed crop and livestock production where they rear mostly indigenous cattle breeds producing 1,800 – 2000 Kg/lactation. The small-scale sector are characterized by low yielding indigenous breeds and mostly own very low numbers of animals (Matekenya, 2016) which ccontribute 2% of the national milk formal supply chain. The small-scale farmers largely depend on extensive production system where most of the cattle diet is through grazing and a little bit of supplementation. In-order to improve the contribution of the small-scale producers in the formal milk chain the Government of Zimbabwe established small-holder dairy development programs which assisted farmers in forming marketing groups and milk collection centres (Chamboko et al., 2017). The government of Zimbabwe saw small-scale dairy farming as a way economic empowerment to the rural people.

2.2.2.2 Large Scale Dairy Farming

The Commercial Dairy farmers in Zimbabwe normally keep pure exotic breeds producing high yields of over 5000kg/year. An average herd of between 50 to 200 milking cows is kept on each farm.The commercial sector dominate the formal milk chain contributing 98% of the national milk supply and are associated with high production as compared to the small-scale sector. The large scale farmers often practice intensive dairy production.

2.3 Agro- Ecological Regions in Zimbabwe

The need to align agricultural practises with changing climatic patterns initiated the revision of Zimbabwe agro- ecological regions which were established in the 1960s to the current one which was developed in 2020. Zimbabwe is divided into 5 agro- ecological regions based on climatic conditions, soil and landforms.

Table 1: Agro-Ecological Regions of Zimbabwe

Region	Climatic Conditions	Dominant Soil Groups	Recommended Land Use
I	Annual rainfall > or less than 1000mm. Rainfall normally exceeds 500mm Maximum temperature 21-25^{0}C	Orthoferrallitic	Mostly suitable for fruit trees like bananas, apples and tea and coffee plantations Cropping is also possible: Maize, soya beans or potatoes Intensive livestock production The region has steep terrain so terracing is advisable
IIa	Annual rainfall 750-1000mm Rainfall normally above 500mm though it is possible to get less at times or more than 1000mm Maximum temperature 23-27^{0}C	Paraferrallitic and Fersiallitic; sporadic occurrence of orthoferrallitic	Suitable for long season maize varieties which require 120-130 days to mature Other suitable crops are wheat and barley which can be grown in winter under irrigation Tobacco, groundnuts, Irish potato, cotton and soybean can also be grown in summer Intensive livestock production

			(beef, dairy and poultry) (based on pastures and pen fattening) is also recommended.
IIb	Annual rainfall between 750-1000mm, length of rain season is 115-120 days and maximum temperature between 25-28^{0}C	Fersiallitic	Suitable for maize, cotton, Irish potato, barley, flue-cured tobacco, groundnuts, sorghum, sugar beans, coffee and horticultural crops can be successfully grown. Winter wheat is also grown under irrigation. Intensive livestock production is also recommended in this region
III	Annual rainfall between 650-800mm, length of rainfall season between 110 and 120days and maximum temperature between 25-28^{0}C	Fersiallitic	Suitable for crops like maize, soybean, groundnuts, cotton and sunflower. Supplementary irrigation is critical for successful crop production. The region is also suitable for semi-intensive livestock production (beef, dairy and small stock (e.g. goats and poultry).
IV	Annual rainfall between 450 - 650mm, length of rainfall season 105-120 days and maximum temperature between 27-29^{0}C	Fersiallitic; sporadic occurrences of the sodic, lithosol and the siallitic	Suitable for short maturing maize varieties and drought tolerant crops like sorghum (finger millet, pearl millet, water melons and cowpeas. Extensive cattle ranching, rearing of small stock (e.g. goats and poultry) and wildlife are ideal farming systems for this region.
Va	Less than 650mm annual rainfall in the south areas of the region and more than 650mm in the northern area like Zambezi Valley, length of rainfall season between 100-120days and maximum temperature between 28 - 30^{0}C	Fersiallitic; sporadic occurrences of vertisol and the siallitic	Goat production, extensive cattle and game ranching Drought tolerant crops like sorghum, finger millet, pearl millet and cowpeas are suitable. Sugarcane is an ideal crop under irrigation. Tree plantations, mainly oranges, lemons and lime are also suitable under irrigation.
Vb	Annual rainfall below 600mm, rainfall season less than 110days and maximum temperature between 28-32 ^{0}C	Siallitic; sporadic occurrences of the sodic and regosols	Tree plantations, mainly oranges, lemons and lime are recommended under irrigation. This region is also suitable for extensive cattle ranching, goats and wildlife tourism.

Source: (Manatsa, et al., 2020)

2.4 Life Cycle Assessment (LCA)

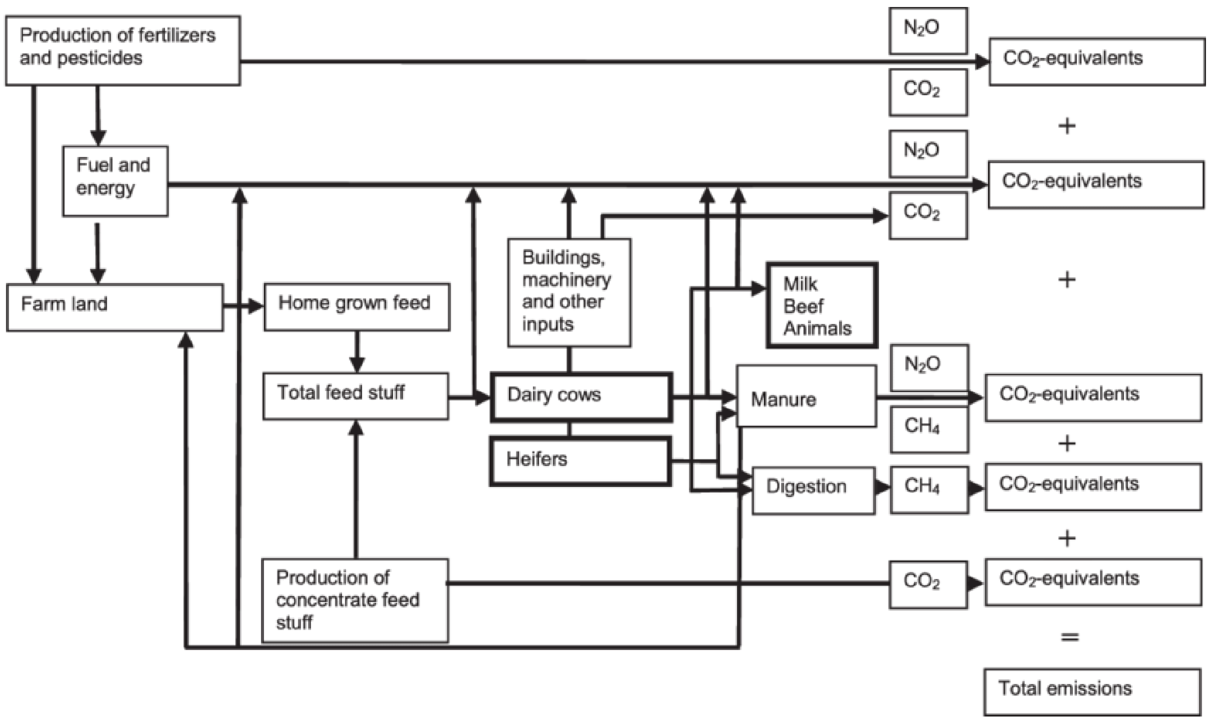
LCA is a technique which involves combined analysis of environmental impacts along the life cycle of a product (Vellinga, et al., 2013). LCA has been criticised for not taking into account emissions which occur outside the product life cycle, in this regard it cannot be a substitute of Environmental Risk Assessment (ERA). There are two methods of LCA which are Attributional and Consequential LCA.

Attributional LCA deals with physical attributes of the environment, its life cycle and subsystems. According to McAuliffe et al. (2018) Life Cycle Assessment (LCA) is an instrument used to compare environmental impacts of various animal production systems. It is noted that beside the environmental impact results, the quality of the product also need to be considered. In livestock systems LCA has been identified as useful tool to appraise environmental hotspots and ensure production developments (McClelland et al., 2018). Weiler et al. (2014) attributed LCA as a method which measure impact of livestock production to greenhouse gases.

The system boundary of LCA include two defined sub-systems which are: Cradle to farm-gate and Farm gate to retail. The cradle to farm-gate involves all processes in dairy production until a finished product is realised that is milk, meat (cull-cows, veal), including production of farm inputs such as feeds etc. These are also called upstream processes. Whereas farm gate to retail entails downstream processes of transporting the product to processing plants, packaging until it reaches the retailer (FAO, 2010b).

Both Life Cycle Assessments (LCA) and Carbon Footprints are research methods which assess full life cycle of a product in this case milk. All inputs and outputs are quantified that is from raw materials which are used to produce the product until it reaches consumption. LCA method indicates where environmental effects take place along the chain. The major difference between LCA and carbon footprint is that LCA focus on more environmental impact categories whilst carbon footprint only focuses on one environmental category which are GHG emissions (Scholten, 2021).

Figure 2: LCA System Boundary 'cradle to farm gate



Source: (Hagemann et al., 2011)

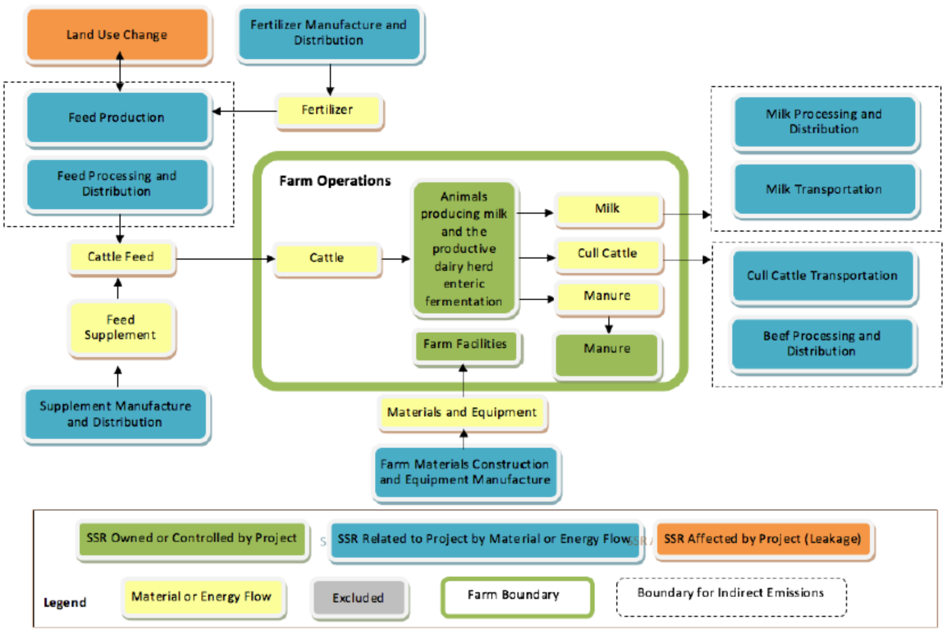
2.5 Sources of GHG Emissions on a Dairy Farm

2.5.1 From cradle to farm gate

Various processes at the farm contribute to emissions some of these include the production of forages, fertilizers, making of supplement feeds for the dry season through collecting crop residues, hay making , silage making, feed mixing, applying manure to the fields etc. all these processes account for direct or indirect N_2O emissions. Whilst enteric fermentation and manure storage account for direct and indirect CH_4 and N_2O. Also CO_2 is produced through energy used in field operations, application of fertilisers, processing of feeds and fodders (FAO, 2010b)

Figure 3: Systems Boundary

Figure 1 – Identification of system boundaries and the sources, sinks and reservoirs (SSRs) for emissions from typical smallholder dairy production systems



Source: (FAO and ILRI, 2016)

2.5.2 From farm gate to retail point

Emissions at this point are from energy used to transport, process, package and refrigerate milk from farm to processing plants until it reaches the retail point. Also transport of animals to dairies and slaughterhouses (FAO, 2010b).

2.6 Contribution of Dairy Farming to Climate Change

Dairy production as a sub-sector of Agriculture, Forestry and Other Land Uses (AFOLU) emits 4% of the total GHG emissions produced by AFOLU. Internationally, AFOLU produces 10-14.5% of the entire emissions. As a result of the increasing population, the demand for milk escalates leading to a projection of an increase in emissions from the dairy sector by 82% (Brandt, et al., 2018). High temperatures is one of the effects of climate change, this may decrease dairy production potential. This heat effect is projected to modify the feed intake, mortality, growth, reproduction, maintenance, and production of animals (Sutton, et al., 2013). Overall, these effects are expected to have a negative impact on livestock productivity.

2.6.1 Enteric Fermentation

Internationally, enteric fermentation is the largest source of agricultural GHGs. Enteric production of methane by dairy animals provides a significant contribution of CH_4 making it a reason for concern in climate change. Methane is exhaled by ruminant animals and is the second most troublesome GHG produced from anthropogenic sources (Thakuri, et al., 2020). CH_4 is released as a result of microbial fermentation in the rumen and large intestine. Advancement in cattle breeding can lead to an increase in enteric methane per category of the dairy animals as well as the overall enteric EFs. This is due to improved bodyweight, which increases the dry matter intake and gross energy requirements (Gao, et al., 2014). Ruminants have higher emission rates per unit of feed intake as compared to non-ruminant animal. This is ascribed to the breaking down of food in the digestive tract by enzymes and microbes, a process of fermentation in the rumen results in the production of methane as one of the by-product of carbohydrates digestion (Thorpe, 2009).

2.6.1.1 Emissions from Enteric Fermentation in Zimbabwe

Enteric fermentation contributed between 156.01 to 208.09 Gg per year between 1990 and 2010 in Zimbabwe. During this period the highest emissions were recorded in 2001 while the lowest was in 1993. Calculations based on the base years showed an increase of emission production from 164.31Gg in 1994 to 205.56Gg in 2000 (Sithole, et al., 2016). However, a decrease was noted in 2006 (170.29Gg) this might be attributed to positive effects of mitigation strategies.

2.6.2 Emissions from Manure management

The difference between feed intake and retention in tissue growth (milk production) results in excretion of N and P nutrients. Hence, organic matter in animal manure is derived from digestibility of organic matter and feed intake (Vellinga, et al., 2013). Nitrification and denitrification of ammonium and nitrate in manure, volatisation of ammonia (NH_3) and nitrate leaching result in direct and indirect N_2O emissions. According to (Rojas-Downing, et al., 2017) the following factors determine amount of N_2O emissions from manure storage: environmental conditions, handling systems, and duration of waste management. Good manure storage such as covering manure heaps can prevent loss of nitrogen, reduce leaching and volatilization thereby reducing N_2O and NH_3 emissions. Nevertheless, this practice can increase CH_4 emissions because of anaerobic conditions (Brandt, et al., 2018). It has been noted that methane emissions from manure management are less than from enteric fermentation. More emissions are obtained from zero grazing systems where animals are always confined. Mostly in these cases manure is kept on liquid basis, proving that N_2O emission quantities depend on manure management practices (IPCC, 2006).

