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Addis Ababa University

College of Development Studies

Centre for Environment and Development

Climate Smart Dairy Farming Practices for Greenhouse Gas Mitigation and Food Security Benefits in the Selale Highlands of Ethiopia

A dissertation submitted to Addis Ababa University, College of Development Studies, Center of Environment and Development, in partial fulfilment of the requirements for the Doctor of Philosophy in Development Studies degree (Environment and Development)

By

Abraham Abera Feyissa

Advisors:

Feyera Senbeta (PhD, Professor)

Adugna Tolera (PhD, Professor)

Dawit Diriba (PhD, Associate professor)

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Addis Ababa, Ethiopia

Declaration

I, the undersigned, certify that this is my original work, that it has never been presented at this or any other university, and that all resources and materials used in the dissertation have been properly acknowledged.

Name: Abraham Abera

Signature:


Date: May, 2023

Addis Ababa, Ethiopia

Date of Submission: _____

This dissertation has been submitted for examination with my approval as the student's supervisor.

Name: (Feyera Senbeta, Professor)

Signature: 

Date: _____

Dedication

I dedicate this work to late parents, Abera Feyissa and my mother Kebebush Kinati, who raised me with affection and love and were instrumental to my success.

They may rejoice on this day from on high!

Statement of author

This dissertation is structured based on the following chapters, which have been published or are submitted for publication in peer-reviewed scientific journals: Abraham Abera Feyissa was/is the corresponding author of these papers. During the writing process, the supervising team contributed their opinions on the papers' structure, editing, and review. The list paper below shows the current track status and publication. Because the manuscripts are separate and are submitted to different journal publishers, the articles or manuscripts should be formatted according to the requirements of the respective journal and publisher.

List of Papers

- Paper I.** Abraham A. Feyissa, Feyera Senbeta, Adugna Tolera, Dawit Diriba, 2022. Variability in Carbon Footprint of Smallholder Dairy Farms in the Central Highlands of Ethiopia. Published, (Published by Springer Ltd. * Tropical Animal Health and Production). Available at: <https://doi.org/10.1007/s11250-022-03379-1>
- Paper II.** Abraham A. Feyissa, Feyera Senbeta, Adugna Tolera, Dawit Diriba, 2022. Unlocking the potential of Smallholder Dairy Farm: Evidence from the central high lands of Ethiopia. Published, (Published by Elsevier Ltd. Journal of agriculture and food research). Available at: <https://doi.org/10.1016/j.jafr.2022.100467>
- Paper III.** Abraham A. Feyissa, Feyera Senbeta, Adugna Tolera, Dawit Diriba, Developing country specific enteric methane emission factors and its response to farming systems dynamics in the Central Highlands of Ethiopia. Under review (Springer * Journal of Carbon Balance and Management)
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Abbreviation and Acronyms

ATT	Average treatment effect
BCS	Body Condition Score
° C	Degree centigrade
CC	Climate Change
CCV	Climate Change and Variability
CH ₄	Methane
CO ₂	Carbon Dioxide
CF	Carbon Foot Prints
CSA	Central Statistical Agency
CSA	Climate Smart Agriculture
CRGE	Climate Resilient Green Economy
CSLF	Climate Smart Livestock Farming
DM	Dry Matter
DMD	Dry Matter Digestibility
ECM	Milk Energy Content
EF	Emission Factor
EI	Emission Intensity
ERM	Endogenous Switching Regression Model
EPCC	Ethiopia Panel on Climate Change
EPE	Environment Policy of Ethiopia
FAO	Food and Agriculture Organization
FGD	Focus Group Discussions
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GTP	Growth and Transformation Plan
ha	Hectare
HDDS	Household Diet Diversity Score
HFCS	Household Food Consumption Score
IPCC	Intergovernmental Panel for Climate Change

ISO	International Standard Organization
KII	Key Informant Interview
LCA	Life Cycle Assessment
LW	Live Weight
m.a.s.l	Meters above sea level
N ₂ O	Nitrous Oxide
NAMA	Nationally Appropriate Mitigation Action, Ethiopia
NAPA	National Adaptation Program of Action, Ethiopia
NMA	National Meteorological Agency
PA	Peasant Association
PPS	Probability Proportional to Size
SF ₆	Sulphur hexafluoride
TLU	Tropical Livestock Unit
UNDP	United Nation Development Program
UNFCCC	United Nations Framework Convention on Climate Change
VFA	Volatile Fatty Acid
VIF	Variance Inflation Factor
WMO	World Meteorological Origination
ZLP	Zonal Livestock Production

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General Abstract

Globally, there is a rising pressure on livestock production to boost productivity in order to increase income and food security, reduce GHG emissions, and strengthen farmers' resilience to climate change effects. The overall objectives of this study were to investigate the economic and environmental benefits of climate-smart livestock farming, with particular emphasis on smallholder dairy farms, as well as the factors influencing the adoption of improved dairy technologies in the Selale milk belt, central highland of Ethiopia. The present study adopts a mixed research design with data from household surveys, livestock activity, and biological data. The econometric model, principal component analysis, lifecycle assessment, ANOVA, and IPCC Tier II were employed for data analysis. The result showed that most farmers had modest awareness and perceptions of climate-smart dairy farming practices and expressed a positive attitude towards reducing GHG emissions from animal agriculture and a willingness to adopt or promote the farming practices. Resource constraints, supply chain bottlenecks and market linkages, inadequate services, and a scarcity of information on dairy management have been reported as hindering improved dairy technology adoption and implementation in the study area. The adoption of a few or an integrated package of improved practices had significant impacts on farmers' food security. The overall average carbon footprints (CF) of milk production were 1.91 and 2.35 kg CO₂e/kg fat and protein corrected milk (FPCM) (IPCC (2007) and IPCC (2014) GWPs), respectively, and have shown significant variation across farming systems. Enteric methane emissions using IPCC Tiers have shown up to 22.1% and 59.6% lower than the IPCC's (2019) default emission factors for dairy cows and other cows, respectively. Methane emission intensity has shown significant variation across the intensification gradients. Finally, our findings concluded that using climate-smart dairy practices would increase animal productivity, reduce GHG emissions, and enhance farmers' food security, thereby contributing to the country's suitable development goal.

Key words: Climate smart, Dairy farm, Food security, Greenhouse gas emissions, Selale

Chapter One

1. General Introduction

1.1 Background of the Study

The global livestock value chain employs 1.3 billion people, contributes 40% of the agricultural GDP, and provides a living for 1 billion of the world's poor (FAO, 2016). Livestock products provide one-third of the protein consumed by humans. According to Udo et al. (2011), livestock plays a vital role in ensuring food security, providing services, contributing to asset, social, cultural, and environmental values, and sustaining livelihoods throughout the tropical country.

In Ethiopia, livestock has a considerable role in sustaining the livelihoods of millions of resource-poor farmers in diverse environments, ranging from pastoral and agro-pastoral systems of the lowlands to mixed farming systems of the highlands (Shapiro et al., 2017). Ethiopia is home to Africa's largest cattle population, currently estimated at 65 million cattle, and is endowed with a diversified breed and different production systems (CSA, 2020). The sector can significantly contribute to the country's national growth and development plan, including poverty alleviation, by improving the livelihoods of smallholder farmers (Gizaw et al., 2016; Tegegne et al., 2013). According to Shapiro et al. (2017), the livestock industry generates 19% of the nation's GDP and 16–19% of the nation's foreign exchange profits. The sector contributes about 35% of agricultural GDP or 45% when indirect contributions are taken into account. Milk production from dairy cattle remains one of the most important economic sectors in Ethiopia.

Like most Tropical countries, smallholder dairying plays an important role in income generation and job creation and contributes greatly to poverty alleviation, household nutrition, and food security in Ethiopia (FAO-NZAGRC, 2017; Mihiret et al., 2017). Smallholder dairy farming, which is defined here as the production, on-farm processing, and marketing of milk and milk products (Gizawu et al., 2017), is responsible for 98% of the total milk production share of dairy cattle for national annual milk output (FAO-NZAGRC, 2017). Smallholder dairying is practiced to supply milk for the family's use and for sale, manure to support crop production, and dairy animals for insurance, emergency monetary requirements, and social status (Tegegn et al., 2013; Gizaw et al., 2017).

On the other hand, the livestock value chain is a substantial source of global greenhouse gas (GHG) emissions due to the production of carbon dioxide (CO₂), methane (CH₄), and nitrous oxide (N₂O). According to Steinfeld et al. (2006) and Thornton and Herrero (2010), the sector is responsible for up to 18% of the world's greenhouse gas (GHG) emissions. More than half of these (65%) are related to cattle (Andeweg and Reisinger, 2014). Additionally, livestock is responsible for a considerable portion of all anthropogenic greenhouse gas (GHG) emissions, accounting for 80% of all agricultural non-CO₂ emissions (Tubiello et al., 2013). Carbon dioxide (CO₂) from changes in land use (feed production, deforestation) is one of the main sources and types of greenhouse gases produced by livestock systems; nitrous oxide (N₂O) from manure and slurry management accounts for 31%; and methane (CH₄) production from ruminants accounts for 25% of emissions. Ruminant livestock represents 80% of total livestock-related GHG emissions (Dourmad et al., 2008; Hristov et al., 2013).

Globally, the energy sector is responsible for 34% of all greenhouse gas emissions, followed by industry (24%), agriculture, forestry, and land use change (AFOLU) (21%), transportation (14%), and building operations (6%) (Lamb et al., 2021). While AFOLU accounts for up to 87% of Ethiopia's anthropogenic GHG emissions, the agriculture and forestry sectors produce 50% and 37% of the emissions, respectively (CRGE, 2011; EPPC, 2015). More than 40% of the emissions in agriculture come from the production of livestock, while deforestation is the leading cause of emissions in forestry (IPCC, 2007b, 2014; FAO-NTZ, 2017). Ethiopia's CH₄ emissions are estimated to be 52 metric tonnes of CO₂ equivalent based on recent statistics from the World Bank, and the cattle industry is responsible for 45% of these emissions. Cattle, which are used for meat, dairy products, and draught animals as well as being valued as financial assets, contribute most to GHG emissions. According to a report by the Global Methane Initiative, Ethiopia's cattle industry has one of the biggest potentials for reducing CH₄ emissions, as well (Global Methane Initiative, 2011).

Contrarily, livestock production in general and dairy farming, in particular, are the most vulnerable sectors to climate variability, and countries whose economies mainly depend on agriculture (crop production and livestock rearing) are considered to be the most vulnerable to the impacts of climate change (IPCC, 2014b, 2015; FAO and ECA, 2018). Empirical evidence has shown that the country has experienced and is already suffering from intense and frequent

extreme events such as erratic rainfall, rising temperatures, droughts, floods, disease outbreaks, and pests (WB, 2006; NMA, 2007; Bewket et al., 2015; MEF, 2015). This has resulted in diminishing the quantity and quality of water and forage resources, thereby leading to declined productivity and the death of livestock, which is the basis for smallholder livelihoods (Teso et al., 2012; Wako et al., 2017).