2.6.2.1 Emissions from Manure Management in Zimbabwe

Manure management contributed less than 4% of the CH_4 emissions from animals which is less than 0.01% of the total GHG emissions in Zimbabwe. For the same period of 1990 to 2010 manure contributed 5.85-8.05Gg per year. However, comparing with enteric emissions there was a considerable increase from 5.97Gg in 1994 to 7.84Gg in 2000 and a slight decrease in 2006 (7.06Gg) (Sithole, et al., 2016).

2.6.2.2 Manure handling methods

Adoption of sustainable manure management technologies (SMMTs) has been identified as an effective method to reduce emissions from livestock manure. While sustainable manure management lessens environmental destruction, it also greatly decreases the use of in-organic fertilizers. Recycle, Biogas and composting were identified as three main methods of SMMTs used in China. Recycle involves application of manure to the land as fertiliser, compost is whereby manure is heaped or stored for some time to produce organic fertilizer and Biogas is a process where biogas is produced when manure is stored in biogas digesters (Pan et al., 2020).

However, it has been noted that applying manure to the fields without any treatment can endanger the environment due to high concentrations of ammonia (Hanifzadeh, et-al., 2017). This was supported by (FAO, 2010b) who stated that productivity of agriculture sector can be enhanced by reducing emissions through treatment of manure. He further mentioned production of useful energy and reduction of emissions by storing manure as liquid through anaerobic digestion. In addition treated solid manure can be used to improve soil nutrition and reduce use of synthetic fertilizers which promote an increase of GHG emissions during their production. The use of superheated steam to dry fresh manure and later combust to solid biofuel has also been used as a manure management method.

In Zimbabwe two manure management systems were identified which are solid storage or dry lot and rangeland or pasture which happens when the animals directly deposit manure in the rangeland when they are grazing. This first practise is usually witnessed in commercial farms whilst small-scale farmers are known to apply manure in their crop fields from their night housing kraals (Sithole, et al., 2016).

2.6.3 Emissions from Feed Manufacturing and Transport

Forage cultivation, transportation of feeds and feed utilization has been pointed out as major factors contributing to GHG emissions in dairy production. On a dairy farm there are different sources of feed which ranges from direct grazing of forages, utilisation of conserved feed (hay, silage), on-farm feed formulation and bought in concentrates/ supplements etc. To acquire all these feeds various processes are done which uses energy, hence the need to calculate emissions from energy used during feed manufacturing and transportation. Scale of production (small or large scale) determine the amount of energy used at a dairy farm with more energy channelled towards feed production, inputs and machinery in zero grazing systems (Rojas-Downing, et al., 2017). The quality of feed used also has an impact on the quality of manure. Distance and mode of transport are the basis used in calculating emissions from transport (Vellinga et al., 2013).

2.6.4 Emissions from Machinery

Emissions from machinery are divided into direct and indirect emissions. Direct emissions are measured from fuel used during cultivation, harvesting etc. whereas indirect emissions are from production and maintenance phase of the machinery which is calculated using number of working hours during its productive life (Vellinga et al, 2013). Carbon (C) in fuel is converted to CO_2 during operation of farm machinery such as tractors and other equipment; this is released in engine exhaust. A conversion factor of 2.637 kg of CO_2 per litre of diesel fuel is used to calculate emissions from machinery. The conversion factor signifies the average amount of fuel used to produce or deliver a unit of feed to the animals (Rotz C. M., 2010).

2.7 The Carbon Footprint

The carbon footprint of milk is defined as the total GHG emissions of CH_4 from digestion of feed, N_2O from manure and feed cultivation. These are calculated in terms of kg equivalent per kg of milk (Henriksson et al, 2011). The carbon footprint of livestock is different depending on production systems and geographical location; this is attributed to differences in feed quality, feed conversion ratio of different animal species and the environmental status of the areas (FAO, 2010). Therefore, it becomes necessary to quantify the GHG emission per production system (small- scale and commercial Dairy farms) and in different regions.

2.7.1 Methane emissions

Dairy animals produce CH_4 from enteric fermentation where the gas is released through eructation and respiration. Methane from enteric fermentation is determined by animal type, size of the animal, breed, age and weight of an animal, quality and quantity of feed supplied (feed digestibility) and animal energy expenditure. On a dairy farm CH_4 is emitted from digestion in the rumen and from manure. This makes enteric fermentation the major contributor of CH_4 followed by emissions from manure storage. Manure deposited directly by animals in pastures and holding areas has been considered to contribute less emission however manure applied to the fields can result in major emissions after a few days of application (Rotz C. M., 2010). Emission factor estimates and estimation equations are used to calculate enteric CH_4. The estimation equations are divided into two depending on the parameters needed for the calculations. The first equation uses feed input data whilst the other is centred on physiological parameters which are milk yield and metabolic body weight (Hagemann et al., 2011).

2.7.2 Nitrous oxide emissions

According to (Rotz, 2018) nitrous oxide (N_2O) on a dairy farm is emitted from manure and fertilisation of crops and pastures through a process of nitrification and denitrification. The process of nitrification and denitrification also occur in heaped manure, slurry manure storage, manure on barn floors and manure on dry lot surfaces. This was supported by (Hagemann et al., 2011) who cited manure handling and storage as well as fertiliser denitrification and fuel combustion as a source of N_2O emissions. N_2O emission factor multiplied by the quantity of nitrogen excrements of dairy animals gives nitrous oxide emissions from manure. N_2O emissions from nitrogen fertilisers are categorised into direct on-farm emissions and indirect emissions from fertiliser manufacturing. Lastly N_2O from fuel combustion is resultant of amount of fuel used multiplied by emission factor.

2.7.3 Carbon dioxide emissions

Animal respiration has been cited as the main source of CO_2 in dairy farms while manure storage and barn floors are the minor sources (Rotz, 2010). Moreover, dairy farms fuel combustion, fertilisers, concentrates, pesticides, machinery, buildings and other assets and inputs such as bedding material or dairy chemicals were cited as the sources of CO_2 emissions. CO_2 emissions from concentrate feeds are calculated basing on feed classes, emissions from farm assets were computed using factors converting their weight into emissions and estimated size of the farm building is used to calculate their CO_2 emissions (Hagemann et al., 2011). In dairy farms since there is cultivation of forages and crops for animal feeding, these crops assimilate CO_2 from the atmosphere during a process of photosynthesis and emit CO_2 by manure decomposition and respiration of soil and plants (Rotz, 2010).

2.8 Climate Smart Dairy

Climate smart agriculture is defined by (FAO, 2010b) as sustainable agriculture that increases productivity, resilience, reduces greenhouse gases, and enhances achievement of national food security and poverty reduction. CSA has been adopted in effort to reduce the intensities of GHG thereby promoting productivity and protection of the environment. Some of the on-farm climate smart technologies include cultivation of improved pastures, advanced animal breeding and feed conservation strategies (Maindi et al., 2020). Climate-smart agriculture (CSA) has been described by (Nyasimi et al., 2014) as a strategy which has availed a prospect to Africa to research and develop appropriate technologies which are in line with the changing environment patterns.

2.9 Functions of Dairy Animals in Zimbabwe

Draught power, manure, meat and social functions are some of the functions of cattle in Zimbabwe making an impact on food production (Ngongoni et al., 2006). Communal cattle has numerous roles that include milk, meat, manure , draught power, indication of wealth status and hides as by products (Tavirimirwa, et al., 2013). In Zimbabwe milk is largely obtained from indigenous cattle and their crosses with exotic beef breeds on most small-scale dairy farms. (Zvinorova et al., 2013) agrees with the above mentioned authors that these animals besides milk production have various functions which include meat, cash through sales, draught power, social security and ceremonies. Dairy farming in the small-scale sector is not mainly practiced for profit making but for other purposes like to get manure for crops, insurance, feeding the family, emergency cash needs as well as social status (Washaya & Chifamba , 2018). However dairying in the commercial sector is purely for profit and the animals are mainly kept for milk production.

2.10 Farm Level Milk production

Milk production depends on various factors which includes breed, production system and feeding. In Zimbabwe milk consumption is below world average as the country is producing less than the demand, which is around 54.3million litres against an annual demand of 120million litres (Washaya & Chifamba , 2018). One of the dairy breed kept in Zimbabwe is Jersey which produces an average milk yield of between 3000 to 5000kg (Misanjo et al., 2013). One of the major dairy breed kept in Zimbabwe is Holstein-Friesian which has an average milk yield of 5000kg (Coffey, et al., 2016). However these productive exotic breeds are mostly kept by commercial farmers with small-scale farmers keeping indigenous and crossbreds. A typical dairy cow in Zimbabwe produces an average of 14 litres per cow per day (NewZWire, 2020).

2.11 Feed Production and Feeding Systems

Feeding systems differ in developed countries from developing countries. Generally developed countries have adopted confined feeding systems designed for large scale production with high yielding cows where animals are either confined all year round or for a certain period of time. Whereas in developing countries the main source of feed is locally produced roughages given to small scale low yielding cows (: FAO, 2014).

(Herdt, 2014) outlined totally mixed rations (TMR), pasture based feeding, separate feeding of concentrates and forages as the three major types of nutritional management systems in dairy farming. These three methods have distinct advantages when compared to each other. The advantage of TMR is having all components of the diet in one even mixture including fibre and non-fibre components. The second method of feeding concentrates and forages separately has an advantage of not requiring special mixing equipment and possibility of supplying concentrate as per nutritional needs of the animal. Lastly pasture based system require serious management to get required pasture yields with good nutritional composition to meets the needs of high producing dairy cows. TMR, partially mixed rations (PMR) which is a combination of TMR and grazing and pasture based systems were also mentioned as different feeding systems in dairy production by (Salado, et al., 2020).

Concentrate feed is defined as supplement to the roughage part of the cow's diet which provide energy and protein and are mostly from grains and oilseeds. It has been noted that concentrate feeding has been commonly practised in most dairy farms in Brazil with almost 60% of the farmers depending on it; this is true in most dairy farms across the world with Zimbabwe not exempted. It is a common practise to mix concentrates with maize, in Zimbabwe protein concentrate feeds are mixed with maize to get the required energy in the feed. This mixture has been known to increase milk yields, increase stocking rate, and improve body score condition of animals and better quality of milk (Yabe, et al., 2015).

2.12 Dairy Business Models

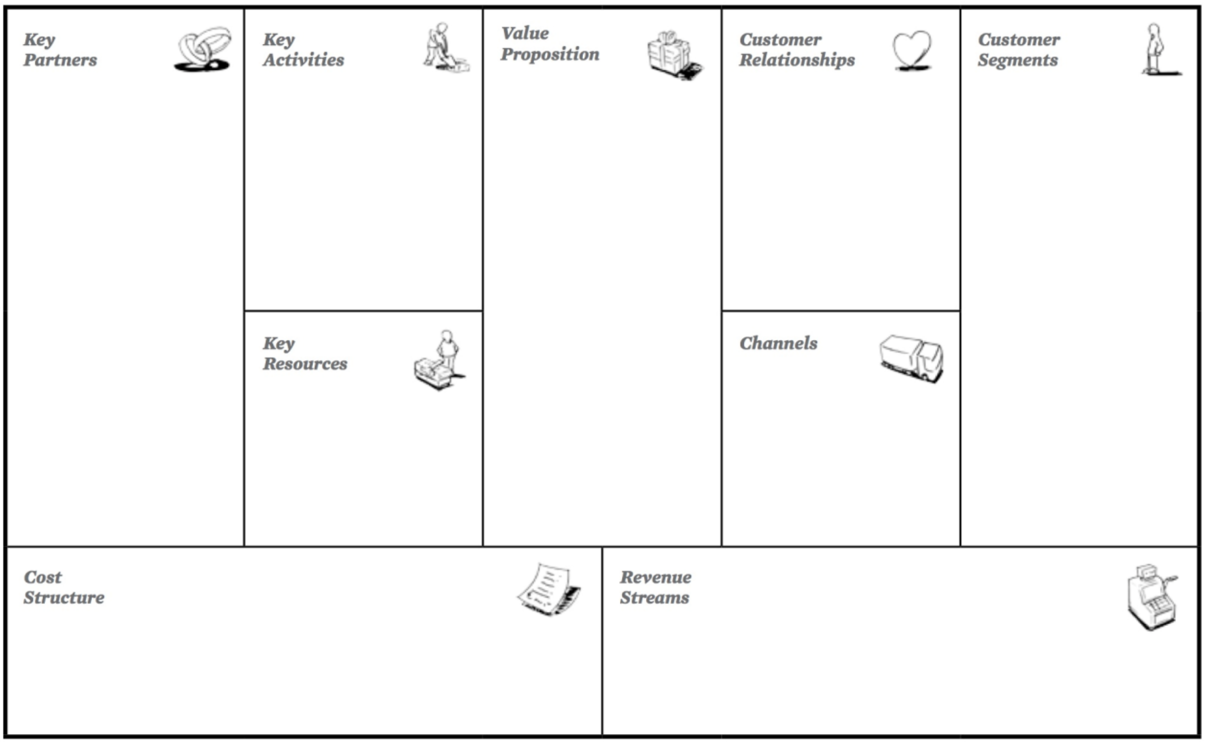
Canvas Business Model is one of the models which can be used in Dairy business. The model has nine building blocks which are: customer segments, value propositions, channels, customer relationships, revenue streams, key resources, key activities, key partnerships and cost structure. Customer Segments block outlines various groups of people a company aims to serve; these can be divided in segments according to their requirements and behaviours. There are various types of customer segments these include mass market, niche market, segmented, diversified and multi sided markets. Value Propositions Building Block defines the package of products and services that create value for a specific Customer Segment. It is a combination of benefits that a company offers to its consumers. Different elements can be used to create value for customers which include new brand of a product, performance, customisation, design, prize etc. To deliver value proposition to customer segments a company needs to communicate through different channels. The channels include communication, distribution and sales these enable interactions with customers (Osterwalder & Pigneur, 2010).

A company has to establish a relationship with specific customer segments for a successful business, these relationships can be through personal assistance, self-service, automated services, communities and co-creation. The Revenue Streams Building Block represents the cash a company generates from each enterprise and Customer Segment. On a dairy farms revenue streams can be from milk sales, heifer, bull, cull-cows and meat sales. Key Resources block defines the most crucial assets required to make a business model work, these can be intellectual, physical, human or financial. The Key Activities Building Block describes the operations a company must do to make its business model work. Companies make partnerships with various partners and suppliers to reduce risks, acquire resources and create alliances. Partnerships may include buyer-supplier relationship, competition, joint ventures and strategic alliances. The last building block is cost structure which entails all costs incurred to run a business. Cost driven and value driven are two broad classes of business model cost structures. These cost structures have the following characteristics: Fixed costs, variable costs, economies of scale and economies of scope (Osterwalder & Pigneur, 2010).