Given the expected fast increases in the Ethiopian population to almost 190 million in 2050, urbanization doubling to nearly 40%, and diet upgrades (UN, 2018), dairy production and consumption value chains face tremendous challenges in increasing productivity and mitigating greenhouse gas (GHG) emissions as well as enhancing resilience to climate change (FAO and NZGRC, 2017; FAO, 2018a; FAO, 2019b). For smallholder farmers, the growing demand for dairy products represents both despair and hope. On the one hand, the condition will provide incentives for dairy farming households to expand their farming, increase productivity through intensification, and use their animals as a means of poverty reduction. On the other hand, maintaining the current model of production while supplying future food demand will lead to serious environmental issues. So, to solve the interconnected challenges of food security, poverty reduction, and climate change without depleting natural resources, animal agriculture must undergo a considerable shift in the next decades (FAO and NZGRC, 2017; FAO, 2018a; FAO, 2019b).

Therefore, it is necessary to identify and characterize the improved dairy farming practices that have lower environmental footprints and are resilient to climate change without considerably compromising animal productivity. These are the core pillars of Climate Smart Dairy (CSD) to transform agriculture by concurrently increasing productivity, reducing GHG emissions, and enhancing resilience (FAO, 2010a; Campbell et al., 2014). This can be achieved by estimating and comparing the GHG emissions from different dairy production systems with different levels of intensification, in addition to comparing their economic benefits. Additionally, understanding how GHG emissions vary across various farming systems helps in identifying production systems that help in the sustainable intensification of dairying, which increases productivity while reducing GHG emissions, and is resilient to climate change (Van de Steeg and Tibbo, 2012).

The Global Livestock Environmental Assessment Model Interactive (GLEAM-i) is an effective tool for estimating the environmental footprint of different livestock systems, ex-ante (FAO, 2020; FAO and NZGRC, 2017a; 2017b). Three methods for calculating methane emissions have also been established by the Intergovernmental Panel on Climate Change (IPCC), ranging from the simple Tier I to more complex Tier II and Tier III approaches. Tier I approach uses default emission factors and livestock population to estimate enteric methane emissions, which do not account for possible differences in CH₄ emissions between cattle of different breeds, ages, and physiological states or differences in intake levels and diet compositions. Tier II approaches require more detailed activity data on animal and feed characteristics to be used in developing emission factors, while the Tier III approach uses region-specific EFs which are commonly built on years of research in that region.

The IPCC Tier II approach can be suitable for the estimation of GHG emissions from dairy cattle in smallholder dairy farms because it generates region-specific enteric methane emission factors. By using this method, more precise environmental footprints that are important for creating Nationally Appropriate Mitigation Actions (NAMAs) and Low Emission Development Strategies would be produced. So far, however, despite the economic and environmental importance, and the huge number of cattle populations in Ethiopia there has been limited information about the environmental impacts of dairy cattle farming in the context of contemporary global warming. The present study, therefore, is designed to examine the role of improved dairy farming practices in reducing GHG emissions and explore the existing mitigation options to reduce GHG emissions while improving livestock productivity in Ethiopia. Furthermore, it aims to address farmer knowledge, attitude, and perception as well as determinants of the adoption of climate-smart dairy farming practices in the Selale Highlands, central Ethiopia. The Selale milk belt, the country's leading dairy development area, has a long history of dairy development dating back to the introduction of modern dairy cows some 60 years ago (Brandsma et al., 2013). The most recent data from North Showa showed that the area holds a high percentage of crossbreds (20%) and easy access to artificial insemination (NSZA, 2020). The area is known for its high production potential and serves as the major milk supplier to the more affluent population in the capital, Addis Ababa (Brandsma et al., 2012; Zijlstra et al., 2015).

1.2 Problem Statements

The development of GHG emission reduction strategies from animal agriculture has become an increasingly prominent global issue. Generating accurate data on the carbon footprints (CF) of milk production is therefore essential for identifying key sources and effective mitigation strategies. Here, the term "carbon footprint" refers to the estimation of GHGs that are directly or indirectly related to a process or product, as well as the conversion of GHGs to carbon dioxide equivalents (CO₂e) based on their potential to cause global warming. Considering the forging, it is advised to develop country-specific Tier II enteric methane emission factors (EF) for Sub-Saharan Africa with a significant cattle population to quantify the effect of future interventions on baseline emissions. Several challenges, however, hamper the generation of robust and valid estimates of GHG emissions from smallholder cattle systems in Ethiopia. Data on Ethiopian emissions, for instance, are scarce and, when they are available, are based on global default Tier I emissions factors (IPCC, 2006) that don't take local farming practices into account.

In addition, ruminant animals in various agro-ecologies and production systems have different access to different types and quantities of feed, leading to different levels of production, excretion, and greenhouse gas emissions (Herrero et al., 2008; Opio et al., 2013). Similarly, Herrero et al. (2008) noted that the spatial distribution of GHG produced by ruminants varies considerably depending on their location since the diet depends largely on agro-ecology and the type of production system in which the animals are kept. The use of location-specific data for livestock CH₄ emissions assessment is pertinent in light of dynamic husbandry practices and feed resources (Jo et al., 2015).

While it is beyond doubt that there are several studies designed to investigate the environmental benefits of improved dairy farming practices globally, only a limited attempt has been made in Ethiopia. The comprehensive work of Opio et al. (2013) evaluated the GHG emissions from ruminant supply chains, which is believed to enable the understanding of emission pathways and hotspots. This work would be a fundamental and initial step to identifying mitigation strategies and informing public debate. It is also much more important to mention the work of De Vries et al. (2017) in West Java, Indonesia, which demonstrated the current level of GHG emissions and

land use of dairy farms and evaluated the potential effects of feeding and manure management interventions on GHG emissions and land use by using life cycle assessment. It is also much more important to mention the extensive work of Du Toti et al. (2017) and O Ndung'u et al. (2019), who designed to develop country-specific greenhouse gas emission factors for South Africa and Kenya livestock on Tier II level and to identify possible mitigation strategies for extensive livestock production systems. It is noteworthy to mention the intensive work of de Varis et al. (2016) and Wassei et al. (2022) in Ethiopia, which relied on small sample sizes and secondary data, respectively.

Ameliorating the benefits and impacts of improved dairy technologies on farmers' food security would be important in designing efficient dairy development, policy, and program interventions. Furthermore, it is important to understand why smallholder farmers don't adopt these new technologies and what factors influence their decision-making. There has been, however, little attention given to the adoption and impact analysis of improved dairy farming practices despite the numerous benefits of dairy technologies and government efforts to encourage smallholder farmers. A majority of previous studies analyzing technology adoption and impact have either focused on improving agricultural practices (improved agronomic practices, soil and water conservation, etc.) (Minale et al., 2024; Moti et al., 2016; 2018) or ignored the scale effects of technology adoption, which can be interrelated and provide better outcomes if they are adopted together (Melesse and Jemal, 2013; Chelkeba et al., 2016; Kebebe et al., 2017; Hadush, 2021).

In addition, farmer knowledge attitude and perceptions (KAP) of environmental issues and their risks are vital for tailoring initiatives to improve the environmental performance of agriculture (Greiner et al., 2009; Deressa et al., 2011; Yazdanpanah et al., 2014). Farmers' KAP may influence their willingness to participate in climate change measures and GHG emission reduction programs (Greiner et al., 2009; Yazdanpanah et al., 2014; Kibue et al., 2015). However, there is a paucity of information regarding farmers' willingness and awareness of climate-smart dairy farming practices. Several KAP studies so far have focused on improved agronomic practices and natural resource management (Kassai et al., 2015; Mije et al., 2015; Jaleta et al., 2016; 2018; Wekesa et al., 2018). Hence, the present study is intended to examine farmers' KAPs about CSD farming practices, farmers' decisions to adopt the improved practices,

and their impacts on farmers' food security to come up with recommendations that could assist in establishing environmentally friendly dairy practices.

Therefore, it is based on these premises that the present study is designed to examine the environmental impacts of animal agriculture from cradle to farm gate, variability across production dynamics, and mitigation options to realize a climate-resilient green economy in the mixed crop-livestock farming system in Selale Highlands, North Shewa. Beyond quantifying GHG emissions, a thorough understanding of the existing production systems and their effects on GHG mitigation is quite important for the development of baseline information and appropriate mitigation and adaptation strategies in Ethiopia. Similarly, as interest in improved dairy farming practices grows, this study's output would contribute to the limited evidence on factors affecting farmers' adoption decisions and the economic and environmental merits of smallholder dairy farming.

1.3. Objectives

1.3.1. General Objective

The overall objectives of this study were to examine the environmental and economic benefits of the improved practices in the Selale highlands of Ethiopia.

1.3.2 Specific Objectives:

The specific objectives of the study were to:

- ❖ Analyze farmers' knowledge, attitudes, and practices (KAP) and their determinants in their adoption of climate-smart dairy farming.
- ❖ Investigate the effects of improved smallholder dairy farming practices on farmers' food security in Selale highlands of Ethiopia.
- ❖ Examine the variability in the carbon footprint of smallholder dairy farms in the Central Highlands of Ethiopia.
- ❖ Develop country-specific enteric methane emission factors and their response to farming system dynamics in the study area.

1.4 Research Questions

The leading questions for the present study are:

- What factors influence farmers' KAP of climate-smart dairy practices and its determinants? What are the main barriers to the adoption of CSD farming practices?
- How do CSD farming practices affect farmers' food security? Which improved package has the greatest impact on food security?
- How do CSD farming practices affect GHG emissions and emissions hotspots? Which farming practices are better for the environment?
- How does the estimation of enteric methane emissions using IPCC Tier II differ from the default emission factors?

1.5 State-of-the-art of climate change and livestock production

1.5.1 Cause of Climate Change

Climate change has emerged as a critical issue in a variety of developmental, environmental, social, and political forums at the grassroots, national, regional, and international levels in recent years (IPCC, 2007b, 2014a; FAO, 2008). Natural factors such as changes in the Earth's orbit around the sun, volcanic eruptions, ocean currents, and even periods of increased or decreased solar activity are thought to play a role in climate change. However, since the mid-twentieth century, anthropogenic greenhouse gas emissions, largely driven by economic and population growth, have resulted in atmospheric concentrations of carbon dioxide, methane, and nitrous oxide, which have been the dominant causes of observed global warming (WMO, 2009; Gerber et al., 2013; IPCC, 2014). Observations from global measurement stations and historical reconstructions of atmospheric composition clearly show that human activities have increased atmospheric concentrations of carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), and various halocarbons (HCFCs and, until recently, CFCs) (MacCracken, 2001).