Canvas business model can enable a business to define its current status as well as help develop the new business models. It simply defines a business model of a dairy farm and outlines the worth of business activities carried out to generate cash (Hasan et al., 2020). A business model entails strategy and operation of activities, it outlines how to implement a strategy into practise. Therefore it is a tool for analysing and understanding operational activities of a business as well as carrying the strategy inorder to maximise profit. Canvas Business Model is used to envision and manage the company's logic (Johnsson-Sederholm & Du, 2016). A business model defines the basis of how an organization generates, conveys, and captures value.

(Johnsson-Sederholm & Du, 2016) defined Sustainable Business Model (SBM) as the one which considers economic, environmental and social aspects in its purpose. It considers the need of every stakeholder and treats environment as a stakeholder. The economic aspect is vital for any dairy farm. Triple Layered Business Model Canvas (TLBMC) has been used as a sustainability approach in companies' business models. TLBMC was developed from the Canvas Business Model by adding two new layers which encompassed sustainability.

Figure 4: Sample Canvas Business Model



Source: VHL notes

CHAPTER THREE: METHODOLOGY

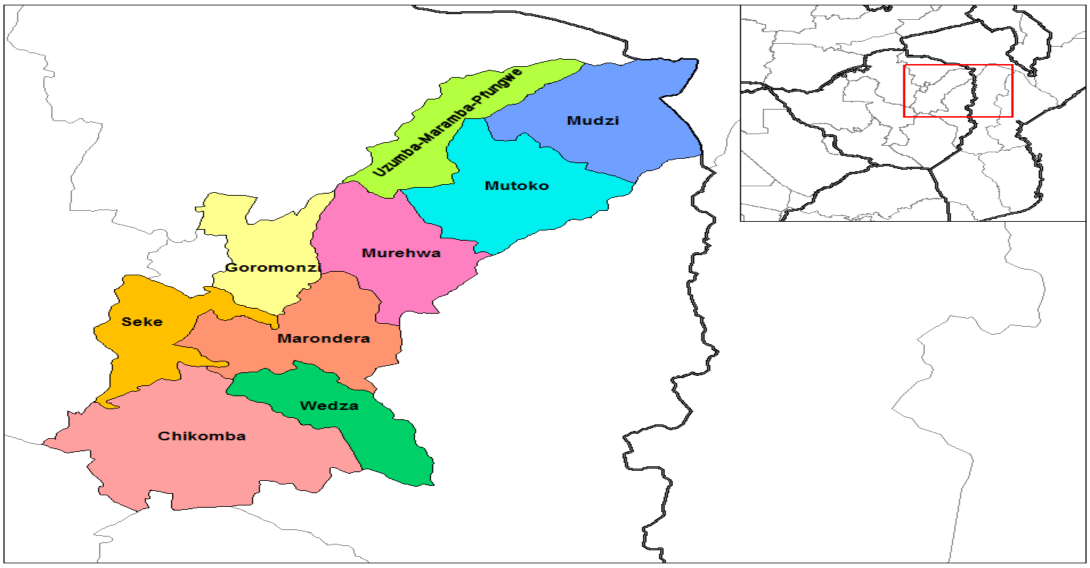
3.1 Description of Study Area

The study was conducted in two provinces of Zimbabwe which are Mashonaland Central and Mashonaland East. Mashonaland central province has 8districts and Mashonaland East has 9 districts. Most parts of Mashonaland central falls in Agro-ecological Region II and some areas are in region IV. Mashonaland East is found in region II, III and IV. The study focused mainly on dairy farms in Agro-ecological region II, which is sub-divided into region IIa and IIb. It receives annual rainfall of between 700-1000mm. Agro- ecological region II is characterised by mean maximum temperature range of 19-23 ºC, mean minimum temperature range of 10-13 ºC and mean annual temperature range of 16-19 ºC (Mugandani et al, 2012). In Mashonaland central farmers were selected from Mazowe and Bindura Districts whilst in Mashonaland East the sampling districts were Marondera, Goromonzi and Seke. Farmers were purposively selected according to the interest of the commissioner and by virtue of their dairy farming activities.

Figure 5: Map of Mashonaland Central Province

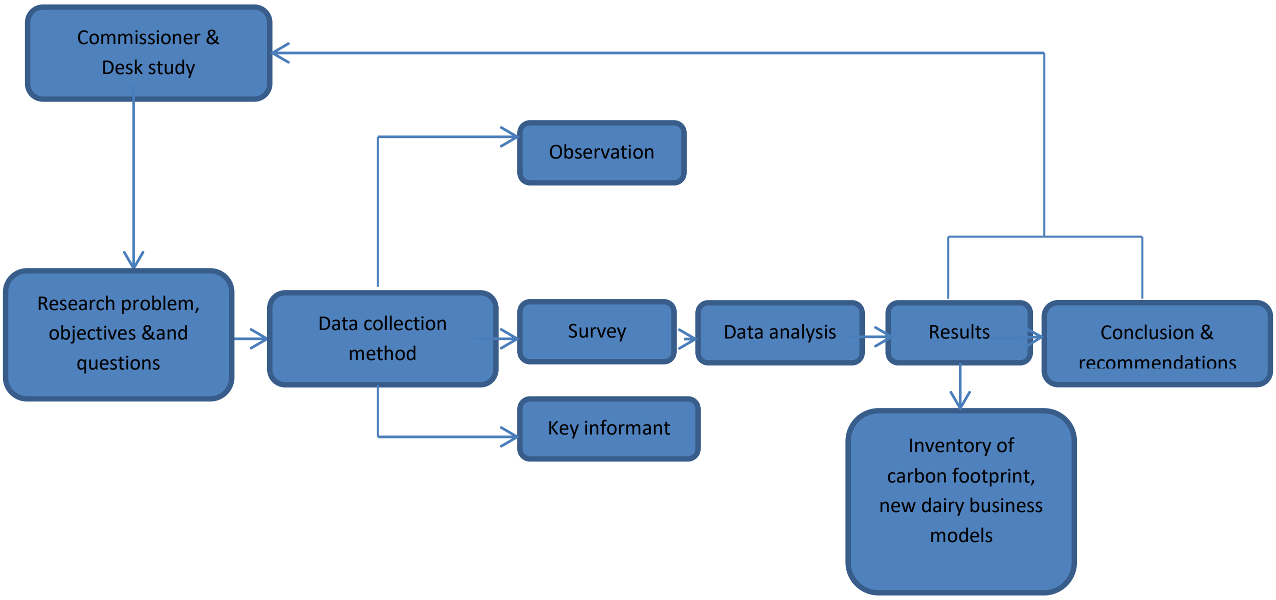
Source: Rarelibra, 2006

Figure 6: Map of Mashonaland East Province



3.2 Research Framework

Figure 7: Research Framework



3.3 Sample size

An inventory of dairy farmers was obtained from the Zimbabwe Association of Dairy Farmers (ZADF) where a sample of 24 farmers was purposively selected from Mashonaland central and Mashonaland East provinces. These farmers include 12 small-scale and 12 commercial, who participated in the study. Purposive sampling was used in selecting the farms according to production system, location (Mash central or Mash East) and scale of production (small-scale or large- scale).

3.4 Data Collection

3.4.1 Desk study

Desk study was used to obtain secondary information on GHG emissions globally, estimated carbon footprint in various countries, the situation in Zimbabwe. Moreover, it was used in outlining and understanding methods of GHG emission calculations in-terms of various equations used, emission factors and guidelines. Literature on small-scale and commercial farm emissions was used to make comparisons. The other purpose of desk study was to understand what has been done so far in Zimbabwe in regard to quantification of the GHG emissions thereby coming up with a research gap which need to be addressed in-line with the commissioner. Most sources which were used are Journal articles, books and thesis from Greeni and Google Scholar search engines.

3.4.2 Survey

A structured questionnaire was used to collect both quantitative and qualitative data by interviewing farmers selected from two production systems which are small-scale and commercial dairy farms. A checklist which is in line with the Life Cycle Assessment method was used during the interviews. Information on feeds, feeding quantities, feed quality, manure management, farm economics, animal numbers, categories, ages etc. was obtained from farmers and their family members or workers who are active in the dairy farming operations. At least one person was interviewed per farm and open questions to any relevant persons around were used to validate the findings.

3.4.3 Observation

Sufficient time was fully allocated per farm to get as much information and allow observation time. Besides responses from the respondents observation was used to validate and triangulate the information gathered. A transect walk was used in all the farms to actually observe what was on the ground in-order to verify with the information given by the farmer.

3.4.4 Key informant interviews

Additional information was collected from Agritex officers, Livestock specialists and Farm managers in the two provinces. These were conducted with district livestock specialists in Mazowe, Bindura, Marondera and Goromonzi districts. These key informants were interviewed on most technical aspects in their areas, information on fertilizer and feed types, application rates, suppliers, costs, transport, farming systems etc. This information was collected at the end of survey after data processing to validate the findings.

3.4.5 Farm Records

Data which is relevant to the study was collected from farm records kept by farmers to back up the interview data.

3.4.6 Data Collection Strategy during Covid 19

Due to the limitation of travel because of the covid pandemic, research assistants were employed for data collection. An online MS Teams meeting was conducted to train the research assistants on the relevant data to collect familiarization with the questionnaire and general understanding of interviewing skills. Moreover, follow up communications with research assistants were being held after every two days of data collection to check if the data was being collected accurately and amendments made where necessary. The research assistants were employed based on their agriculture background and present experience in research activities.

3.4.6 Feedback Meeting

A feedback meeting is going to be conducted with participants after the research to advise them on the results of the carbon footprint at their farms and new business models developed which they can make use of to improve their productivity and sustainability.

3.5 Data Analysis

GHG quantification calculations were based on formulas and guidelines of IPCC (2006) or 2013 tier 2. LCA computation tool (De Vries et al., 2021) and SPSS were used to calculate the carbon footprint and to analyse quantitative data respectively. Canvas Business Model was used to identify existing and design new business models. Climate-smart dairy practices framework from literature was used to identify existing practices on these dairy farms.

Table 2: Summary of Data collection and Analysis

Research Question	Data collection Method	Data analysis Method	Expected Output
1. What are the differences of carbon footprint per farm between small scale and commercial dairy farms?			
i. What is the farm level milk production in both small-scale and commercial dairy farms?	Interviews (full-structured questionnaire) Observation Farm records	SPSS	Differences in milk production levels of dairy animals between small scale and large-scale dairy farms
ii. What are the GHG emissions from enteric fermentation on small and large scale farms?	Interviews Observations Farm records	Gold standard formulas (IPCC Tier 2 approach), Life Cycle Analysis computation tool and SPSS	CH_4 emissions from enteric fermentation, quantity and quality of feed
iii. What are the GHG emissions from manure and fertiliser applications in both small and large-scale farms?	Interviews Observations Farm records	Life Cycle Analysis computation tool Gold standard formulars and SPSS	N_2O and CH_4 emissions from manure and synthetic fertilizers
Iv.What are the GHG emissions on farm machinery, feed transport and manufacturing?	Interviews (Questionnaire) Farm records	Life Cycle Analysis computation tool Gold standard formulars and SPSS	CO_2 emissions from farm machinery, feed transportation and feed production
2. What are possible climate smart dairy business models for			

the small scale and commercial dairy farmers?			
i. What are the climate smart dairy farming practices currently practiced at the dairy farms to reduce emissions?	Farm records Interviews Observation	Climate-smart practices framework	Inventory of climate smart dairy farming practices
Ii.What are the current business models being practiced by the dairy farmers in Mashonaland Central and Mashonaland East provinces?	Interviews of farmers and key informant interviews Observation Farm records	Canvas business model	Current business models New sustainable business models

3.6 Limitation of the study

The major limitation to this study was not being able to go back to Zimbabwe and collect data on my own. This was a challenge because I had to rely on research assistants to do the data collection which I feel was not the same as collecting it myself. A lot of back and forth questions were involved during the process, sometimes due to communication problem they would end up deciding on some crucial elements. The timing of data collection was another setback as the people I engaged had other duties of their own to perform as a result data was collected late which affected my time to process, analyse and present the results within the deadline. Some of the specific questions and follow up questions I would have loved to ask myself were not possible to do. The issue of observation was also a challenge since the research assistants were observing for me, I cannot personally relate to what they observed except to rely on what they told me. During field work majority of farmers were complaining about the length of the questionnaire it was very long as I tried to make sure that I capture as much data as possible. As a result some farmers could not complete the questionnaire at first visit they would request the research assistants to come the next day to collect. This might have distorted the results as verification was difficult to do in such cases since the farmer was left to fill in the questionnaire alone. Moreover, some farmers could not answer the questions fully as they indicated that they didn’t have knowledge of some of the questions asked. Such scenarios needed more probing from myself but were not possible due to my absence. Finding adequate number of farmers was also a challenge since most farmers were not welcoming outsiders due to covid related reasons. Accurate quantification of manure was a challenge since most farmers were not weighing their manure so most figures provided were estimates.

3.7 Gold standard equations for calculating GHG emissions

Equations which were used to calculate GHG emissions from different sources according to IPCC guidelines and formulas:

(i) CH4 Emissions from manure management

$$CH_{4Manure} = \sum_{(T)} \frac{(EF_{(T)} \cdot N_{(T)})}{10^6}$$

Where:

CH4Manure = CH4 emissions from manure management, for a defined population, Gg CH4 yr-1

EF(T) = emission factor for the defined livestock population, kg CH4 head-1 yr-1

N(T) = the number of head of livestock species/category T in the country

T = species/category of livestock

(ii) Direct N2O emissions from manure

$$N_2O_{D(mm)} = \sum S \sum T\left(N_T \cdot Nex_{(T)} \cdot MS_{(TS)}\right) \cdot EF_{3(S)} \cdot \frac{44}{28}$$

Where:

N2OD(mm) = direct N2O emissions from Manure Management in the country, kg N2O yr-1

N(T) = number of head of livestock species/category T in the country

Nex(T)= annual average N excretion per head of species/category T in the country, kg N animal-1 yr-1

MS(T,S) = fraction of total annual nitrogen excretion for each livestock species/category T that is managed

in manure management system S in the country, dimensionless

EF3(S) = emission factor for direct N2O emissions from manure management system S in the country, kg

N2O-N/kg N in manure management system S

S = manure management system

T = species/category of livestock

44/28 = conversion of (N2O-N) (mm) emissions to N2O (mm) emissions

(iii) Equation for estimating dry matter intake for mature dairy cows consuming low quality forages

EQUATION 10.18b

ESTIMATION OF DRY MATTER INTAKE FOR MATURE DAIRY COWS

$$DMI = \frac{\left(5.4 \bullet BW \right)}{\left(\frac{100 - DE\%}{100} \right)}$$

Where:

DMI = dry matter intake, kg day ^{1}

BW = live body weight, kg

DE%= digestible energy expressed as a percentage of gross energy (typically 45-55% for low qualityforages)

(iv) To estimate total emission, the selected emission factors are multiplied by the associated animal population

$$Emissions = EF_{(T)} \cdot \frac{N_{(T)}}{10^6}$$

Where:

Emissions = methane emissions from Enteric Fermentation, Gg CH4 yr-1

EF(T) = emission factor for the defined livestock population, kg CH4 head-1 yr-1

N(T) = the number of head of livestock species / category T in the country

T = species/category of livestock

(v) Total emissions from livestock fermentation

Total $CH_{4Enteric} = \sum_i E_i$

Where:

Total CH4Enteric = total methane emissions from Enteric Fermentation, Gg CH4 yr-1

Ei = is the emissions for the ith livestock categories and subcategories

(vi) Emissions from Farm Machinery

$$Efuel = Fuelcons * EFfuel$$

Where:

Efuel = emissions of a given GHG by type of fuel (kg GHG)

Fuelcons = amount of fuel combusted (L)

EFfuel = emission factor of a given GHG by type of fuel (kg gas/L).

(vii) Equation for calculating milk yield

$$\mathbf{MilkBS,j,i,t = MilkBS,j,t/Nj}$$

Where:

MilkBS,j,i,t = Average annual milk yield per cow in the baseline in the jth farm (kg uncorrected milk yield * head-1 * year-1)

MilkBS,j,t = Total uncorrected milk yield produced on farm j in the baseline year t (kg uncorrected milk yield * farm-1 * year-1)

Nj = Number of lactating cows on the jth farm (head-1 * year-1)

BS = index of baseline scenario i = index of individual animals j= index of individual farms t = index of year (FAO and ILRI, 2016).

(viii) The equation for calculating FPCM from uncorrected milk yield

$$\mathbf{FPCMi,t = Milki,t \times (0.337 + 0.116 \times Milkfat + 0.06 \times Milkprotein}$$

Where:

FPCMi,t = Fat and protein corrected milk yield for the ith cow (kg FPCM * head-1 * year-1)

MilkI,t = Total uncorrected milk production for the ith animal (kg-1 * head-1 * year-1)

Milk fat = % fat content of milk (IPCC default value is 4.0)

Milk protein = % protein content of milk (IPCC default value is 3.3) i = index of individual animals

(ix) Baseline annual emissions

$$\mathbf{BEBS,i = (BEEnteric,i + BEFeed,i + BEManure,i)}$$

Where:

BEBS,i = Baseline emissions estimated with baseline survey data for the ith animal (kg CO2e)

BEEnteric,i = Baseline enteric methane emissions for the ith animal (kg CO2e)

BEFeed,i = Baseline embodied emissions in feed (including supplements) for the ith animal (kg CO2e)

BEManure,i = Baseline methane emissions from manure management for the ith animal (kg CO2e)

BS = index of baseline scenario

i = index of individual animals

(x) Enteric Methane Emissions

$$, = \left(\mathbf{25 \times 365 \times GE_i \times \left(\frac{YM}{100}\right)}\right) \div \mathbf{55.65}$$

Where:

$BE_{Enteric,i}$ = Baseline enteric methane emissions for the ith dairy animal (kg CO_2e)

25 = Global warming potential over 100 years of methane

GEi = Gross energy20 intake of the daily total mixed ration (feed and supplements) of the ith animal (MJ * $head^{-1}$ * day^{-1})

YM = Methane conversion factor (IPCC default factor for dairy cattle = 6.5 ±1.0%)[21]

55.65 energy content of methane (MJ * kg CH_4^{-1})

i = index of individual animals

(xi)GE for each individual animal in the baseline survey:

$$\mathbf{GE}_{\mathbf{Feed,i}} = (\mathbf{DMI}_{\mathbf{i}} \times \mathbf{18.45})$$

Where:

GEi = Gross energy32 intake of the daily total mixed ration (feed and supplements) of the ith animal (MJ * head-1 * day-1)

DMI_i = Daily dry matter intake for the ith animal (kg-1 dry matter * head-1 * day-1)

i = index of individual animals

(xii) **Embodied feed emission intensity**

$$\mathbf{BE}_{\mathbf{Feed,i}} = (\mathbf{EF}_{\mathbf{Feed,i}} \times \mathbf{Feed}_{\mathbf{Survey,i}})$$

Where:

$BE_{\mathbf{Feed,i}}$ = Baseline embodied emissions in feed for the ith animal (kg CO_2e)

$EF_{\mathbf{Feed,i}}$ = Emission factor for embodied emissions in feed in the total mixed ration of the ith animal (kg CO_2e)

Feed $_{\mathbf{Survey,i}}$ = Feed used to feed the ith animal from the baseline survey (kg feed * head-1 * year-1)

i = index of individual animals

(xiii) Quantification of GHG emission intensity per farm

$$\mathbf{BEI}_{\mathbf{BS},j,t} = ((\textstyle\sum_i(\mathbf{BE}_{\mathbf{Enteric},i,j} + \mathbf{BE}_{\mathbf{Feed},i,j} + \mathbf{BE}_{\mathbf{Manure},i,j})) + \mathbf{BE}_{\mathbf{Replace},j}) / (\textstyle\sum \mathbf{i}\ \mathbf{FPCM}_{\mathbf{BS},i,j,t})$$

Where:

$BEI_{BS,j,t}$ = Baseline emission intensity of milk production estimated with baseline survey data for the jth farm (kg CO_2e * kg FPCM -1)

$BE_{Enteric,i,j}$ = Baseline enteric methane emissions for the ith animal on the jth farm (kg CO_2e)

$BE_{Feed,i,j}$ = Baseline embodied emissions in feed (including supplements) for the ith animal on the jth farm (kg CO2e)

$BE_{Manure,i,j}$ = Baseline methane emissions from manure management for the ith animal on the jth farm (kg CO2e)

$BE_{Replace,j}$ = Baseline GHG emissions from replacement animals currently off-farm for the jth farm (kg CO2e)

$FPCM_{BS,i,j,t}$ = Baseline fat and protein corrected milk yield for the ith animal on the jth farm in the baseline survey (kg FPCM * head-1* year-1)

BS = index of baseline scenario

i = index of individual animals

j= index of individual farms

Source of Equations: (FAO and ILRI, 2016)

CHAPTER 4: RESULTS

4.1 Farm Characteristics

All farms in the study had a total average herd size of 137.6 and 67.9 milking cows, this shows that dairy farming in these areas is mainly done on a large scale. The large-scale and small-scale farmers had an average herd size of 249.6 and 25.6 respectively. The maximum herd size was 1487 and 47 for large-scale and small-scale farmers respectively. Having such a huge herd size of 1487 indicated some level of commitment to dairy farming by some farmers. Milk yield per cow per year was significantly high with an average FPCM yield/cow/year of 4689 and 2837 litres for large and small-scale farms respectively. The study showed that dairy farmers owned very large piece of land which was committed to dairy production and other farm activities. For purposes of this study only land allocated to dairy production was recorded. Average production of milk per hectare was 1102 and 5682 for small and large-scale farmers respectively.

Table 3: Average (mean) of farm characteristics

Parameter	**Mean total ±SD (n=24)**	**Large-scale Mean ±SD (n=12)**	**Small-scale Mean ±SD (n=12)**	**P-value**
Average Farm Land size (ha)	78.4 ±101.1	123.9 ±128.9	32.8 ±15.3	0.033*
Average Herd size	137.6 ±299.6	249.6 ±400.2	25.6 ±13.3	0.079#
Average Milking cows	67.9 ±144.8	124.1 ±192.2	11.8 ±5.5	0.068#
Average Milk yield/cow/year	3763 ±1774	4689 ±1274.6	2837 ±1757.2	0.007*
Average Farm Milk yield/year	376440 ±1037522	723162 ±1409981	29717 ±20639	0.117
Average Livestock Unit	113.1 ±257.2	206.2 ±345.4	19.9 ±9.6	0.089#
Average Production per hectare	3392 ±3870.9	5682 ±4390.95	1102 ±782.01	0.004*

Statistically significant difference: P< 0.05 *

P< 0.1

4.2 Greenhouse Gas Emissions

Table 4 shows average, standard-deviation and level of significance of emissions from enteric fermentation, manure and fertiliser management, fodder production and feed production.

Table 4: Average GHG emissions of milk production in CO2 eq/kg FPCM

Mean total: n=24 Large-scale: n=12 Small-scale n=12

Parameter	Mean total ±SD	Large-scale Mean ±SD	Small-scale Mean ±SD	P- value
Enteric	1.4 ±0.9	0.92 ±0.34	1.8 ±1.01	0.012*
Manure & fert	0.3 ±0.2	0.1 ±0.39	0.4 ±0.28	0.004*
Fodder production	0.06 ±0.1	0.01 ±0.0.125	0.11 ±0.26	0.128
Fertiliser prodn	0.1 ±0.2	0.009 ±0.0099	0.13 ±0.28	0.099#
Feed production	0.4 ±0.3	0.27 ±0.16	0.53 ±0.46	0.079#
Carbon footprint	2.3 ±1.09	1.30 ±0.42	2.97 ±1.76	0.007*

* **Statistically significant difference**: P< 0.05 *

P< 0.1 #

4.2.1 Enteric emissions

Enteric emissions were calculated based on Fat and Protein Corrected Milk (FPCM) which was 4.03 and 3.3 for Large-scale farms and 3.66 and 3.17% for small-scale farmers. These figures were obtained from Dairiboard Zimbabwe Limited (DZL) were most farmers in Mashonaland East and Central sell their milk. The average enteric emission CO2eq/kg FPCM was 0.92 and 1.8 for large-scale farms and small-scale farms respectively (Table 4). These results show high enteric emission CO2eq/kg FPCM in small-scale farms as compared to large-scale farms. Concluding that the higher the milk production the less enteric emissions CO2eq/kg FPCM. This is evidently shown in farm number 20 were milk production is 750 litres/cow/year FPCM which is lower than all farms in the study but have the highest enteric emissions C02eq/kg FPCM which is 4.09.

4.2.2 Manure and Fertiliser Management Emissions

The average manure and fertiliser management emissions CO2eq/kg FPCM were 0.1 and 0.4 for large and small-scale farms respectively (Table 4). These results show that emissions from manure and fertiliser application that's CO2eq/kg FPCM were quite high in small-scale farms than in large-scale farms, even though large producers applied more manure and fertilisers than small-scale farmers. It was noted that most farmers did not practise good manure handling procedures as they left manure were it was deposited by the animals. That is how the pastures were fertilised by default but no proper treatment and application of manure.

Table 5: N quantities in Large and Small-scale farms

Parameter	Large-scale Farms	Small-scale farms
Total kgs N application	19088	5799
Average kgs N per farm	1591	483
CO2 eq/kg FPCM from fertiliser application	0.023	0.234

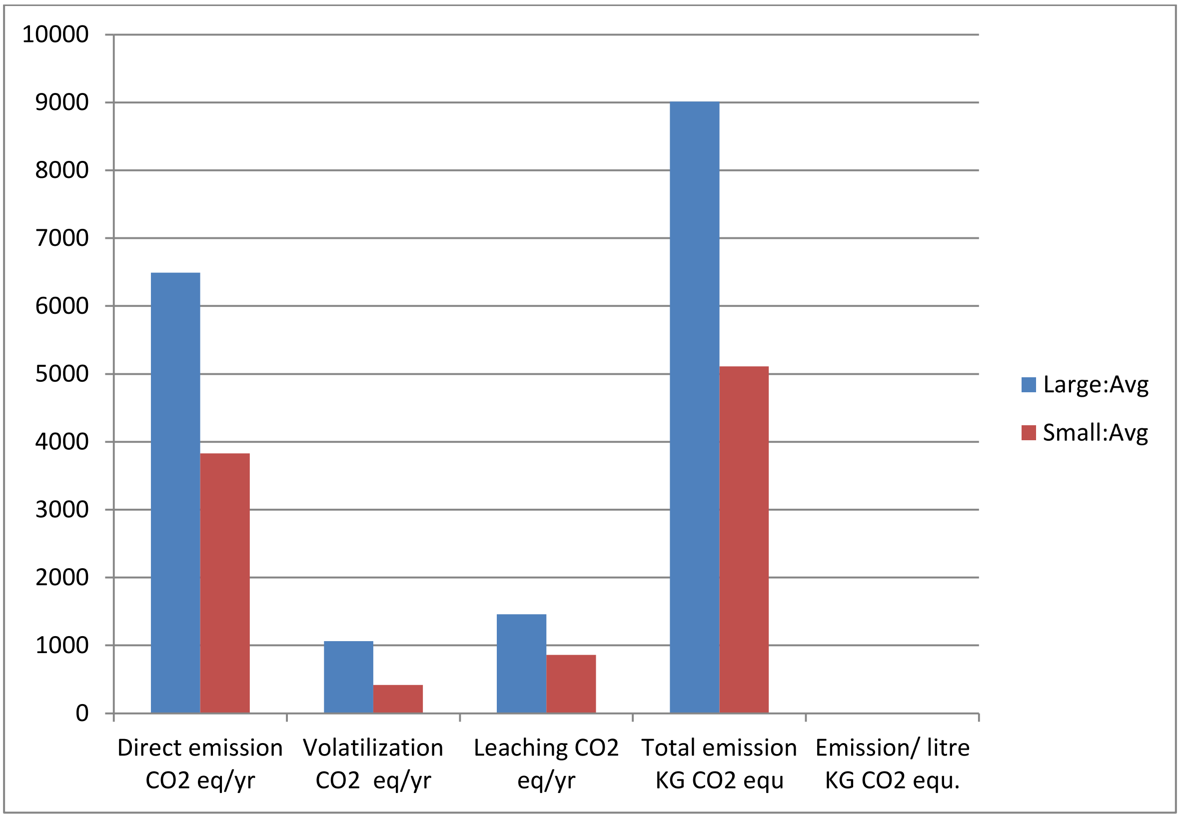
Most farmers in this research grow maize and some forage like Rhodes grass, Star grass, Brachiaria and kikuyu. The commonly used fertilisers were Ammonium nitrate (AN) which has 34% nitrogen and Compound D used as basal fertiliser with 7% nitrogen. Very few farmers were using Urea fertilizer with 46% nitrogen. Large scale dairy farmers used more fertilisers as indicated in Table 5 with total N application of 19088kg as compared to small-scale farmers who applied a total 5799kg of N. The average quantities of N application per farm were 1591 and 483kg for large and small-scale farms respectively. Fertiliser application emissions CO2 eq/kg FPCM were high in small-scale farms (0.234) than in large-scale farms (0.023).

Table 6: GHG emissions through Direct and Indirect N20 and CH4 emissions from manure management in CO2 eq/kg FPCM per year

Parameter	Large-scale (n=12) Mean ±SD	Small-scale (n=12) Mean ±SD	P- value
Direct emissions	6493 ±7683	3830 ±4326	0.307
Volatilisation	1061 ±1551	417 ±431	0.179
Leaching	1461 ±1729	862 ±973	0.307
Total emissions(direct & in-direct)	9015 ±10951	5109 ±5729	0.285

Indirect emissions from manure management were measured from volatilisation and leaching as CO2 equivalent per year. Average total direct and indirect emissions CO2 eq/kg FPCM from manure management for large-scale farmers were 9015 and 5109 for small-scale farmers. Total emissions kg CO2 equivalent were the summation of direct and indirect emissions CO2 eq/kg FPCM per year. Direct emissions were higher than indirect emissions from both (volatilization and leaching) combined for both small and large-scale farms.