Carbon dioxide, the leading GHG, has increased from 280 parts per million by volume (ppm) in pre-industrial times to 370 ppm today, which is 30%–40% higher than its pre-industrial value, and it is estimated that the concentration will range between 540 and 970 ppm in the year 2100 if current trends continue (MacCracken, 2001; WMO, 2009; Gerber et al., 2013). This increase has been due primarily to the combustion of fossil fuels, deforestation (the release of carbon into the atmosphere caused by the burning and decomposition of forests), and ploughing of soil for agriculture. The concentration of CH₄ has increased by more than 150% (MacCracken, 2001), owing primarily to ruminant livestock, biomass burning, landfills, and the development, transmission, and combustion of fossil fuels (MacCracken, 2001; IPCC, 2007b; Gabler et al., 2009). The increase in N₂O concentration is primarily due to agriculture (IPCC, 2007a).

Despite an increasing number of climate change mitigation policies, total anthropogenic GHG emissions increased from 1970 to 2010, with larger absolute increases between 2000 and 2010 (IPCC, 2014a). According to the IPCC (2014), CO₂ emissions from fossil fuel combustion and industrial processes contributed approximately 78% of the total GHG emissions increase from 1970 to 2010, with a similar percentage contribution for the increase from 2000 to 2010.

1.5.2 Climate Change Impacts

The impacts of climate change on biological and environmental systems are already being felt and are expected to have wide-ranging impacts on biodiversity, water availability, agricultural production, and food security, and this makes the issue a priority at the local, regional, and international levels (UNFCCC, 2007; IPCC, 2007b, 2012, 2013). In some cases, these changes impose new challenges while exacerbating existing ones. The magnitude of such changes and their negative consequences are not uniform across the globe, with lower latitudes experiencing far more negative consequences. More importantly, the effects of rising average temperatures, variability in rainfall, and an increase in the frequency and severity of droughts are undeniably worse in the tropics than in temperate regions (IPCC, 2007b, 2014b). Furthermore, climate risks are unequally distributed and generally worse for people who rely on natural resource sectors, such as coastal, agricultural, pastoral, and forest communities; and those experiencing multiple forms of inequality, marginalisation, and poverty are the most vulnerable to them (WMO, 2021; IPCC, 2007b, 2014b). The situation is intolerable for African countries whose economies are

largely dependent on rain-fed agriculture, which has low input and output and is thus highly susceptible to climate change because their economy is climate sensitive (Chauvin et al., 2012). The IPCC report predicts that even with a 1-2.5°C temperature increase, there will be serious consequences such as reduced crop yields and food security in tropical areas, the spread of climate-borne diseases such as malaria, an increased risk of water stress in Africa, and an increased risk of biodiversity extinction (IPCC, 2007b, 2014b).

Although no country is immune from climate change impacts, poor countries, which contributed the least to the problem, are the most vulnerable and the least likely to adapt to its impacts (IPCC, 2007b; UNFCCC, 2007; Niang et al., 2015). Previous research showed that Sub-Saharan Africa is one of the region's most vulnerable to and most affected by the impacts of climate change (Conway and Schipper, 2011; Daron, 2014). In the region, small-scale farmers and pastoralists are among the most vulnerable communities to these impacts because of their direct dependence on climate and natural resources, relative poverty, and often poor access to support systems and safety nets (IPCC, 2007b; UNFCCC, 2007; Niang et al., 2015). The IPCC predicted that millions of poor people in developing countries would face greater risks of climate-borne disease and shortages of water and food over the next few decades as a result of a changing climate (IPCC, 2007b).

According to historical trends and scientific research, Ethiopia is the most vulnerable country to the effects of climate change (NAMA, 2007; Conway and Schipper, 2011; EPCC, 2015). The country has already experienced climate change-related hazards such as drought, erratic rainfall, frost, and heat waves, as well as their consequences. However, the limited economic, infrastructure, and institutional capacity of the country to mitigate and adapt to climate change and variability exacerbates the vulnerability of farmers and pastoralists to climate change-induced hazards (NMA, 2007; ONRPPACC, 2010; Conway and Schipper, 2011; MEF, 2015). Recurrent draught and erratic rainfall are the two most important manifestations of extreme events related to climate change in Ethiopia (World Bank, 2006; Oumer et al., 2007; Funk et al., 2012; Mahoo et al., 2013; MEF, 2015; USAID, 2016).

1.5.3 Livestock Nexus Climate Change

1.5.3.1 Climate Change Impacts on Livestock Production

Livestock is a valuable asset for people in mixed crop livestock, agro-pastoral, and pastoral systems, serving multiple economic, social, and risk management functions (Azage Tegegne et al., 2013; B. Shapiro et al., 2015; Gizaw et al., 2016; FAO-NZAGRC, 2017). However, livestock production is currently under increasing pressure due to a variety of stressors such as climate change, grazing land fragmentation, insecure communal land rights, human population growth, and market failures. According to the IPCC (2007a) and UNFCCC (2007), changes in the frequency and severity of extreme climate events will have a negative impact on crop and livestock productivity, as well as poor farmers' food production and food security. For example, in the recent past, the impact of climate change on livestock in Ethiopian lowlands has resulted in a large number of livestock losses, and as a result, pastoralists whose livelihood is primarily dependent on livestock have become food insecure (Amsalu and Adem, 2009; Berhanu and Beyene, 2014; Megersa et al., 2014). According to Steeg and Tibbo (2012), the effects of climate change on livestock can be explained by animal productivity, animal health, feed supply quality and quantity, heat stress, and pasture carrying capacity. Indeed, scholars from various disciplines have documented that climate change and variability can severely limit animal productivity by reducing water availability, forage production, and quality, and thus pastureland carrying capacity (Angassa and Oba, 2007; Berhanu et al., 2007; Homann et al., 2008; Tache and Sjaastad, 2010).

1.5.3.2 Global Livestock GHG Emissions

On the contrary, global warming has become a more public issue in livestock farming in recent years as a result of alarming UN reports and the popular documentary *Cowspiracy* (Steinfeld et al., 2006; Andersen and Kuhn, 2014), which show that animal agriculture is responsible for considerable global GHG emissions. The livestock sector is responsible for 18% of anthropogenic GHG emissions (37% of anthropogenic CH₄ emissions and 65% of N₂O emissions), using a 100-year global warming potential (GWP) (Steinfeld et al., 2006). Livestock contributes to global warming by emitting GHG either directly (e.g., from enteric fermentation

and manure management) or indirectly (e.g., from feed-production activities and the conversion of forest into pasture). Feed production and processing and enteric fermentation from ruminants account for 45 and 39 percent of sector emissions, respectively, while manure storage and processing account for 10 percent. The remainder is attributable to the processing and transportation of animal products (Gerber et al., 2013). From livestock production, beef and cattle milk production account for the majority of emissions, respectively contributing 41 and 20 percent of the sector's emissions (Steinfeld et al., 2006; Gerber et al., 2013).

The indispensable and eye-opening work of Steinfeld et al. (2006), entitled "*Livestock's Long Shadow: Environmental Issues and Options*," suggested that the livestock sector should be a major policy focus as the sector emerges as one of the top two or three most significant contributors to the most serious environmental problems, at every scale from local to global. Reducing the increase in GHG emissions from agriculture, especially from livestock production, should therefore be a top priority because it could limit global warming substantially and faster (Sejian et al., 2011). As a consequence, livestock management alterations have been argued to have significant potential for mitigating atmospheric GHGs and reducing future climate change (Steinfeld and Wassenaar, 2007). Indeed, livestock emission reduction opportunities include managing grazing land resources, changing feeding practises, improving animal manure treatment or use, changing animal product processing and transportation, and changing species and breeds in animal production (Steinfeld et al., 2006; Gerber et al., 2013). Owing to the aforementioned problems, scenarios, and solutions suggested, the issue of mitigation and adaptation of the livestock sector to climate change and variability is unquestionable in Ethiopia, which has Africa's largest livestock population.

1.5.3.3 National livestock GHG missions

An increase in global atmospheric temperature has been attributed to an increase in the concentration of greenhouse gases in the atmosphere, an occurrence known as global warming (IPCC, 2007b; FAO, 2008). A significant amount of the global GHG emissions currently comes from enteric fermentation and animal manure from traditional smallholder mixed farms in developing countries (Steinfeld et al., 2006; IPCC, 2007b; FAO, 2008). Indeed, Ethiopia's GHG emissions per capita are very low when compared to other countries: 1.3 tonne

CO₂e per capita, which is one-fifth of the global average (6.3 tonne CO₂e per capita) and lower than the sub-Saharan African average (CRGE, 2011; EPCC, 2015). Ethiopia's GHG emissions are dominated by agriculture and forestry, which account for 85% of total emissions. Within the agricultural sector, livestock production is the largest source of emissions, accounting for 80% of total agricultural emissions. The livestock production system directly contributes to global climate change by producing CH₄ from enteric fermentation and both CH₄ and nitrous oxide (N₂O) from manure management (CRGE, 2011). Cattle, which are used for meat, milk, and as draught animals, are the major contributors to GHG emissions among Ethiopian livestock species. Cattle production currently accounts for 84 percent of livestock emissions (CRGE, 2011); their water footprint per tonne is more than three times that of small ruminants and poultry; and grasslands account for 40 percent of land (FAO, 2016a).

Ethiopia has over 65 million cattle, producing over 3.8 billion litres of milk (FAO-NZAGRC, 2017) and approximately one million metric tonnes of beef per year (Shapiro et al., 2015). According to available projections, beef and milk consumption will increase by 53 to 193 percent and 115 to over 750 percent, respectively, over the next 35 years, with any difference explained by the underlying models and datasets (FAO, 2017; GPS, 2017). Given current practises, the cattle population is likely to increase from today's around 65 million (CSA, 2020) to more than 90 million in 2030 (CRGE, 2011), thereby almost reaching the cattle carrying capacity of the country and doubling emissions (projected to increase from 65 Mt CO₂e in 2010 to 124 Mt CO₂e in 2030) from the livestock sector. It is crucial that the rapidly growing livestock sector develop in a climate-smart manner in order to prevent the projected doubling of livestock-related emissions.

Most importantly, Ethiopia ratified the Paris Agreement in 2017 and promotes the importance of rapid economic growth happening in a climate-smart manner. The country recognizes the importance of mitigating global carbon emissions and is committed to contributing to worldwide efforts. As a result of the scarcity of relevant and/or reliable empirical data on the environmental footprints of animal agriculture, this study attempts to identify the major contributors to climate change and possible mitigation actions that should be policy priorities.