Figure 8: Direct and indirect N2O and CH4 emissions from manure management



CO2 eq/kg FPCM per year

Figure 9 clearly illustrating direct emissions from manure management being the highest in both small and large-scale farms.

4.2.3 Fodder production emissions (Machinery and Transport)

Emissions from fodder production were measured from fuel and hours used by machinery to cultivate and harvest fodder as well as transport used to ferry feeds from on-farm and off-farm locations. The most common transport which was used by farmers to carry feeds from off-farm locations were trucks whilst on-farm farmers used scotch-carts, wheelbarrows and tractors depending on the quantities of feed being transported. Average fodder production CO2eq/kg FPCM for large and small-scale farms was 0.01 and 0.11 respectively (Table 4). Forages were cultivated on farm and fodder preservation that's making of hay and silage was also done on-farm. Only one small-scale farmer indicated that he was buying silage from a large-scale farmer. Small-scale farmers who did not cultivate fodder during the year of study were relying on natural grasses grazing and concentrate feeds from the stock-feed shops. Quite a considerable percentage of farmers relied on concentrate and straight feeds as supplements for their animals.

4.2.4 Fertiliser production emissions

These emissions were calculated based on production of AN, Compound D and Urea fertilisers. The calculations were based on ecoinvent database as N at regional storehouse. The ecoinvent factors used were 4.318, 0.889 and 5.8421 for AN, Compound D and Urea respectively. Average emissions from fertiliser production CO2eq/kg FPCM were 0.009 and 0.13 for large-scale and small-scale farmers respectively (Table 4). Some farms recorded 0.000 emissions because they did not cultivate fodder during the year of this study therefore no fertilisers were used for dairy production.

4.2.5 Emissions from production of off-farm feeds and by-products

These emissions were based on production of off-farms feed and by products. Farmers in this study used straight feeds, mineral blocks, concentrates, molasses and brewery waste as supplementary feeding to their animals. Average emissions from production of feeds and by-products CO_2 eq/kg FPCM were 0.27 and 0.53 for large and small-scale farms respectively (Table 4).

4.2.6 Total Emissions

Figure 10 summarises the averages of all the emissions from enteric, feed, manure, off-farm fertilisers, off-farm feed and concentrates CO_2 eq/kg FPCM for both small-scale and large scale farms. Enteric emissions were the highest as compared to all other emissions for both small and large-scale farms. The average carbon footprint per farm for large-scale farms and small-scale farms were 1.30 and 2.97 CO_2 eq/kg FPCM respectively. The maximum carbon footprint per farm were 2.39 and 6.91 for large and small-scale farms respectively, clearly indicating that small-scale farms are producing more greenhouse gas emissions in CO_2 eq/kg FPCM.

Figure 9: Carbon footprint per output (enteric, feed, manure, off-farm fertiliser and feed production) in CO2 eq/kg FPCM

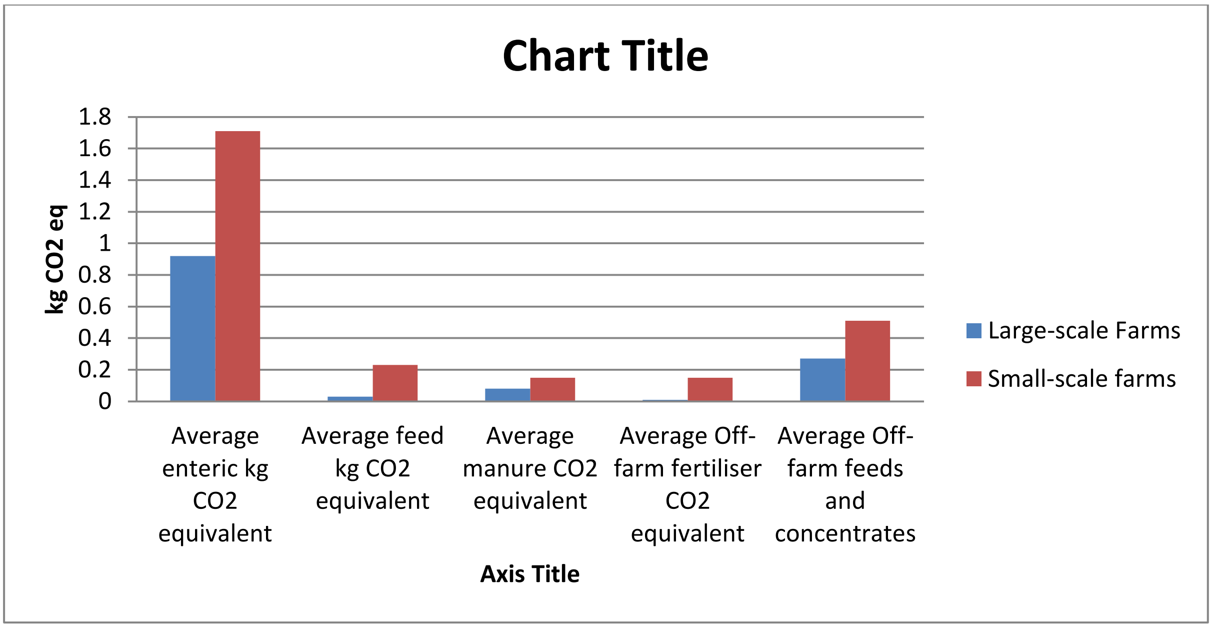


Figure 10: Large-scale Farms GHG emissions in %

Enteric fermentation 70.3% Manure and Fertiliser 7.6% Fodder 0.76% Fertiliser 0.69% Feed 20.65%

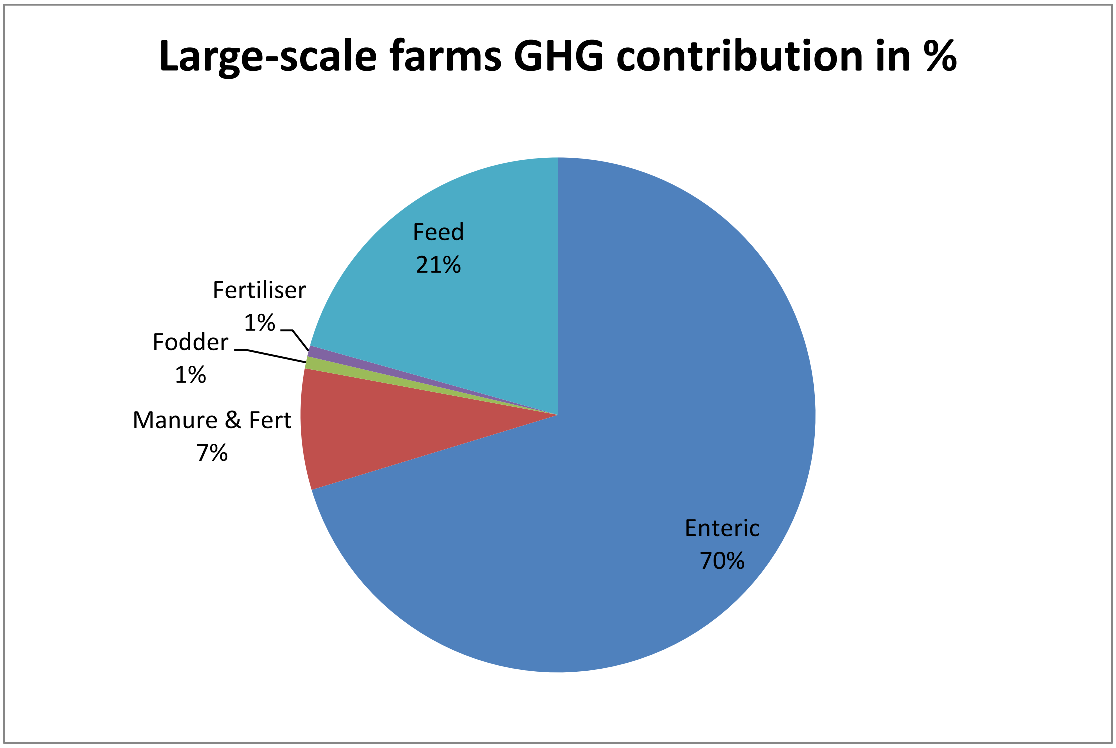


Figure 11: Small-scale farms GHG emissions in %

Enteric fermentation 61% Manure and Fertiliser application 13.5% Fodder 3.7% Fertiliser production 4.4% Feed production 17.4%

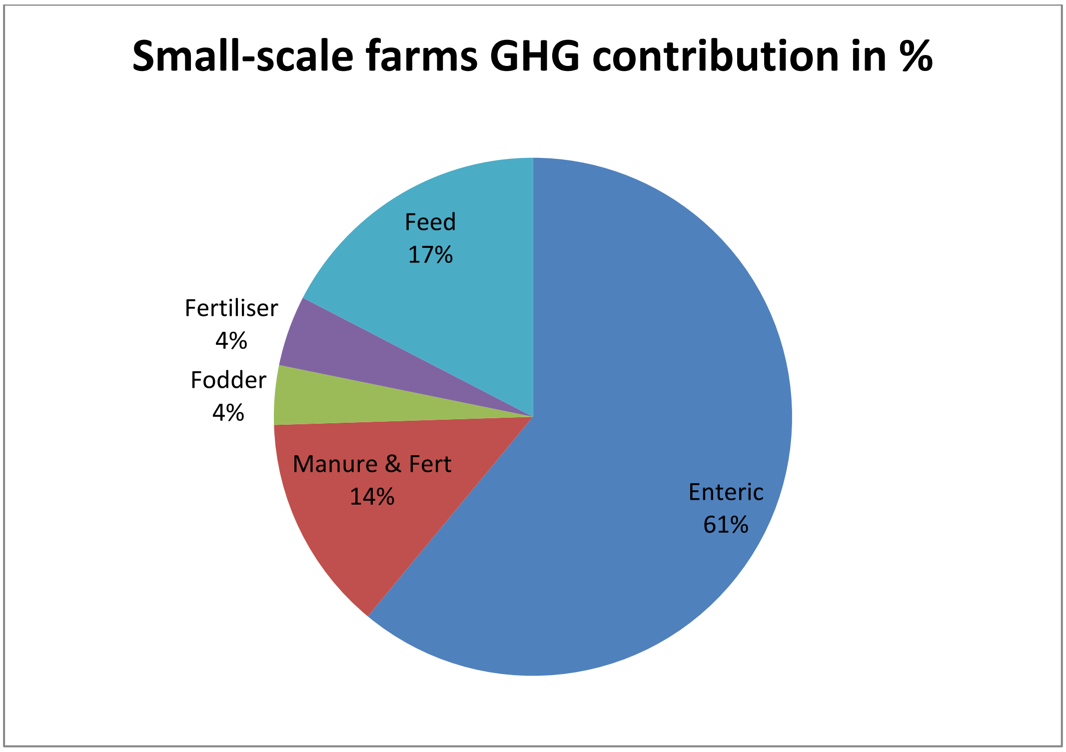
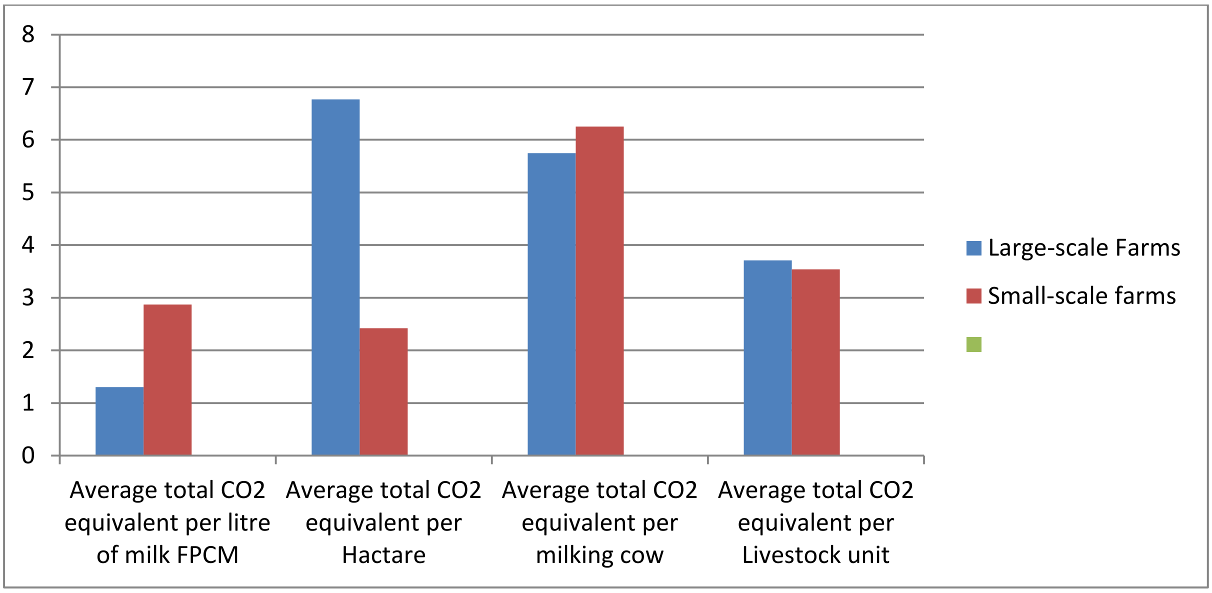


Table 7: Average Total Emissions in CO2 eq/kg FPCM

Parameter	Mean total ± SD (n=24)	Large-scale (n=12) Mean ±SD	Small-scale (n=12) Mean ±SD	P- value
Milk production	2.3 ±1.09	1.3 ±0.42	2.97 ±1.76	0.007*
Per hectare	4.6 ±4.09	6.77 ±4.76	2.41 ±1.43	0.006*
Milking cow	6 ±2.27	5.75±1.33	6.25 ±2.98	0.601
Livestock unit	3.62 ±0.99	3.71 ±0.68	3.5 ±1.25	0.690

Average total emissions CO2eq/kg FPCM for milk production and milking cow were lower in large-scale farms than in small-scale farms. However, average CO2eq/kg FPCM emissions per hectare and livestock unit were higher in large-scale farms when compared to small-scale farms.

Figure 12: CO2 eq/kg FPCM Average total emissions



4.3 Climate -smart dairy practises

A number of climate smart dairy practises were identified in both small- scale and large scale dairy production as indicated in the table below which shows mitigation measures, practises identified and percentage adoption per farming system. As presented in the table manure management practises are not adopted in both small scale and large scale farming, almost all farmers leave manure where they are dropped by cattle that are either in paddocks, pasture or in animal shelters. Adoption of improved forage grasses is gaining momentum especially with large scale farmers where Rhodes grass is being grown by 42% 0f interviewed farmers. However, adoption of legumes is slow as compared to grasses with lucerne being used by 25% large-scale farmers and only 8% small-scale farmers. Soil conservation practises such as crop rotation and mixed cropping was evident in most farms as they grow maize, soya bean, wheat etc. for animal and home consumption. Majority of dairy cattle owned by large-scale farmers is purely exotic breeds (67%) which include Friesland-Holstein and Red-Dane, while 33% own cross-breeds cattle which are crosses of exotic and indigenous breeds. Small-scale farmers own 75% of cross-bred, 17% indigenous and 8% exotic dairy animals. A high percentage of farmers feed their animals with dairy concentrates that's both small-scale (75%) and large-scale farmers (92%). Another interesting point was noting a considerable number of farmers using crop residues and by products such as brewery waste, orange peels, maize stover, and wheat straw to feed their animals. Hay and silage making were the main methods used to conserve fodder in both production systems with the large-scale farmers conserving more. Only one farmer indicated using urea treatment for maize stover out of all the farmers interviewed.

Table 8: Climate Smart Practises

Mitigation measures	Practices identified	Adoption level(n=12) SS	Adoption level (n=12) LS
Manure management	Composting, biogass, spread in fields, anaerobic lagoon	0%	0%
	Solid storage	100%	100%
Fodder crops	Rhodes grass	25%	42%
	Star grass	42%	83%
	Kikuyu	25%	33%
	Brachiaria	8%	33%
	Napier	17%	0%
	Lucerne	8%	25%
Soil conservation	Crop rotation, mixed cropping,	75%	67%
	Agroforestry, contouring, terracing	0%	0%
High yielding cows	Purely exotic	8%	67%
	Crosses	75%	33%
	Indigenous	17%	0%
Feeding concentrates	Dairy meal	75%	92%
	Cotton seed cake	33%	50%
	Soya bean and sunflower meal	175	25%
Crop residues and by products feeding	Maize stover	50%	58%
	Maize bran	17%	25%
	Wheat straw	8%	0%
	Brewery waste	17%	67%
	Molasses	8%	33%
	Orange peels	8%	17%
	Poultry waste	0%	8%
Fodder conservation	Hay	75%	92%
	Silage	42%	83%
	Urea treatment of fodder	8%	0%

Source: Author, 2021

Legend: SS- small-scale

LS- Large-scale

4.4 Canvas Business Model for Large Scale Farmers

Table 9: Canvas Business Model for Large-scale farmers

Text in black represent existing and text in red represent the added elements

<table>
<tr>
<td rowspan="2">Key partners
Milk processors (Dairiboard Zimbabwe Limited, Den-dairy, Pro-dairy etc.)
Ministry of Lands, Agriculture, Water and Rural Resettlements (Extension, Research Institutes, Dairy Services)
Zimbabwe Agriculture Growth Programme (ZAGP)
Input suppliers (stock feed shops, veterinary distributors, detergents and disinfectants)
Financial Institutions (Agri-bank)
National Dairy Cooperative (transport)
National Association</td>
<td>Key activities
Milking cows
Feeding animals
Fodder cultivation
Hay bales making
Silage making
Hands on training of small-scale farmers
Mixed pasture production of grasses and legumes eg. Star- grass & silver leaf combination</td>
<td rowspan="2">Value proposition
High quality milk production
High milk yields
On farm milk processing</td>
<td>Customer relationship
Mutual trust
Communication
Expert advice from processors
Signed contracts
Field trips
Trainings provided by processors</td>
<td rowspan="2">Customer segments
Formal market through processors (DZL, Pro-dairy, Den-dairy)
Own factory like Red- Dane dairy owning Kefalos factory</td>
</tr>
<tr>
<td>Key resources
Dairy animals (Exotic and crosses)
Land
Infrastructure
Capital
Inputs (feeds,</td>
<td>Channels
National Dairy Cooperative transporting milk to processing plants
Processors’ own transport</td>
</tr>
</table>

of Dairy farmers (NADF)	veterinary drugs, fertilizers, seeds etc)			

Cost structure • Feeds • Veterinary drugs • Maintenance of milking machines/equipment • Salaries • Fertilisers and seeds/planting material • Transport costs • Utility costs (electricity, fuels and water) • Breeding costs • Purchasing and installation of biogas digesters, composting materials for proper manure handling • Investing in irrigation equipment	**Revenue streams** • Milk sales • Bull calf sales • Cull cows sales • Hay bales sales • Adopting selling of surplus forages to other farmers • Selling manure • Biogas energy sales
Social and environmental costs • Greenhouse gas emissions (enteric, transport, manure and feed production emissions) • Draught (erratic rains and high temperatures) • Air pollution • Ground water contamination from not well managed manure	**Social and environmental benefits** • Cultivation of improved fodder (eg lucerne)- improves soil nutrition • Improved milk production and quality from practising climate smart dairy technologies (High yielding exotic breeds, improved forages) • Reduced GHG emissions • Soil conservation • Good Manure management- composting, use of biogas digesters reduce GHG emissions • Applying treated manure in crops and pastures • Low GHG emissions

4.5 Canvas business model for Small-scale farmers

Table 10: Canvas Business Model for Small-scale Farmers

Text in black represent existing and text in red represent the added elements

<table>
<tr>
<td rowspan="2">Key partners
Milk processors (Dairiboard, Pro-dairy etc)
Ministry of Lands, Agriculture, Water and Rural Resettlements (Extension, Dairy Services)
NGOs e.g Zimbabwe Agriculture Growth Programme (ZAGP)
Input suppliers (stock feed shops, veterinary distributors, detergents and disinfectants)
Smallholder Dairy Farmers’ Association (SDFA)
Research Institutes
Financial Institutions (Agri-bank)</td>
<td>Key activities
Milking cows
Feeding animals
Fodder cultivation
Hay bales making
Silage making
Cultivation of other crops
More fodder and forage production improved forages with legume inclusion</td>
<td rowspan="2">Value proposition
Quality milk
High milk production
Improved dairy breeds
Consistent milk supply</td>
<td>Customer relationship
Communication
Mutual trust
Contracts</td>
<td rowspan="2">Customer segments
Formal market through processors
Informal market through selling to locals
Institutional customers (schools, hospitals</td>
</tr>
<tr>
<td>Key resources
Dairy animals (cross-breds and indigenous breeds)
Land
Infrastructure
Inputs for pasture and crop production
Consider high yielding cows (exotic breeds)</td>
<td>Channels
Individual transport to transport milk to processors
Farm gate
Consider arranged bulk transport from processors
Reviving milk collection centres and cooperatives</td>
</tr>
<tr>
<td colspan="2">Cost structure
Feeds
Veterinary drugs</td>
<td colspan="3">Revenue streams
Milk sales
Bull calf sales</td>
</tr>
</table>

• Maintenance of milking machines/equipment • Fertilisers and seeds • Transport costs • Utility costs (electricity, fuels and water) • Investing in irrigation equipment	• Cull cows sales • Manure sales • Hay bales sales • Meat sales • Hides sales
Social and environmental costs • Methane and nitrous oxide emissions • Seasonal food shortages (effects of dry spell) • Costs of adopting climate smart dairy practises- (improved pasture production, manure handling facilities	**Social and environmental benefits** • Cultivation of improved fodder (eg lucerne)- improves soil nutrition • Proper manure management- composting, use of biogas digestors reduce methane and nitrous oxide emissions • Applying treated manure in crops and pastures- improves and conserves the soil, reducing nitrogen losses in the soil.

These two business models were designed by the author from compilation of information obtained from the survey.

<u>Large-Scale Business Canvas Model</u>

Large-scale farmers has an almost 100% relationship with milk processors as they deliver all their milk to them. In both Mashonaland East and Mashonaland central provinces Dairiboard Zimbabwe Limited was observed as the major buyer of milk. However, in Mash East there seem to be a tough competition with Pro- dairy. Very few large scale farmers have their own processing plants which is a good value addition proposition which can boast profitability of these farmers. During the study it was noted that manure handling techniques were lacking in both small-scale and large –scale farming systems. Hence, the proposal to invest in biogas digesters and practising composting to generate energy as well as reduce greenhouse gas emissions. Most large-scale farmers were cultivating improved forages to feed their animal but the practise has not been adopted 100% more hectares need to be committed to fodder production. Land is not a problem since all farmers interviewed have vast land to make optimum production. Investing in irrigation will go a long way in addressing feed shortages during the dry season as forages can be grown all year round with irrigation.

Small-Scale Business Canvas Model

In this study some small-scale farmers indicated that they sell their milk to milk processors and some sell their milk in the informal market through farm gate milk sales, selling directly to individuals and some through milk vendors. Proper transport arrangements from processors and resuscitation of milk collection centres can increase milk supply to the formal market from small-scale farmers. They may also extend their market to institutional consumers such as schools, hospitals, hotels and prisons. Quite a considerable number of small-scale farmers own cross-bred dairy animals and indigenous breeds. Considering cross-breeds from pure exotic breeds crossed with indigenous breeds will address milk yields as well as adaptability to the local climatic conditions. On revenue streams farmers can include sell of manure, forages and hay to boast their income than leaving manure to waste. Feed conservation practises such as silage and hay making help in addressing feed shortages during the dry season and cut on costs of buying more concentrates for supplementation. Proper manure handling procedures need to be practised to reduce emissions.

NB: The black texts in the models indicate identified practises and the red texts indicate the dimensions which can be added in the new business models.

CHAPTER 5: DISCUSSION

5.1 Farming system Herd size and Milk Production

This study involved dairy farmers in two provinces of Zimbabwe which were selected according to their scale of production. Farmers with a herd size of 50 animals and above were considered large-scale and 49 animals and below small-scale. The average herd size was 249.6 and 25.6 for large-scale and small-scale farms respectively. Herd size showed a statistical significance difference to $P < 0.1$ which signals a significant difference in dairy animals owned between these two farming systems. According to (Matekenya, 2016) small-scale farms are characterized by low yielding indigenous breeds and mostly own very low numbers of animals. However, most small-scale farmers interviewed in this study had cross-bred animals which are 75%, while 17% own indigenous breeds and only 8% of the small-scale farmers had exotic breeds. The percentage of small-scale farmers owning crossbreeds (75%) was almost similar with what was found in Ethiopia by (Tezera, 2018) where 89% of urban farmers were keeping Holstein- Friesian crossed with indigenous breeds. Similarly the larger percentage of cross-breed dairy animals in Zimbabwe are crosses of Holstein-Friesian and indigenous breeds.In large-scale farms 33% had dairy cross animals while 67% of the farmers had exotic dairy breeds which are mainly Holstein-Friesian and Red-Dane.

The average herd size in small-scale farms was 25 which is higher than studies in other African countries, as shown by a study which was done in Kenya respondents kept an average herd of 3 and 9 in Ruiru and Githunguri sub-counties respectively (Kiiza, 2018) and (wilkes et al., 2020) recorded an average household herd of 3.36 in Kenya as well. This was because of smaller sizes of land these farmers own which couldn't support a bigger herd. In contrary the study in Zimbabwe revealed that both small and large scale farmers have large pieces of land which allow them to keep huge numbers of cattle as well as cultivating forages for the animals. The land size was statistically significant different with average farm size of 123.9 and 32.8 hectares for large and small-scale farms respectively. Average production of milk per hectare was 5681.5 and 1102.4 for large and small-scale farms respectively which was also statistically significant different. However GHG emissions were high per hectare in large-scale farms (6.77) and lower in small-scale farms (2.41), this can be due to high milk production per hectare in commercial farms. There was a significant difference in average milk yield per cow per year which was 4688.5 and 2837.3 kg FPCM for large and small-scale farms respectively. This yield for large-scale farms was quite higher than 2450 kg FPCM cow/year which was recorded in Kenya in all feeding systems (Wilkes et al., 2020). However, the average milk yield for small-scale farmers was almost similar with Kenya milk yield. The total average milk yield in this study was 3763 which is still higher than recorded in Kenya.

5.2 Greenhouse Gas Emissions

5.1.1 Emissions from Enteric Fermentation

The study indicated average enteric fermentation emissions of 0.92 and 1.8 CO_2 eq/kg FPCM per farm for large-scale and small-scale farms respectively. These results are quite in line with what was obtained by Tezera, 2018 in Ethiopia who obtained enteric emissions of 1.4 and 2.66 CO_2 eq/kg FPCM for urban and peri-urban farms respectively. Garg et al. (2016) in his study on carbon footprint of milk production under smallholder dairying in Anand district of Western India obtained enteric fermentation emissions of 1.7 CO_2 eq/kg FPCM which is quite similar with the indications from this study. Comparing the small and large scale farms in Zimbabwe, enteric CH_4 emissions from large scale were much higher than from small-scale farms interms of CO_2 eq/year. The reason behind this difference might be due to some improvements being made in animal breeding as most large-scale farmers in this study own purely exotic dairy breeds or cross-breeds. Improvement in breeding lead to increase in enteric methane due to improved body weight which increases dry matter intake and gross energy requirements (Gao, et al., 2014). Also the size of the herd has a direct impact in the amount of enteric emissions produced. This explains why small-scale farms had a low average enteric emission of 1720.5 kg equivalent per year. However, in-terms of CO_2 eq/kg FPCM large-scale farms had 0.92 as compared to 1.8 in small-scale farms which is less enteric emissions per kg of milk produced. Enteric emissions contributed 70.3% and 61% of the total emissions in the study for large and small-scale farms respectively. The contribution of 70.3% from large scale farms was almost in-line with what was discovered by (Rotz, 2010) who recorded 76% contribution of enteric emissions. In Kenya enteric emissions accounted for 55.5% of the total GHG emissions (Wilkes et al., 2020) which is almost similar contribution obtained on enteric emissions from small-scale farms in Zimbabwe (61%).

5.1.2 Emissions from Manure and Fertiliser Application

Most respondents in the study indicated that they use AN and Compound D to fertilise their pastures and crops. The study showed that farmers were not practising treatment and good manure handling practises. Manure was left where it is deposited by an animal that is in pasture or in rangelands. This is in support with what was discovered by (Sithole et al., 2016) as he identified two manure management systems in Zimbabwe which are solid storage and application of manure to crops. He defined solid storage as practise where manure is left where they are directly deposited by animals, and this practise is mostly done by large-scale farmers. Then the second method was mostly done by small-scale farmers who practise mixed cropping. Results show that emissions from manure and fertiliser application in terms of CO_2 eq/kg FPCM were quite high in small-scale farms than in large-scale farms thus 0.4 and 0.1 respectively. This might support what was stated by (Rojas-Downings et al., 2017) that emissions in mixed crop-livestock systems where manure is applied is 40% higher than where manure are directly deposited in the pasture. Manure and fertiliser management contributed 7.6 and 13.25% of total GHG emissions from large and small-scale farms respectively, with the percentage from small-scale farms almost similar to 12.6% found in Kenya (Wilkes et al., 2019).