1.5.4. The Contribution of Ruminant Animal to GHGs Emission

Domestic ruminants such as cattle, buffaloes, sheep, and goats are the principal sources of anthropogenic CH₄ emissions. Ruminant animals are characterized by having a unique digestive system (Jahnke, 1982), which enables them to digest plant materials and is a major producer of methane, a potent greenhouse gas (FAO, 2006). The rumen is characterized as a large fermentation vat where approximately 200 species and strains of microorganisms are present (Tamminga et al., 2007; Thorpe, 2009). The microbes in the rumen convert coarse and fibrous roughages to absorbable nutrients in the process of enteric fermentation. Fermentative digestion (microbial digestion) takes place mainly in the reticulo-rumen, with a small amount in the large intestine (O'Hara et al., 2003; Thorpe, 2009). Typically, more than 80% of CH₄ is produced in the rumen and the rest in the lower digestive tract (O'Hara et al., 2003). The products of enteric fermentation provide the animal with the nutrients it needs for survival, enabling them to subsist on coarse plant material. Ruminant animals release methane into the atmosphere through eructation (83%), breath/exhaling (16%), and anus (1-2%) or ruminating through the mouth and nostrils (Murry, 1976; Kebede, 2006; Vlaming, 2008). It is also reported that approximately 89% of the CH₄ produced in the large intestine is absorbed into the blood and released into the lungs (Murry, 1976; Vlaming, 2008).

The digestive systems of ruminants produce much greater amounts of CH₄ per tonne of output than those of non-ruminant animals (Niggli et al., 2009). In monogastric animals, significant fermentation takes place in the large intestine, allowing significant digestion and use of plant material. Ruminants produce small amounts of CH₄ per unit of fermented feed, perhaps as a result of the availability of hydrogen sinks other than CH₄ (Jensen et al., 1996). Large ruminants such as buffalo and cattle produce a larger amount of CH₄ than small ruminants because of their feed intake (Johnson et al., 2000). Among farm animals, GHG emissions from cattle, for instance, represent about 65 percent of the livestock sector's emissions, making cattle the largest contributor to total sector emissions (Johnson and Johnson, 1995; Gerber et al., 2013). Enteric fermentation emissions for cattle are estimated by multiplying the emission factor for each species by the relevant cattle populations. The emission factors are an estimate of the amount of CH₄ produced (kg) per animal and are based on animal and feed characteristics, the average

energy requirement of the animal, the average feed intake, and the quality of the feed consumed (Sejian et al., 2011a). According to Herrero et al. (2008), the estimated average CH₄ emission factor for African domestic ruminants is 31.1kg CH₄ per year per TLU, which is similar to the value of 32kg CH₄ per year estimated by the IPCC (1996).

In ruminant production, there is a strong relationship between productivity and emission intensity. Gerber et al. (2013) state that there is an inverse relationship between productivity and emission intensity. Gerber et al. (2011) demonstrate this relationship for milk, illustrating how high-yield animals produce more milk per lactation and exhibit lower emission intensities. Accordingly, high-yielding animals that produce more milk per lactation generally exhibit lower emission intensities for three main reasons. First, because emissions are spread over more units of milk, thus diluting emissions relative to the maintenance requirements of the animals. Second, productivity gains are often achieved through improved practices and technologies that also contribute to emissions reduction, such as high-quality feed and high performance animal genetics. And third, because productivity gains are generally achieved through herd management, animal health, and husbandry practices that increase the proportion of resources utilized for productive purposes rather than simply being used to maintain the animals.

According to Sejian, the emission factors are an estimate of the amount of CH₄ produced (kg) per animal and are based on animal and feed characteristics, the average energy requirement of the animal, the average feed intake, and the quality of the feed consumed (Sejian et al., 2011). Hence, improved productivity at the animal and herd level can lead to a reduction in emission intensities while at the same time increasing milk output. Therefore, any measures to mitigate enteric fermentation not only reduce emissions but also raise animal productivity through increased digestive efficiency, which has better economic implications (Moss et al., 1995) for livestock producers.

1.5.5 Measurements and mitigation of GHG emissions

1.5.5.1 Measurements and modelling GHG Emissions

Accurate, reliable, repeatable, and cost-effective measurements of ruminant enteric CH₄ production are required for investigating potential mitigation options, screening animals for breeding program, assessing alternative management strategies, and reducing uncertainties associated with national GHG inventories (Patra, 2016; Patra and Lalhriatpuii, 2016; Negussie et al., 2017). A number of methods, ranging from building respiration chambers with various gas analyzers to tracer techniques, mass-balance techniques, and the use of lasers to the estimation of models, have been developed and used to measure and estimate CH₄ emissions from ruminants. These methods have various scopes of applications, precision, and repeatability; some are suitable for grazing animals, some for housed livestock; some can handle many animals, some only a few; and none of this is perfect in all aspects (Huhtanen et al., 2015; Hill et al., 2016; Patra, 2016). However, because most enteric methane emission measurement techniques are costly, time-consuming, and impractical, this review summarized the most common and relevant estimation methods for this study.

Measurement of CH₄ emissions from individual animals is difficult and labor-intensive; it requires sophisticated and expensive equipment, and a total national emissions calculation is not possible. Recently, therefore, several emissions models have been developed to: (i) predict total emissions from livestock; and (ii) evaluate the impacts of a range of mitigation strategies used for reducing CH₄ production (Ellis et al., 2009; Moraes et al., 2014). Several prediction models have been developed and widely used for estimating national or global emissions of animals based on existing data, such as animal characteristics (e.g., weight, age, breed), feed characteristics (e.g., nutrient and energy content), intake data (dry matter or nutrients), or digested nutrients (Ellis et al., 2009; Moraes et al., 2014; Rotz, 2018). According to Kebreab et al. (2008), mathematical models can be classified into two principal groups: empirical (statistical) models and dynamic mechanistic models. The models also vary in complexity and range from simple static empirical models, which estimate CH₄ production from nutrient intake directly (Patra, 2014; Patra and Lalhriatpuii, 2016), to complicated dynamic, mechanistic

models, which predict CH₄ emissions using mathematical descriptions of rumen fermentation biochemistry using the COWPOLL model (Dijkstra, 1992) and the MOLLY model (Baldwin, 1995).

In its 2006 national greenhouse gas inventories guidelines, the Intergovernmental Panel on Climate Change (IPCC) outlines methods for estimating CH₄ emissions from enteric fermentation at three levels of detail and complexity (IPCC, 2006). The IPCC operates at three different levels to estimate greenhouse gas emissions (IPCC, 2006). These three levels depend on the quality of the database established in the country in question and are known as Tiers 1, 2, and 3, where Tier 1 is the simplest calculation method and Tier 3 is the most complex and data-dependent method. The Tier 1 method is a simplified approach that relies on default emission factors (EF) drawn from previous studies. Therefore, only readily available animal population data are needed to estimate emissions. IPCC (2006) recommends the tier 2 (or tier 3, which requires further refinement) method for estimating CH₄ emissions from enteric fermentation for those countries with large cattle populations. Hence, based on enhanced characterization of activity data, this study used IPCC Tier 2 approaches to estimate GHG emissions in genera and enteric methane emissions from smallholder dairy cattle.

1.5.5.2 Mitigation strategies for GHG emissions

The aim of mitigation is to reduce future climate change by slowing the rate of increase in (or even reducing) greenhouse gas concentrations in the atmosphere. It is defined by the IPCC as "technological change and substitution that reduce resource inputs and emissions per unit of output (IPCC, 2006). Because the livestock sector contributes significantly to global warming, there are numerous and effective options for livestock-related GHG emissions mitigation (Paltsev et al., 2003; Steinfeld et al., 2006). These mitigation strategies range from diet manipulation, feed additive inclusion in the diet, rumen micro-flora modifications, changes in the market structure of animal products and by-products, and others (USEPA, 1999). Several authors, on the other hand, have argued the hypothetical mitigation potential of various dietary change scenarios, such as dietary change reducing production and consumption by lowering the emission intensity of production (Westhoek et al., 2011; Smith et al., 2013), or a combination of

the two (Westhoek et al., 2011; Gerber et al., 2013; Smith et al., 2013). In view of this, Smith et al. (2013) proposed two options to reduce GHG emissions through changes in food demand: 1) reduction of losses and wastes of food in the supply chain as well as during final consumption; 2) changes in diet towards less resource-intensive food, i.e., shifts to less GHG-intensive animal food products or to appropriate plant-based food to maintain protein supply. Furthermore, the positive effects of reducing animal protein consumption on human health are also suggested among populations consuming high levels of animal products (Westhoek et al., 2011; Smith et al., 2013). However, the effects of dietary changes in the context of mitigation scenarios and associated costs have yet to be studied quantitatively (Stehfest et al., 2009; Westhoek et al., 2011).

Although reducing non-carbon dioxide GHG emissions from ruminant livestock appears technically difficult, it has to be achieved in the face of rising demand for animal products and a projected substantial increase in livestock products over the next four decades, primarily in low and middle-income countries (Steinfeld et al., 2006). The authors also advised that even if technical solutions are available, they must also be holistic, practical to implement, and economically viable if farmers are to adopt them (Steinfeld et al., 2006; Clark, 2009). This is important because there are currently few or no incentives for the adoption of mitigation technologies due to a general lack of a price signal. Emission trading schemes are in place in a number of countries, but none of these schemes include agriculture (Clark, 2009).

Hence, the important question is: which mitigation option would be viable, and can Ethiopia engage in reducing CH₄ emissions from livestock? As Fitzgerald et al. (1995) advised for African livestock, the most relevant and practical option for Ethiopian livestock producers seems to be improvements in the quality of the diet and rangeland management. As previously indicated, options for mitigating GHG emissions should be identified, defined, and implemented based on local production contexts, as described earlier. These mitigation options, therefore, include increasing feed efficiency through improved digestibility of feed, improving the genetic potential of local breeds, culling unproductive animals, and improving animal health services, which increase the overall efficiency of animal productivity and reduce GHG emissions (Gerber et al., 2011; Gerg et al., 2013). Similarly, mitigation options within the livestock production

sector must be consistent with and complementary to the national development plan in order to be viable.

1.5.6 Climate Smart Dairy (CSD)

1.5.6.1 Concept and principles of CSA

The concept of CSA emerged at a time when researchers and development stakeholders around the world were looking for ways to increase sustainable production and build and strengthen farmers' resilience to climate shocks while also reducing agricultural GHG emissions and increasing carbon sequestration (FAO, 2010a). CSA has faced considerable controversy and variation about the concept, approach, and policies of sustainable agricultural development and how they are pursued in the climate change policy-making process (Verhagen et al., 2014; Lipper and Zilberman, 2018). The role of agricultural mitigation and financing in developing countries, as well as the development and deployment of agricultural technologies, are two key areas of ongoing policy debate (Lipper and Zilberman, 2018). The first expressions of the climate-smart agriculture concept argue that the agricultural sector is key to climate change response, not only because of its high vulnerability to climate change effects but also because it is a main contributor to the problem. It was also argued that sustainable transformation of the agricultural sector is key to achieving food security, and thus it is essential to frame climate change responses within this priority (FAO, 2010a, 2013a).