However, the total average direct and indirect emissions from manure and fertiliser management was 9015 and 5109 kg CO_2 eq/year in large and small-scale farms respectively this might be attributed to huge herd size owned by large-scale farmers as there is direct relation of herd size to manure produced and also, application of untreated manure in their fields. According to (FAO, 2010b) treatment of manure can significantly reduce emissions and increase productivity. IPCC 2006, stated that more emissions are obtained from zero grazing where animals are kept confined this might explain why the emissions from manure in Zimbabwe are low despite lack of manure treatment animals are left to graze in paddocks reducing piling of manure in confined areas. Moreover, manure stored as liquid decomposes anaerobically leading to high production of CH_4 whereas manure left where they are deposited decomposes aerobically thereby producing less CH_4 (IPCC, 2006). A study which was done by (Tesfahun, 2018) in Ethiopia showed total direct and indirect nitrous oxide emission per year from manure management of sampled dairy farms as 1762 and 1850 KgCO_2eq in urban and peri-urban dairy production respectively. These figures are quite lower than what was found in Zimbabwe. This huge difference might be attributed to the fact that in Ethiopia they use their manure for fuel as dry dung cake and input for crop production.

5:1:3 Emissions from Fodder, Feed and Fertiliser Production

Transportation of feed to livestock farms contribute to GHG emissions, the length of the distance determines the amount of emissions emitted with long distances causing more emissions. Also, scale of production determines amount of energy used at a farm, with more energy channelled towards feed production, inputs and machinery in zero grazing systems (Rojas-Downings, et al, 2017). This is in support with the results in this study where emissions from fodder production were 3276.6 and 1687.4 kg CO_2 equivalent for large-scale and small-scale farms respectively. It was evident during the survey that large scale farmers were using a lot of energy in production of feeds for their huge herd sizes as compared to small-scale farms. Respondents in the study sourced supplementary feeds like concentrates, mineral blocks and straight feeds in nearest towns. Distance and mode of transport are the basis used in calculating emissions from transport (Vellinga et al., 2013). The average emissions for fertiliser production were 3279.5 and 1896.2 kg equivalent CO_2 for large-scale and small-scale farms respectively. This explains the amount of forage production done in large farms as compared to small-scale farms. CO_2 eq/kg FPCM from fodder production was 0.01 and 0.13 for large and small-scale farms respectively. High milk production in large-scale farms led to low CO_2 eq/kg FPCM.

5.1.4 Emissions from all sources

Enteric fermentation has been noted as the largest source of GHG emissions from cattle and other ruminants, contributing between 43% and 63% of the livestock sector emissions (Rojas-Downings, et al., 2017). This is in agreement with results from this study enteric fermentation had high emissions contributing 70.3% and 61% for large and small-scale farms respectively. Feed production and transport had the second contribution on total GHG emissions in Kenya contributing 31.6% (Wilkes et al., 2019), this is quite similar with the trend observed in this study where off- farm feed and concentrates production was second and contributed 20.65 and 17.55% in large and small-scale farms respectively. In-terms of kg CO_2 equivalent per kg of milk farms with high milk production had low emissions than farms with low milk production. This is as shown with the results of average carbon footprint per farm for large-scale farms and small-scale farms which are 1.30 and 2.97 respectively. Average CF was 2.99 kg CO_2e/kg FPCM in Kenya with all emissions allocated to milk (Wilkes et al., 2019) which is equivalent to CF found in small-scale farms in Zimbabwe (2.97) but higher than average total in this study which was 2.3. Evidence that farming practises in small-scale farms are almost similar in Africa. The CF of milk production in small-scale farms in Anand district of India was 2.2 CO_2 eq/kg FPCM (Garg., et al, 2016), which is quite comparable with the findings in this study. CF in large-scale farms showed that there is improved climate smart agriculture adoption in large scale farms than in small-scale farms. In Ethiopia CF of 2.07 and 4.71 CO_2eq/kg FPCM was calculated in urban and peri-urban production respectively (Tezera, 2018). Again these figures are quite comparable with what was found in this study. The maximum carbon footprint per farm was 2.39 and 6.30 for large and small-scale farms respectively. The global average carbon footprint for sub-Saharan Africa is 2.4 and 7.5kg CO_2 (FAO, 2010). The carbon footprint per farm of large-scale and small-scale farms in this study fall in this range. Thornton and Herrero, (2010) predicted an increase in methane emissions in Africa due to increases in livestock populations and further stated that a change in feeding practices and manure management could moderate methane emissions.

5.3 Climate Smart Technologies

During the study mitigation measures against climate change were identified in the farms interviewed. The following categories were used to define mitigation measures: Manure Management, Fodder crops, Soil conservation, High yielding cows, Feeding concentrates, Fodder conservation, Crop residues and by products feeding. Climate smart agriculture was defined as sustainable agriculture that increases productivity, resilience and reduces greenhouse gas emissions in an effort to achieve national food security and reduce poverty (FAO, 2010b). On manure management results showed that most farmers leave manure where they are dropped by the animal that's either in the rangeland or pastures. Less effort was being put in managing manure except for a few small-scale farmers who would use manure to fertilise their other crops which are not related to dairy production. It was observed that practises like biogas production, covering of manure and composting have an impact in reducing greenhouse gas emissions and reduce ground water contamination (Misselbrook et al., 2013). Proper handling of manure can go a long way in reducing carbon footprint per farm in Zimbabwe.

Cultivation of fodder crops was identified in most farms, as most farmers have adopted the use of improved fodder. Katambora Rhodes grass, star-grass, napier (bana grass), kikuyu and a little bit of lucerne were amongst the forages identified in farms. Adoption of these forages was high in large-scale farms as compared to small-scale farms. Grasses were better adopted than legumes for example only 25% and 8% of the interviewed large and small-scale farmers respectively grow lucerne which is quite low as compared to cultivation of Rhodes grass were 42% large and 25% small had adopted growing it. However, this climate smart technology is not fully embraced in the country concluding from these percentages as most farmers prefer using their arable land for crops other than pastures. According to (Rojas- Dawnings, et al., 2017) poor forage quality can increase methane emissions per unit of gross energy consumed, hence the need to promote adoption of improved forages. Fodder conservation was observed in both scales of production hay and silage making were the main methods identified. Katambora Rhodes and star-grass were the grasses mostly used to make hay and maize for silage making. On farm climate smart technologies were identified as cultivation of improved pastures, advanced animal breeding and feed conservation strategies (Maindi et al., 2020).

Majority of dairy cattle owned by large-scale farmers is purely exotic breeds (67%) which include Friesland-Holstein and Red- Dane, while 33% own cross-breeds cattle which are crosses of exotic and indigenous breeds. Small-scale farmers own 75% of cross-bred, 17% indigenous and 8% exotic dairy animals. Improved breeds are known for their high feed conversion efficiency attribute which translates to high milk production when compared to our local breeds (Ouma et al., 2007). This explains high milk production which was observed in this study. Of particular interest was one large-scale farm with a huge herd of 1487 Red-Dane dairy breed they had high milk production of over 7000litres per cow per year. This has a positive impact in reducing greenhouse gas emissions per litre of milk produced that's kg CO_2/litre FPCM as this farm had a carbon footprint of 1.12 whilst the farm with the lowest milk production in this study had a carbon footprint of 6.91.

The use of crop residues was well practised in farms maize, wheat and soya-bean straw were among the used crop residues to feed the animals. Orange peels and brewers waste were some of the by-products which were actively used by some farmers. This mitigation measure goes a long way in addressing feed shortages during the dry season and it is a cheaper source of feed which is readily available from crop production. Residues of legume crops like soya-bean straw have better nutritional composition which might equate to low emissions and treatment of maize stover with urea can also improve the quality of these residues. This was supported by (Kitaw et al., 2016) who linked improved digestibility to straw treatment which also reduce enteric emissions. Supplementation with concentrates and straight feeds was also done by farmers in this study (92%) large and (75%) small-scale. This high use of concentrates led to such high milk production levels observed in the study.

5.4 Sustainable Business Models

The key driver of creative innovation is sustainability, transforming existing business models can be a basis of capturing new value and surviving competition (Alexandre et al., 2016). Sustainable business models must logically integrate economic, environmental, and social concerns of a firm, in this instance a dairy farm. During the study two scale of production were discovered which are Large-scale and small-scale dairy production. In the large-scale milk production linkages can be done to integrate three dimensions of sustainability. Considering huge possession of land, large-scale farmers can link with financial institutions to get funds as well as saving their own funds from their proceedings to establish processing facilities within their farms. This will go a long way in improving them economically and supplying the local market with milk made products such as cheese, yoghurts and ice-cream. Environmentally, this innovation will reduce greenhouse gas emissions from transport as well as transport costs of ferrying milk to processors. Another innovation which can go a long way in saving energy costs and emissions from manure is investing in bio-gas digesters as a way of manure management but benefiting environmentally and economically. Fully amassing fodder production for the benefit of animal feeding, sustaining the environment and developing a business by selling excess fodder to other farmers.

In small-scale dairy farming most farmers practise mixed farming whereby they grow some crops for animal and home consumption. In light of this farmers can integrate their farming systems by using manure from dairy animals to fertilise their crops and in-turn use the crops to feed the animals. These practises will make the farmer save some money by not buying fertilizers and feeds at the same time conserving the soil that's addressing environmental aspect. The other viable business linkages are to connect with institutional management for bulk selling of their milk which will enable them to have lump sum of money on their sales than individual selling. Facilitation between these farmers and customers will address mutual trust along the chain and enable farmers to have sustainable markets based on loyalty. Incorporation of the identified climate smart technologies shown in red text in table 15 and 16 will go a long way in achieving sustainable dairy farming for both small-scale and large scale farmers. Studies conducted on adoption of Climate Smart Agriculture technologies identified little awareness of climate change amongst the farmers, limited technologies which are agro-ecological specific and constraints in proving the value added by adopting these technologies (Groot, et al., 2018). Thus development of new business model in the canvas business model template can help visualise and understand benefits attached to these new interventions.

5.5 Reflection as a Researcher

Conducting this research has been a long journey full of lessons, obstacles and a lot of effort to accomplish the task. My journey started with the support of my supervisor in moulding the research problem which needed to be addressed. As climate change has been a talk all over the world and ways to mitigate the effects is still an on-going research area. I was privileged to have the commissioner being my employer in the Ministry of Lands, Agriculture, Water, Fisheries and Rural Resettlements who wanted to address the knowledge gap of the carbon footprint of dairy farms in Zimbabwe. The global pandemic of corona affected my travel back home to do my data collection in person. This left me with a choice of working with research assistants who helped me with data collection. The role of research assistants was to visit farmers on my behalf with a questionnaire I had designed and then interview the farmers guiding them in understanding the questions. Observation was another task they were to perform as well as verify the data given by doing actual measurements like on milk yields and animal weights. The data they collected was reliable to some extent after the trainings I did online with them. However, follow-up trainings were necessary after every farm visit. This was not possible due to network constraints so we ended up having conversations after a day or two of the visits verifying the data, also with the help of Key Informants.

My initial plan was to conduct this study in Mashonaland Central and Mashonaland West provinces in Zimbabwe. However, things didn't go according to my plan on the ground I ended up substituting Mashonaland West with Mashonaland East. Getting the data base of farmers to involve in the study was a very difficult task which took me a long period trying to engage different stakeholders in the dairy value chain. All these efforts were fruitless as the people involved were not forthcoming. This experience taught me to first do the ground work before leaving the country on people and all stakeholders you would want to work with in the research. This would mean having an area of study in mind before starting the Master's program. In facing all these challenges of getting farmers, the commissioner finally helped me in finding the respondents. A vital lesson I learnt in this situation was it is very important to have a strong relationship with your commissioner when doing research as they will give you full support when needed.

Logistical issues when doing research need to be properly planned to avoid delay in data collection. I realised that size of the questionnaire determines the time and depth of data one can get. My study was covering a lot of aspects at one goal which made my questionnaire very big. This did not go well with some farmers as it was consuming much of their time to an extent that they would request the research assistants to come the following day to finish data collection. This affected the quality of data collected as the farmer was left to fill the questionnaire alone without guidance of research assistant and required a lot of resources since more travelling was involved. In such instances you would find some contradicting data, which needed much verification and follow up. This experience taught me to focus mainly on one major aspect when conducting research to avoid such circumstances.

The sample size of my study ended up being 24 farms instead of 30 farms I initially planned. This was caused by all logistical constraints I mentioned earlier. The lesson I got from this is things don't always go the way we plan, sometimes there are things which are beyond our control. However, through all this as a researcher one should find ways of managing such scenarios and ensure accomplishment of the task within the given time. Doing this kind of research has enabled me to acquire new skills specifically in the use of Life Cycle Analysis (LCA) computation tool to calculate the carbon footprint. Above all, this process has taught me to be independent plan my own things, facilitate the proceedings, managing some complex situations without losing focus. It was not an easy journey but a worthwhile lesson in developing professionally.

CHAPTER 6: CONCLUSION

This chapter concludes the findings in addressing the research questions and objective of this study. The study aimed to identify climate smart practises, calculate the carbon footprint, identify existing and develop new climate smart business models in small and large-scale dairy farms. Also to note differences in GHG emissions and milk produced by small and large-scale farmers.

6.1 Farming systems and milk production

The study showed a significant difference in milk yield between the small and large-scale farms with large scale farms having an average milk production per cow/year of 4689 and 2837 kg FPCM for small-scale farms. There was also a significant difference in average herd size per farm between these two farming systems, 250 and 26 for large and small-scale farms respectively. In both provinces Mashonaland central and Mashonaland East Dairyboard Zimbabwe Limited was the common processor buying milk from the farmers. However, in Mashonaland East Prodairy was the big competitor. Large scale farmers sold all their milk through the formal market whilst small-scale farmers were selling either through formal or informal markets.

6.2 Climate smart technologies

Adoption of improved forages was slowly being embraced in both farming systems with large-scale farmers on the lead. Forage grasses were mostly grown as compared to legume forages. Although large-scale farmers owned 67% exotic breeds and 33% crossbreeds, small-scale farmers still had a very small percentage of exotic breeds. The practise of agroforestry and contouring was not common in many farms. Many farmers were utilising crop residues to feed their animals; maize stover, wheat straw, groundnut straw and soya-bean straw were among the commonly identified crop residues used in farms. Delta beverages were the main supplier of brewers waste which was used in most farms. Fodder preservation was noticed in both farming systems with hay and silage making being the major preservation practises observed. Hay was made from cultivated forage grasses, natural grasses and wheat straw. Silage was mostly made from maize. Feed scarcity during the dry season was a major problem; during this period hay, silage and concentrate feeds were used to supplement the animals. The study discovered that manure management was generally poor in all farms as no particular attention was paid to it.

6.3 Carbon footprint of milk

The average total CO_2 equivalent per kg of milk FPCM was 1.30 and 2.97 for large and small-scale farms respectively comparable with studies done in Kenya, Ethiopia and India. In both farming systems enteric fermentation emissions had a huge contribution to greenhouse gas emissions as compared to other sources of emissions. Emissions CO_2 equivalent/kg FPCM from enteric, feed, manure, off-farm fertiliser, off-farm feeds and concentrates were high in small-scale farms than in large-scale farms because of high production in commercial dairy farms. High milk production leads to less emission. However, average total CO_2 equivalent per hectare and livestock unit was higher in large scale farms than in small scale farms.

CHAPTER 7: RECOMMENDATIONS

Commissioner

- ✓ **Trainings-** In line with the findings the commissioner is advised to conduct trainings on climate smart technologies to both small and large scale farmers in order to create awareness and ensure implementation of the practises.
- ✓ **Linkages-** The commissioner is advised to create linkages with partners along the dairy value chain. In particular linking the processors and small-scale farmers to come up with strategies to increase farmer productivity, profitability whilst conserving the environment.
- ✓ **Resuscitation of milk collection centres-** The commissioner is advised to revive the use of collection centres to reduce transport problems for small-scale farmers by bulk transportation thereby reducing emissions.
- ✓ **On farm feed formulation-** Commissioner is recommended to promote on-farm feed formulation using cultivated pastures like Velvet beans and Cowpeas as protein sources. Courses on feed formulation using available packages should be availed to farmers as well as support in acquiring some of the ingredients through creating linkages with input suppliers.
- ✓ **Breeding stock-** as the centre of excellency, the commissioner is advised to conserve our local indigenous breed Mashona cattle and crossbreed with pure dairy breed like Friesland to produce dairy crosses which produce optimum milk yields and are adaptable to local climatic conditions. Then sell at subsidised prices to dairy farmers, to improve their productivity reduce emissions and mitigate effects of climate change.

Large-scale farmers

- ✓ **Proper manure handling-** Adoption of composting and use of biogas-digesters is recommended to reduce greenhouse gas emissions as well as generate energy and conserve the environment. Selling of manure can go a long way in improving the farmers economically considering the sizes of their herd of cattle.
- ✓ **Improved forages**- Cultivation of improved fodder need to be practised at a large scale and mixing of grass and legume need to be practised to improve nutrition status of the forages thereby reducing emissions.
- ✓ **Fodder conservation-** Including napier grass in silage making is advised as a way of lessening competition of maize consumption between human beings and dairy animals because of its high herbage quantities.
- ✓ **Processing –** Farms with high milk production and capacity can process their own milk, this will reduce greenhouse gases emissions from transport as well as increase profitability of the farms

Small-scale farmers

- ✓ **Improvement of productivity-** Adoption of high yielding cows can go a long way in reducing greenhouse gas emissions because of high milk production. However, a balance has to be made between high yield and adaptability to the environment hence crossbred cows with both qualities are recommended. Improving animal nutrition can go a long way in reducing enteric emissions
- ✓ **Proper manure management-** Active application of manure to the crops is recommended to cut on fertiliser costs, reduce CH_4 and N_2O emissions, conserve and improve soil nutrition.

Treating manure and selling can be a source of income which will lead to improved livelihoods.

- ✓ **Agroforestry practises-** Adopting planting of forage trees in the farms along the boundaries will help to improve animal nutrition and have a positive environmental impact. Legume trees such as *Lucaena leucocephalla* and *Accacia anguistissima* can be planted based on how they have been successfully grown in Research Institutions which are in the same region.
- ✓ **Generally-** Recommendations in red in both large and small-scale business models should be implemented.

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Annex 1: Dairy farms questionnaire

Basic Details

Date: Email/mobile number

Province: District:

Name of Farm: Agro-ecological region:

Household Information

Sex of farm owner	Male		Female											
Age														
Farm Type	Small-scale		Commercial											
Farm size	Total farm area (ha)		Ha arable		Ha buildings		Ha grassland		Ha fodder					
Level of education	Illiterate		Primary		Secondary		Certificate		Diploma		Degree			
House- hold composition	Total household members		Number of females		Number of males		Adult females		Adult males		Female children		Male children	

Herd composition	Milking cows	Dry cows	Pregnant heifers	Heifers	Steers	Bulls	Female calves	Male calves
Animal numbers								
Sales within a year								
Prizes/animal								
Age at first calving								
Total lactation days								
Average lactation days								
Average weight								
Calve birth weight								
Calving interval								
Breeding methods (AI or Bull)				Cost of breeding				
Percentage female that give birth per year								
Culling within a year								
Replacement %								
Animal Breed(local/ Exotic/ cross)								
Average milk production/cow/day (wet season)		Maximum milk production/cow/day (wet season		Average milk production/cow/day (dry season)		Maximum milk production /day/cow (dry season)		
Total milk production per year				Total number of animals culled				

Milking cow- Refer to the cows currently being milked

Dry cow- cows not being currently milked due to pregnancy or other reasons

Calving interval- a period from one calving to the next calving

Feed Intake

Type of feed /forage/fodder/stover	Estimated amount of feed/ forage given per day per animal in kgs													
	Milking cows		Dry cows		Pregnant cows		Heifers		calves		Bulls		Oxen	
	D	W	D	W	D	W	D	W	D	W	D	W	D	W

D- Dry season

W- Wet season

NB: Indicate if it is fresh or dry matter

Codes

List of forages grown on farm **(a)**	Area under each forage grown (ha)	Estimated cost of forage production (us$)	Type & quantity of fertilisers applied (kg) **(b)**	Quantity of manure applied (kg)	Yield of the forages per year (kg)	List of homemade feeds	List of bought in feeds **(c)**	Sources of inputs for forage production
Quantities of concentrate/supplements purchased (kg) per year	Distance to the source	Mode of transport for concentrates **(g)**	Cost of transportation	Sources of off-farm feeds **(d)**	Methods of fodder preservation **(e)**	Source of energy for processing homemade feeds **(f)**	Mode of transport for on and off-farm feed **(g)**	Feeding strategy **(h)**

(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)
1= Star grass 2= Silver leaf 3=Katambora 4= Bana grass/Napier 5= Rye grass 6= Brachiaria 7=Kikuyu 8=Maize stover 9=Soya bean stover 10= Wheat straw 11=Maize 12= Natural grasses 13=Lucerne 14= Other (specify)	1=Ammonium nitrate 2=Urea 3=Compound fertilizers 4=Single super phosphate 5=Double super phosphate 6= Other (specify)	1=Straight feeds 2= Concentrates 3=Mineral blocks 4=Winter blocks 5=Cotton seed cake 6= Soya bean meal 7=Sunflower cake/meal 8= Poultry waste 6=Other (specify)	1=Other farms 2= Stock-feed shops 3= Other (specify)	1=Hay 2=Silage 3=Others (specify)	1=Electricity 2= Solar 3= Diesel 4= Petrol	1=Scotch cart 2=Truck 3=Tractor 4= Wheelbarrow 5=Other (specify)	1=Zero grazing (confined) 2=Grazing 3=Pasture

Manure

Total manure produced per year	% manure applied on pasture	% manure applied on crops	Manure storage **(a)**	Total duration per storage system (months)	Total amount of manure per storage method	Manure disposal method **(b)**	Materials used as bedding **(c)**

Codes

(a)	(b)	(c)
1= Dry storage 2= Daily spread 3= Biogas 4= Solid storage 5= Compost 6=Liquid/Slurry 7= Uncovered anaerobic lagoon 8= Other (specify)	1= Applied in pasture 2=Applied in arable land (crops) 3= Left where deposited on pasture 4= Left where animals are kept 5= Sold 6= Other (specify)	1= Saw dust 2= Hay 3= Plastic sponge 4= Crop residuals 5= Waste feeds 6= Earth / cement floor 6=Others (specify)

Climate smart dairy technologies

Mitigation measures	Practices identified
Soil conservation	Crop rotation | mixed cropping | mulching | manure for crops | agroforestry | terracing | contouring | other
Fodder crops	Star grass | Bana grass | Legume pastures | Fodder trees | Other (specify)
Fodder conservation	Hay | Silage | Other (specify)
Feeding crop residues and by-products	Maize Stover | wheat straw | Soybeans/bean straw | brewers waste | Other (specify)
Feeding concentrates	Dairy meal | dairy concentrate | protein blocks | mineral blocks | Other (specify)
Water harvesting	Canals | dams | electric pumps | Other (specify)
Zero grazing	Dairy cow sheds | Other (specify)
Improved Dairy Breeds	Holstein-Friesian | Jersey | Red Dane | Cross- breeds | Ayrshire | Guernsey | Local | Other (specify)
Manure management	Composting | biogas | spread in fields | stored but not covered | Other (specify)
Low emission collection	Milk collection centre within walking distance | minimum use of energy in transporting feeds | other (specify)

<u>**Establishment, harvesting, transporting of feed crops and forages**</u>

Machinery	No of hectares ploughed/harvested	Hours/year	Litres of diesel used			
Tractor						

Combine harvester						
Vehicle Type	**Vehicle capacity**	**Distance travelled to transport feed (km)**	**Cost per rate (us$)**	**Km per single trip**	**Litres of fuel per trip**	**Frequency**
Isuzu						
Motorbike						
Truck						
Wheel barrow						
Scotch cart						
Other (specify)						

Litres of fuel required to plough 1 ha of land

Litres of fuel required to harvest 1 ha of cereal crop/ forage

Annex 2: Farm characteristics and milk production

	Milk prod Litres/year	**Milk prod FPCM**	**Farm land (Ha)**	**Herd size**	**Milking Cows**	**Milkyield/cow/year Litres**	**Milk yield/cow/yr FPCM**	**LU**	**Prod/ha**
AVE	376298	376440	78.4	137.6	67.9	3829	3763	113.1	3392.0
min	7260	6910	8.5	9.0	4.0	788	750	7.1	172.7
max	5146988	5159753	418.0	1487.0	721.0	7139	7156	1279.6	12921.4
sd	1034691	1037522	101.1	299.6	144.8	1776	1774	257.2	3870.9
AVE1	721373	723162	123.9	249.6	124.1	4677	4689	206.2	5681.5
Min1	70470	70645	20.0	53.0	27.0	2430	2436	39.8	1136.8
Max1	5146988	5159753	418.0	1487.0	721.0	7139	7156	1279.6	12921.4
Sd1	1406493	1409981	128.9	400.2	192.2	1272	1275	345.4	4391.0
AVE2	31223	29717	32.9	25.6	11.8	2981	2837	19.9	1102.5
Min2	7260	6910	8.5	9.0	4.0	788	750	7.1	172.7
Max2	76860	73152	51.0	47.0	22.0	6100	5806	37.0	2848.1
Sd2	21685	20639	15.3	13.3	5.5	1846	1757	9.6	782.1

Annex 3: Amount of fertilisers and manure applied

Farm	Amount of AN(kg)	Amount of N from AN	Kg CO2-eq from AN production	Amount of compound D (kg)	Amount of N from C D (kg)	kg CO2-eq from CD production	Amount of Urea (kg)	Amount of N from Urea (kg)	Kg CO2-eq from urea production	Total kg CO2-eq/yr from production of mineral fertilizer	Amount of N from manure
Large											
Average	2209	689	2973	3320	194	172	50	25	134	3279	879
Minimum	0	0	0	0	0	0	0	0	0	0	140
Maximum	10 000	3400	14681	20000	1400	1245	600	276	1612	15926	6245
Std Dev	2733	912	3939	6011	391	348	173	83	465	4352	1700
Small											
Average	1175	400	1725	1823	128	104	27	0	67	1896	72
Minimum	0	0	0	0.0	0.0	0.0	0	0	0	0	0
Maximum	4000	1360	5872.5	8000.0	560.0	497.8	300	138.0	806	6370	197
Std Dev	1367.89	465.08	2008.23	2857.04	199.99	172.65	90.45	39.84	232.73	2213.68	59.73
Overal Av	1670	544	2349	2536	162	138	39	18	101	2588	476

Annex 4: Independent Samples Test on Farm characteristics and Milk production

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Farm size	Equal variances assumed	14.529	.001	2.430	22	.024	91.04167	37.46716	13.33954	168.74379
	Equal variances not assumed			2.430	11.310	.033	91.04167	37.46716	8.85172	173.23162
Herd size	Equal variances assumed	5.459	.029	1.938	22	.066	224.00000	115.58874	-15.71637	463.71637
	Equal variances not assumed			1.938	11.024	.079	224.00000	115.58874	-30.34038	478.34038
Milking cows	Equal variances assumed	5.158	.033	2.024	22	.055	112.33333	55.49237	-2.75079	227.41746
	Equal variances not assumed			2.024	11.018	.068	112.33333	55.49237	-9.78035	234.44702

Milk yield per cow	Equal variances assumed	3.094	.093	2.954	22	.007	1851.25000	626.64811	551.66135	3150.83865
	Equal variances not assumed			2.954	20.066	.008	1851.25000	626.64811	544.36007	3158.13993
Farm milk production	Equal variances assumed	4.684	.042	1.704	22	.103	693445.91667	407070.02894	-150765.65311	1537657.48645
	Equal variances not assumed			1.704	11.005	.117	693445.91667	407070.02894	-202462.35647	1589354.18981
Livestock unit	Equal variances assumed	5.217	.032	1.868	22	.075	186.28333	99.73824	-20.56113	393.12779
	Equal variances not assumed			1.868	11.017	.089	186.28333	99.73824	-33.19786	405.76452
Production per hectare	Equal variances assumed	32.890	.000	3.557	22	.002	4579.08333	1287.50432	1908.96281	7249.20386
	Equal variances not assumed			3.557	11.697	.004	4579.08333	1287.50432	1765.77450	7392.39216

Annex 5: Independent Samples Test on GHG emissions

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Enteric emissions	Equal variances assumed	8.133	.009	-2.884	22	.009	-.88917	.30832	-1.52858	-.24976
	Equal variances not assumed			-2.884	13.472	.012	-.88917	.30832	-1.55288	-.22546
Manure and Fertiliser Management emissions	Equal variances assumed	28.247	.000	-3.646	22	.001	-.29742	.08157	-.46658	-.12825
	Equal variances not assumed			-3.646	11.419	.004	-.29742	.08157	-.47615	-.11869
Fodder production	Equal variances assumed	10.641	.004	-1.645	22	.114	-.12283	.07469	-.27772	.03206
	Equal variances not assumed			-1.645	11.052	.128	-.12283	.07469	-.28712	.04146

Fertiliser production emissions	Equal variances assumed	13.834	.001	-1.902	21	.071	-.15451	.08121	-.32340	.01439
	Equal variances not assumed			-1.818	10.023	.099	-.15451	.08500	-.34384	.03483
Off-farm feeds	Equal variances assumed	7.844	.010	-1.899	22	.071	-.26500	.13953	-.55437	.02437
	Equal variances not assumed			-1.899	13.704	.079	-.26500	.13953	-.56487	.03487

Annex 6: Images from the field work

Hay bales transported by scotch-cart