The concept of CSA was first introduced in 2009, and it has since been reshaped as a result of the inputs and interactions of the various stakeholders involved in developing and implementing the concept. The conceptual foundations of CSA, according to Lipper et al. (2018), draw on theory and concepts from agricultural development, institutional economics, and resource economics. Climate change policy evolution, which has been linked to collective global actions to stabilize greenhouse gas (GHG) emissions, has also played a role in CSA conceptualization. There are three objectives of the CSA concept: increasing food security and income through a sustainable increase in productivity and income; building resilience and adapting to climate change; and reducing greenhouse gas emissions over a baseline scenario (2010). Similarly, CSA is an approach that requires site-specific assessments to identify suitable agricultural production

technologies and practices, rather than a single specific agricultural technology or practice that can be universally applied.

This study incorporates the concepts, essences, and application of climate smart agriculture from FAO (2010) and Lipper et al. (2014), as well as the definition of sustainable intensification (SI) from Pretty et al. (2011), to guide agricultural management in the face of climate change by

- Sustainably increasing agricultural productivity and income, enhancing food security, and improving livelihoods
- Reducing and/or removing greenhouse gas emissions, including through reducing emissions for each kilogramme of milk and meat produced; and managing grazing land and forage in ways that enhance their potential as carbon sinks, thereby absorbing CO₂ from the atmosphere.
- Reduce vulnerability (enhance adaptation to climate change) where possible, with a focus on enhancing capacity to adapt.

Similarly, any livestock management practices that reduce environmental impacts, improve productivity, or make efficient use of scarce resources can be considered climate-smart due to the potential benefits in terms of food security, even if no direct measures to counteract negative climate effects are taken (Ayantunde et al., 2015).

1.5.6.2. Existing knowledge of livestock farming practices in Ethiopia

The Ethiopian livestock sector is diverse in terms of climatic zones, food production systems, and socioeconomic conditions. Agriculture has to address the intertwined challenges simultaneously to ensure food security through increased productivity and income, adapting to climate change, and contributing to climate change mitigation (FAO, 2013a, 2016b; Lipper et al., 2014; Kipkoech et al., 2015). It is an approach to addressing food security and climate change jointly by bringing together agricultural practices, policies, institutions, and financing. According to FAO (2016), CSD has multiple entry points and extends beyond single farm-level technologies to include the integration of multiple interventions at the food system, landscape, value chain, and policy levels. It also involves innovative practices such as improved weather forecasting, early warning systems, and climate risk insurance (FAO, 2016b; Eshete et al., 2020).

However, because of the country's diverse agro-ecologies and crop-livestock systems, there will be no single, silver-bullet CSD technology, practice, or policy that will address all of these issues (Kiros et al., 2019). The country should, therefore, consider appropriate sets of CSA interventions at relevant scales that are selected and tailored to local contexts and livelihood needs.

Ethiopia's policy responses to climate change challenges are numerous, though there is no direct mention of climate-smart agriculture. However, even before climate change became one of the most important factors in sustainable development, several of Ethiopia's development and sectorial policies and program addressed the issue. To name a few, the CRGE objectives and guiding principles, the productive safety net program (PSNP), and the sustainable land management program (SLMP) all share the goal of climate-smart agriculture for long-term development (CRGE, 2011; CRGE-NAP, 2019). The Kyoto Protocol's establishment of the Clean Development Mechanism (CDM) provided a foundation for emissions reductions highly relevant to agricultural development in terms of carbon sequestration through improved soil management and forestry. Ethiopia is also a signatory to a number of multilateral agreements that affect the country's efforts towards sustainable development and reducing GHG emissions. As a signatory to the global methane pledge since 2021, Ethiopia committed to reduce global methane emissions by 30 percent by 2030 as compared to 2020 baseline levels (FAO, 2022).

Although there are several crop-targeted projects based on CS principles in Ethiopia, there is a scarcity of information on livestock-oriented climate smart practices (Kipkoech et al., 2015; FAO, 2016b; Eshete et al., 2020). Nonetheless, a number of interventions for sustainable intensified livestock production in Ethiopia in general and in the central highlands in particular have been identified within the current context (Amole and Ayantunde, 2016; FAO, 2017; Keros et al., 2019; Eshete et al., 2020). The climate-smart dairy outlined in this chapter will have practical relevance for smallholder dairy farming systems in the study area. As stated in FAO (2017) and in the context of this study, the two terms will not be used as separate measures but rather to demonstrate complementarities and synergies.

The following are some of the strategies suggested by FAO and earlier research to lower emissions from livestock production, boost climate change resistance, and boost productivity and

farmers' income in the study area (Table 1). These interventions can be grouped into four major types: feed and feeding-related interventions, breeding and breeding practices and livestock management practices.

Livestock production can make a large contribution to a climate-smart food supply system. The sector offers substantial potential for climate change mitigation and adaptation (FAO, 2013b; Gaitán et al., 2016). The systems are considered "climate smart" by contributing to increasing food security, mitigation, and adaptation in a sustainable way (FAO, 2013b; Amole and Ayantunde, 2016; Gaitán et al., 2016). In addition to improving productivity or maximising the efficient use of scarce resources, livestock management practises that increase food security can be viewed as climate-smart even when no direct measures are taken to counteract negative climate effects (Zougmone et al., 2015). Similarly, the effects of mitigation interventions have been important in increasing animal productivity and, as a result, smallholder farmers' food security (Gerber et al., 2013; Garg et al., 2014). Furthermore, according to FAO, (2013b), livestock plays an important role in adaptation practices by managing organic matter and nutrients as well as diversifying income. The current study, therefore, evaluated the three pillars of CSA: improved productivity, reduced emissions, and resilience to climate change, based on this conceptual argument.

Table 1. Climate smart dairy farming practices of the study area

	Management objectives	Practices/Technology	CSD Pillars			Suggested ways of improvement
			Food security	Adaptation	Mitigation /sink	
Feed related intervention	Concentrate/supplementary feeding	Use of concentrate feed, industrial bi-products	++	+	++	Improving diet increase feed conversion efficiency, animal productivity and reduce GHG emissions
	Forage cultivation	Improved forage grass and legumes cultivation	++	++	+++	Increase palatability and digestibility, reduce GHG emissions thereby enhance animal productivity
	Feed conservation & treatment	Harvesting and conservation of pasture	++	++	+	Proper harvesting and preservation used to reduce feed shortage, improve feed quality and palatability, and nutrient lost
	Grazing conditions	Stall feeding, semi-grazing	++	+++	+++	Reduce maintenance requirement for grazing, used for grazing land management and efficient utilization of feed
Improved breed & breeding	Increasing productivity per animal/herd	Exotic/ crossbred cattle	+++	++	++	Breeding more productive animals increases animal efficiency, increase productivity and reduce GHG emissions per production
	Improve animal productivity and reproduction	Improve herd health management	+++	+++	+++	Better herd health management to improve productivity and reduce GHG emissions
Manure management	Manure handling & treatment and storage practices	Anaerobic digester for biogas and fertilizer, composting, application	+	++	++	Efficient treatments of manure can reduce emissions of GHG, maintain nutrient recycle & increase crop productivity.

Sources: Amole and Ayantunde, 2016; FAO, 2017; Keros et al., 2019; Eshete et al., 2020
 Food security / adaptation / mitigation potential: + = low; ++ = medium; and +++= high

1.5.7 Conceptual Framework

This study used the concepts, essences, and core pillars that are applicable and necessary in CSA described in previous section. Various adaptation and mitigation concepts have been proposed to understand and manage the relationship between climate change and food production, as well as how people can drive their livelihood without compromising the natural environment for future generations. The basic framework in CSA depicts the fundamental relationship between climate change, agriculture, and food security, in order to address what Vosti and Readon (1997) refer to as the critical triangle of development objectives of increasing production, reducing vulnerability, and using natural resources sustainably in the face of changing climate. As a concept, CSA is thus geared toward guiding agricultural management in the face of climate change Lipper and Zilberman (2018) and achieving food security while also mitigating climate change and contributing to other development goals (Verhagen et al., 2014). Through the promise of a "triple-win solution," this emerging paradigm seeks to reconcile the goals of climate change mitigation and adaptation with the need to increase agricultural productivity and reduce poverty and hunger in developing countries (FAO, 2010a).

Understanding the synergy and tradeoffs of and characterizing important key interacting factors at different production units in livestock farming systems is essential to identifying and implementing effective livestock intensification to enhance livestock productivity and reduce the environmental footprint of the sector (Udo et al., 2011). Improved feed and feeding, for example, increase feed use efficiency and livestock productivity while lowering emissions per unit of product (Herrero et al., 2009; Gerber et al., 2013; Hristov et al., 2013; Lorenz et al., 2019). The strong correlation between increases in animal productivity and reducing enteric methane emissions offers large opportunities for low-cost mitigation and economic benefits. As Linger et al. (2018) highlighted, however, these relationships occur in the wider environment of a given location. The core pillars of CSD farming practices, as well as their interdependence, can be influenced and conditioned by location, policy, programmes, and the availability of appropriate technologies and institutions (Watkiss et al., 2015). Similarly, the degree to which a smallholder farmer is food secure is determined by decisions to adopt improved farming practices, which are influenced by socioeconomic, institutional, and technological factors.

The present study, therefore, relies on this theoretical and conceptual framework to envisage the adoption benefits of CSD farming practice in reducing greenhouse gas emissions and enhancing farmers' food security (Figure 1).

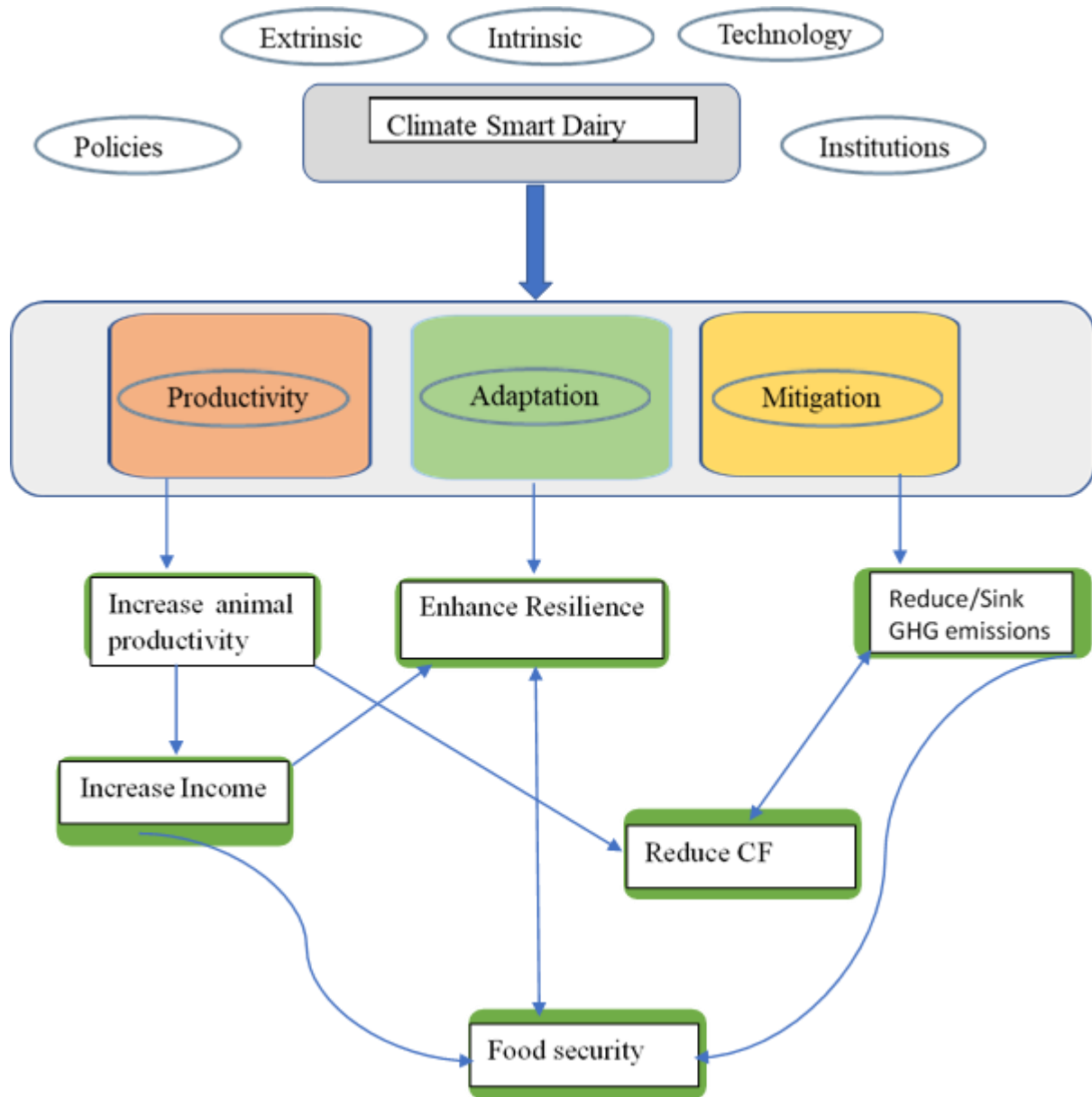


Figure 1. Conceptual framework of the study

Source: This conceptual framework was developed for this study

1.6 General Methodology

1.6.1 Description of the study area

The description of the study area depends on data from secondary sources and key informant interviews. A secondary data set was compiled from the regional bureaus, district offices, and woreda-level offices. Data related to climate were gathered from different metrological stations in the study area and from the National Meteorological Agency (NMA) central office. 40 years data from five districts were used for the study. We conducted interviews with key informants and focus group discussions at the institution level (region, woreda, and sector offices) as well as at the local community level in the study sites.

1.6.2 Overview of the study region

The central highlands of Ethiopia occupy the central parts of the country and cover 40% of the areas of the country, making them the largest of their kind in sub-Saharan Africa (Brandsma et al., 2013). Selale highlands, administratively found in the Oromia regional state, North Shewa Zone, Ethiopia (Figure 2). Geographically, the study area is located between 9°30"N latitude and 38°40"E longitude. The area has a variety of topographical features ranging in altitude from 3500 m above sea level (masl) at the tip of the mountain to 1000 m above sea level (masl) across the majority of the plains on its 9775.3 km² land area. The area's topography is mountainous in the highlands and midlands and plain in the lowlands.

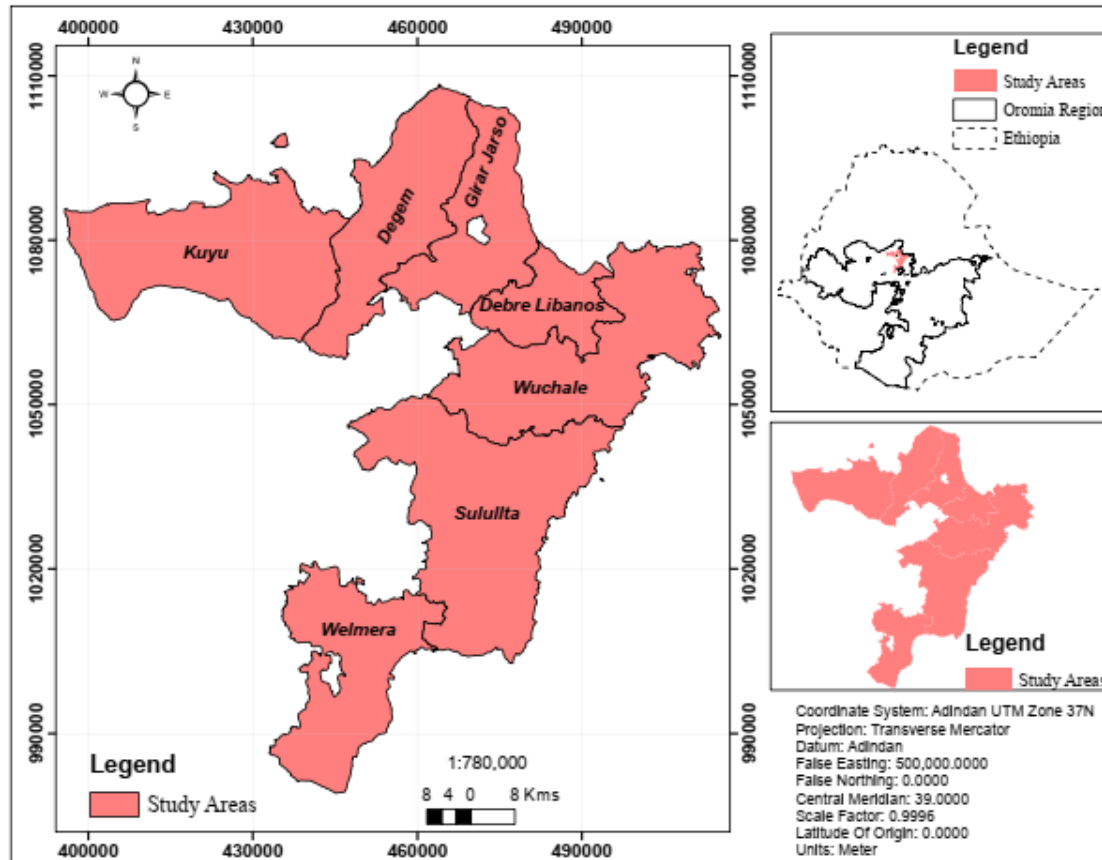


Figure 2. Location map of the study area

Climate: The Selale highland is characterised by highland agro-ecology. Based on the traditional agro-ecological classification, the major part of the region is about 55% highland, 30% midland, and the remaining 15% lowland (BoPPO, 2020), with a bimodal rain fall. The climate of the area, like that of the rest of the country, is influenced by the seasonal migration of the Intertropical Convergence Zone (ITCZ) and the associated atmospheric circulation, as well as by the complex topography (Fazzini et al., 2015). The study area has a bimodal rainfall pattern, with rain falling during both *Belg*, the short rainy season that lasts from February to April, and *Kiremt*, the main rainy season that lasts from June to September. Over 70 % of the rain occurs during the main rainy season, and about 30% of the rain occurs during the short rainy season. According to Brandsma et al. (2013), a large portion of the region (42%) has a tropical highland climate similar to that of temperate regions, and nearly a quarter of the land in the area is typical tropical dry land, with the remainder experiencing an intermediate climatic condition. The mean annual rainfall from 1988 to 2018 ranged from 700 mm to 1800 mm (Figure 3).

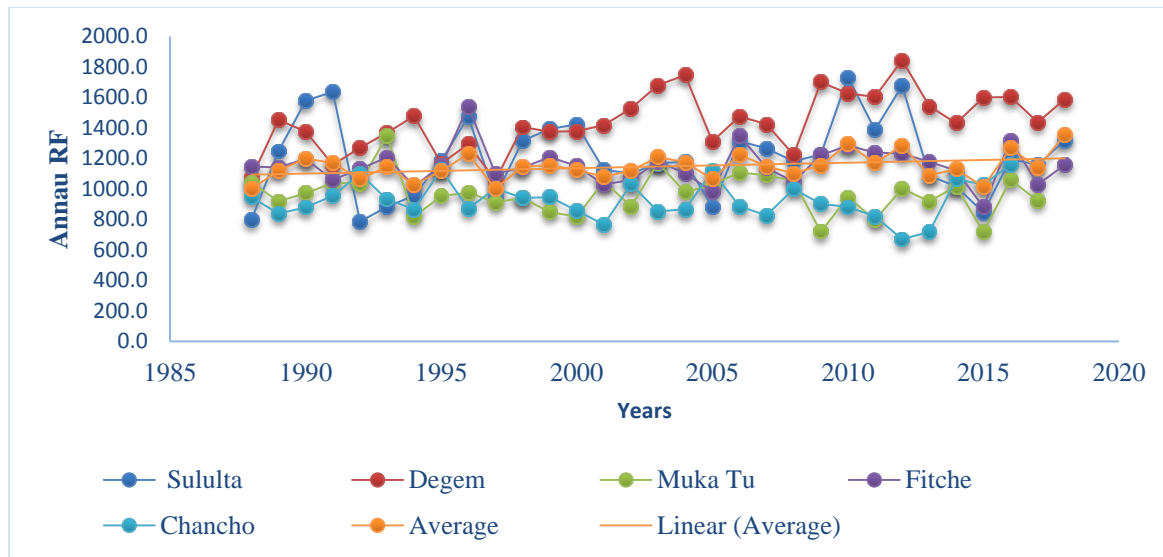


Figure 3. Mean annual rainfall

Average annual rainfall patterns over the past 40 years show increasing amounts and changes in timing (Table 2). The precipitation trend showed an increasing trend during the long rainy season (Kiremt) and a decreasing trend during the short rainy season (Belg).

Table 2. Trends in mean annual precipitation of the study area

Stations	Time series	Mann-kendall trend		Sen's slope estimate
		Test Z		Q
Degem	ANNUAL	0.54 ^{ns}		1.93
	LRS	1.7	+	4.786
	SRS	-3.30	***	-3.59
Fitche	ANNUAL	0.32		0.783
	LRS	1.22		2.238
	SRS	-3.54	***	-3.47
MT	ANNUAL	0.14 ^{ns}		0.66
	LRS	0.27		1.018
	SRS	-2.62	**	-2.754
Chancho	ANNUAL	1.78	+	4.84
	LRS	2.29	*	5.59
	SRS	-1.84	+	-2.15
Sululta	ANNUAL	0.44 ^{ns}		3
	LRS	1.05		5.72
	SRS	-1.48	**	-2.657

*** $p \leq 0.001$; ** $p \leq 0.01$; * $p \leq 0.05$; + $p \leq 0.1$; ns: not significant (Amnell et al., 2002)

LRS (Kiremt) = Long rain season, SRS (Belg) = Short rainy season

The average annual minimum and maximum temperatures for the same period (1988–2018) vary between 7.9 °C and 21 °C. These values are a bit different from the previous average value of 6.5 °C in Ethiopia's central highlands (Berhe et al., 2004; Brandsma et al., 2013).

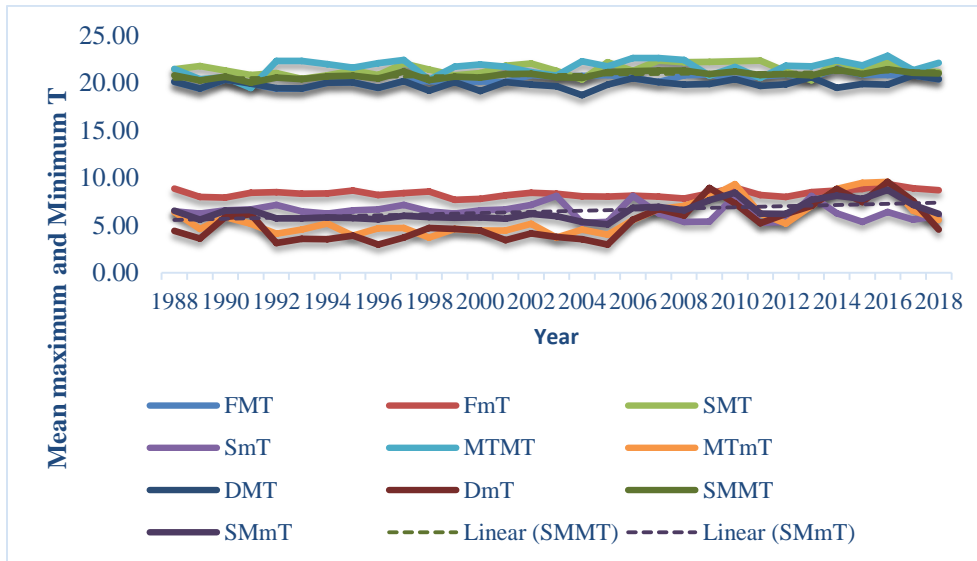


Figure 4. Mean maximum and minimum temperature

The Mann-Kendall (MK) test showed that the mean annual temperature showed an increasing (significant) trend in all stations except Suluta weather station (Table 3). The Sen's slope estimator showed that the local temperature has increased at a rate of 0.029 °C, 0.063 °C, 0.077 °C, and 0.039 °C per annum at Fitch, Muka Ture, Chancho, and Degem stations, respectively.

Table 3. Trends of average annual temperature of the study area

Stations	Time series	Mann-kendall trend Test Z	Sen's slope estimator Q
Fitch	Annual	4.32***	0.029
Sululta	Annual	-0.07 ^{ns}	0.000
MT	Annual	3.26**	0.063
Chancho	Annual	3.28**	0.077
Degem	Annual	3.5***	0.039

*** $p \leq 0.001$; ** $p \leq 0.01$; * $p \leq 0.05$; + $p \leq 0.1$; ns: not significant. Amnell et al. (2002)

Soil and land use type: The major soil types of the study area are classified as vertisols, nitisols, and leptosols, which cover 90% of the landmass. Vertisols are the dominant soil type, which is

characterized by its high water-holding capacity, low organic matter, and total nitrogen (Elias, 2016). Vertisol soil is found predominantly on flat to gently sloping topography, Nitisols on flat to moderately steep slopes; and Leptosols on upper footslopes, backslopes, and where erosion is severe. The major land use types can generally be categorized into farmlands, grazing land, and pasture land. Population growth and urban expansions have led to severe competition in land use between crop, grazing, and forest lands (Berhe et al., 2004; Feyissa et al., 2018). The conversion of pasture land to crop production reduced the availability of livestock feed, lowering livestock productivity. Furthermore, as a result of vegetation clearing for cultivation, many steep areas have become vulnerable to wind and water erosion.

Vegetation: The natural vegetation is diverse and reveals successions of species based on altitude in the central highlands (Berhe et al., 2004), containing a mixture of annual herbaceous and woody vegetation. The dominant vegetation types consist of scattered bushes and shrubs. The grassland composition is dominantly composed of *Andropogon spp.*, *Festuca spp.*, *Hyparrhenia spp.*, and *Pennisetum spp.* among grasses and different native annual *Trifolium species* among legumes (Feyissa et al., 2014). The vast pastureland coupled with a favourable climate make the region suitable for fodder production. The vast land that farmers used for crop production is now left for grazing animals due to its reduction in fertility and the increase in profitability of dairying (Brandsma et al., 2013). Hay is produced after a three-month rest period that lasts from the peak rainy season in mid-July until mid-October, when hay harvesting begins under normal conditions.

Livelihoods and farming activities

Agriculture is the main economic activity and source of livelihoods in the Selale Highlands. Mixed crop-livestock production is the dominant mode of farming practices which is referred to as a predominantly subsistence farming system (Brandsma et al., 2013). In this system, crops and livestock play interdependent roles, with livestock providing draught power and manure for crop agriculture while crop residues provide feed for the livestock. Rain fed livestock and crop production are the two major sources of livelihood. The major crops grown in the study area include cereal crops, pulses, and oil crops. These include: teff (*Eragrostis tef*), sorghum (*Sorghum vulgare*), barley (*Hordeum vulgare L.*), maize (*Zea mays*), harricot bean (*Phaseolus vulgaris*), fababean (*Vicia faba L.*), and soy bean (*Glycine max*). Apart from crop farming,

livestock production also constitutes an important part of the agricultural activities of the zone. The farmers are also involved in other off-farm activities for income generation, such as brokering, dung cake making, and wage labor.

The smallholder agricultural production system in the highlands is primarily subsistence mixed crop-livestock farming. Smallholder dairy farming systems can be categorized into urban, peri-urban, and rural based on production objectives, intensity of input and output, market availability, feeding conditions, and location (Brandsma et al., 2013; Gizaw et al., 2016). Smallholder dairy farming is practiced to support family income in addition to crop production and other non-agricultural activities. Livestock, especially dairying, is the dominant agricultural enterprise in the study area. According to the Zonal Livestock and Fisheries Bureau (2020), the zone had 1,519,495 cattle, 1,049,491 sheep, 284,396 goats, 252,922 donkeys, 101,921 horses, 8,986 mules, and 828,232 poultry. From the total cattle population, about 20% were improved cattle breeds (305,689 heads) (ZLSF, 2020). Furthermore, the region has favorable conditions for fodder production and by-product utilization, and farmers have a high percentage of crossbreds and easy access to artificial insemination (AI) (Zijlstra et al., 2015). This is also the area that supplies milk to the most affluent population, about 5 million citizens in the capital.

1.6.3 Research Approaches

According to Creswell (2014), the intersection of research approaches includes the worldviews the researchers bring to the study, the research design related to the worldview, and the specific research methods used to implement the approach. The present research, therefore, followed a mixed research approach that concurrently employed both quantitative and qualitative data to address the intended research problem. The core assumption behind the mixed approach, as described in Creswell (2014), is that it provides a more holistic understanding of the problem than either approach.

1.6.3.1 Research Design

Research practice is guided by philosophical ideas, although they remain largely hidden in research (Slife and Williams, 1995). This set of beliefs or worldviews that guide research practices is commonly known as a paradigm (Mertens, 2010; Guba and Lincoln, 2011).

Paradigms are metaphysical frameworks that aid researchers in identifying and clarifying their beliefs about ethics, reality, knowledge, and methodology (Mertens, 2010). According to Elliott (2004), in research, paradigms shape researchers' stances and positions about how to understand reality (ontology), how researchers know what they know (epistemology), and how to apply methods and interpret the results (methodology). Ontology, epistemology, and methodology are closely interrelated in that ontology dictates epistemology, which dictates methodology, and finally makes sense of research questions (Grix, 2002).

The present study promotes a pragmatic worldview, which argues that research should emphasize the research problem and use all approaches available to understand the problem rather than focusing on methods (Saunders et al., 2009; Creswell, 2014). In comparison to other philosophies such as positivism and interpretivism, pragmatism allows researchers to design flexible methods for collecting both qualitative and quantitative data, allowing them to better address the research problem (Saunders et al., 2009).

Specifically, this study, which was aimed to investigate the environmental and economic implications of climate-smart livestock farming, covered a wide range of issues, from socioeconomic to biological, and required both quantitative and qualitative data. Descriptive and analytical types of research were employed in survey research methods. The design was comparative research that compared two or more groups on one or more variables, such as the effects of farming practices (management practices) on greenhouse gas emissions from dairy cattle and farmers' food security. This research used reproductive and production data from dairy cattle kept under different management practices to evaluate the carbon footprint of animal agriculture. These biological data were complemented by a cross-sectional survey, group discussion, and key informant interview that also examined farmers' food security status, and farmers' knowledge, attitude and perceptions of climate smart practices.

Types and sources of data

A cross-sectional household survey conducted in July 2020 and February 2021 enumerated 480 smallholder farmers in the central highlands of Ethiopia.

Key informant interviews: Key informant interviews were used to generate information pertinent to the environmental importance of livestock production, GHG emissions mitigation, and adoptions of climate-smart dairy farming practices. Experts with environmental and agricultural backgrounds in the Kebeles, Woreda, and Zone Offices were interviewed.

Focus Group Discussion (FGD): Participants for FGD were selected from people with diverse backgrounds and opinions, which allows for in-depth discussions to obtain information. FGD is advantageous in allowing for in-depth discussion and probing on an issue of interest, providing a tremendous amount of information at a reasonable cost, and obtaining more people within a shorter time frame compared to in-depth interviews. For this study, single focus group discussions comprising 9–13 people were selected from farmers of different wealth groups, sexes, farming experiences, and development agents.

Secondary data: data on human and livestock populations, crop production, rainfall, temperature, agro-ecology, soil type, feed chemical compositions, and other pertinent data to the study objectives were gathered from secondary sources.

Household Survey: One of the methods used to collect data for this study was a household survey. The questionnaire encompasses detailed information on each household's socio-economic characteristics, farming system and management practices, and the environmental and economic importance of climate-smart dairy farming (CSD) practices. Following that, the respondents' knowledge, attitude, and perception (KAP) of CSD and the practices they adopted, key constraints they faced in adopting, and determinants of adoption in the area were assessed.

Field measurements: Using heart girth measurements, the live body weight of different animal categories was estimated (FAO, 2012). Data on milk yield during the lactation season of 2019–2020 was taken from the National Livestock Development Institute and supported by a household survey. Using the test interval approach mentioned by Sargent et al. (1968) and Meseret et al. (2015), the standard 305-d milk yield for each animal was calculated from test date (TD) milk production records.

Sampling design

To achieve the overall objectives of the study, a multi-stage stratified random sampling technique with a combination of purposive and random sampling procedures was used to select sample zones, districts, kebeles, and households. At the first stage, North Shewa Zone, the Selale milk belt was purposefully selected based on livestock population potential, a favorable environment for dairy and pasture production, and its representativeness in reflecting the realities of market-oriented smallholder mixed farming in the central highlands of Ethiopia. Out of 13 administrative districts (Warada) of the zone, four potential mixed-farming districts (Suluta, Wuchale/Muka Ture, Fitcha (G/J), and Degem) were purposively selected to represent urban, peri-urban, and rural smallholder farming systems. Most of the sampled districts were supposed to have homogeneous agro-ecology and farming systems. Smallholder farmers' were then stratified to urban, peri-urban and rural farming systems based location, scale of production, production objectives, degree of intensification, and feeding conditions. In the third stage, 16 peasant associations (PAs), the smallest administrative unit, four from each district, were selected by considering SHF registered under national dairy cattle data base and proximity to main roads. In the fourth stage, representative households were randomly selected from each of the selected groups or strata and used for interviews. Finally a total of 480 (urban = 120, peri-urban = 180, and rural = 180) SHF were randomly selected to represent all farming systems on the basis of the probability proportional to size (PPS) sampling procedure following Arsham (2000) and Wilkes et al. (2019) smallholder dairy methodology.

The sample size for the multistage stratified random sampling method used in this study was determined by Cochran (1977) utilizing characteristics of adopters and non-adopters (urban, peri-urban, and rural) smallholder farmers depending on degree of intensification. The calculated sample size is adjusted through a design effects suggested by Cochran (1977) and Daniel (1999). The acceptable margin of error in the previous studies following Cochran (1977) between 3%-5% was used. The present study, therefore, used the following formula to determine total sample size for household survey.

$$n = \frac{NZ^2 P(P - 1)}{e^2 (N - 1) + Z^2 P(P - 1)}$$

Where:

n = Sample size of smallholder farmers

N = Total number of smallholder farming unit (population size)

Z = Z statistics for a level of confidences, 95% confidence interval which is equal to 1.96 was used

P = is the (estimated/expected) proportion of the population

e = allowable margin of error (level of precision)

The minimal sample size for a valid result was determined to be 480, taking into account the number of smallholder dairy producers in the study region who are registered with the National Livestock Development Institute (National dairy cow data base).

1.6.3.4. Data analysis

Information gathered from qualitative data was used to triangulate and substantiate the quantitative data. The Non-parametric Mann-Kendall (MK) statistic and Sens' estimator test were used to analyse the time series of both precipitation and temperature of the study area. Both descriptive statistics (chi-square), an econometric model, an index, an ANOVA, and a life cycle assessment (LCA) were used to analyse quantitative data gathered from primary and secondary sources. A lifecycle assessment (LCA) method was used to estimate the environmental footprints of dairy farming in a mixed crop-livestock farming system (IPCC, 2006; Opio et al., 2013). Similarly, direct methane emissions from dairy cattle were estimated using Tier 2 methodology of the IPCC adopted for tropical production systems (du Toit et al., 2013). The endogenous switching regression model was used to investigate the effects of improved technology adoption on farmers' food security and its determinants. To investigate factors influencing knowledge, attitude, and perceptions (KAP) and their determinants in the adoption of climate-smart dairy farming practises, a binary and ordered logistic regression model was used. In addition, the chi-square test and the correlation model were used to assess the relationship between KAP and improved farming technologies.

Mann-Kendall test: The Mann-Kendall test is applicable in cases when the data values x_i of a time series can be assumed to obey the model:

$$x_i = f(t_i) + \sum_i \quad (1)$$

Where $f(t)$ is a continuous monotonic increasing or decreasing function of time, and the residuals \sum_i can be assumed to be from the same distribution with a zero mean.

The number of annual values in the studied data series is denoted by n . Missing values are allowed and n can thus be smaller than the number of years in the studied time series.

The Mann-Kendall test statistic S is calculated using the formula (Mann, 1945; Kendall, 1975)

$$S = \sum_{k=1}^{n-1} \sum_j^n k + 1 \operatorname{sgn}(x_j - x_k) \quad (2)$$

Where x_j and x_k are the annual data values in years j and k , $j > k$, respectively, and n is the number of annual values in the studied data series, and $\operatorname{sgn}(x_j - x_k)$ is the sign function as:

$$\operatorname{sgn}(x_j - x_k) = \begin{cases} 1 & \text{if } x_j - x_k > 0 \\ 0 & \text{if } x_j - x_k = 0 \\ -1 & \text{if } x_j - x_k < 0 \end{cases} \quad (3)$$

The variance of S is computed the following equation:

$$\operatorname{Var}(S) = \frac{n(n-1)(2n+5) \sum_{p=1}^q t_p(t_p-1)(2t_p+5)}{18} \quad (4)$$

Where n is the number of data point, q is the number of tied groups and t_p denotes the number of data values in the p^{th} group. A tied group is a set of sample data with the same value. When the sample size is more than 10, the standard normal test statistic Z_S is computed as follows:

$$Z = \begin{cases} \frac{S-1}{\sqrt{\operatorname{VAR}(S)}} & \text{if } S \geq 0 \\ 0 & \text{if } S = 0 \\ \frac{S+1}{\sqrt{\operatorname{VAR}(S)}} & \text{if } S < 0 \end{cases} \quad (5)$$

The presence of a statistically significant trend is evaluated using the Z value. A positive or negative value of Z indicates an increasing or decreasing trends. Testing trends is done at the specific α level of significance. When $|Z_S| > Z_{1-\alpha/2}$, the null hypothesis is rejected and a significant trend exists in the time series. In the present study the significant levels $\alpha = 0.01$ and $\alpha = 0.05$ were used. The null hypothesis of no trend is rejected if $|Z_S| > 1.96$ at the 5% significance level and rejected if $|Z_S| > 2.576$ at the 1% significance level.

Sen's slop estimator

To estimate the true slope of an existing trend (as change per year) the Sen's nonparametric method is used (Sen, 1968).

$$Q_i = \frac{x_j - x_k}{j - k} \text{ for } i = 1, \dots, N, \quad (6)$$

Where x_j and x_k are the data values at times j and k ($j > k$), respectively.

$N = \frac{n(n-1)}{2}$ if there is one datum in the time series, where n is the number of time period, and $N < \frac{n(n-1)}{2}$ if there are multiple observations in one or more time periods, time series, where n is the total number of observations.

The Sen's slop estimator (the median of slop) is computed as:

$$Q_{med} \left\{ \begin{array}{l} Q_{[(N+1)/2]}, \text{ if } N \text{ is odd} \\ \frac{Q_{[N/2]} + Q_{[(N+2)/2]}}{2}, \text{ if } N \text{ is even} \end{array} \right\} \quad (7)$$

The Q_{med} sign reflects the data trend, and its value indicates how steep the trend is. One should obtain the confidence interval of Q_{med} with specific probability to determine whether the median slope is statistically different from zero. The confidence interval can be computed as follows:

$$C_\alpha = Z_{1-\alpha/2} \sqrt{Var(S)} \quad (8)$$

Two significance levels were used in this study ($\alpha=0.01$ and $\alpha=0.05$).

1.7 Organization of the Study

The study is organized into five chapters. The first chapter introduces the context and the research problem. It discusses the problem's background, problem statement, objectives of the study, research questions, state-of-the-art, conceptual framework, general methodology, significance of the study, and scope and limitations of the study. From chapter two to chapter five, each chapter presents the main findings of the study as a separate chapter with its own introduction, methodology, results and discussions, and conclusions. The final chapter, presents the dissertation's synthesis, which includes a general summary, conclusion, and recommendations.

Chapter Two

2. Farmers' Knowledge, Attitudes, and Practice and its Determinants in Adoption of Climate Smart Dairy Farming

Abstract

This study examines the factors that influence farmers' knowledge, attitudes, and perceptions (KAP) of climate-smart dairy farming (CSD) and the constraints that prevent the adoption of these practices. A multi-stage stratified random sampling technique was used to select 480 smallholder farmers from four districts. The study employed Principal Component Analysis (PCA), and ordinal and binary logistic regression models were used to analyse the data. Our findings showed that age, education, and extension services positively explained KAP, whereas the distance to the farmers' training center (FTC) and market negatively explained KAP. Resource endowments and better access to input services and the output market had an impact on smallholder farmers' KAP toward new technology. Resource constraints, supply chain bottlenecks and market linkages, insufficient services, and a lack of information were identified as barriers to adopting and implementing improved dairy technologies in the study area. Therefore, interventions that overcome the constraints related to access to farm resources and the supply chain for technological inputs and services and output markets could facilitate the uptake of dairy technologies. Improvements in infrastructure and targeted institutional arrangements for the distribution of technology inputs and services could ease market access constraints.

Keywords: Adoption, Attitude, Climate-smart dairy, Knowledge, Perception, Selale, Smallholder farmer

2.1 Introduction

Anthropogenic global warming shows no signs of decreasing and is expected to result in long-term changes in weather conditions (IPCC 2007a; FAO 2008). The IPCC (2007b) highlighted past, current, and predicted future greenhouse gas emissions as well as their potential negative impacts on nations' socioeconomic development. If greenhouse gas (GHG) emissions, the primary cause of climate change, continue to rise, global temperatures will rise by 1.4-5.8°C by the end of the twenty-first century (IPCC 2001a, IPCC 2001b). These changes could be especially damaging for developing countries, whose livelihoods are vulnerable to extreme weather events such as droughts and floods (IPCC, 2001b).

In Ethiopia, agriculture remains the most important source of income and employment in the rural areas, as it is in many other developing countries (FAO, 2016a; CSA, 2020). The sector accounts for roughly 42 percent of national GDP and employs 80 percent of the labor force (FAO, 2016a; FAO-NZAGRC, 2017). In contrast, agriculture contributes 14% of global greenhouse gas emissions (GHGs) (Smith et al., 2008) and 25% of deforestation caused by agriculture is taken into account (Schaffnit-Chatterjee et al., 2011). According to FAO (2009), low and middle-income countries account for 74% of agricultural GHG emissions. In Ethiopia, for instance, agriculture contributes considerably to global GHG emissions, accounting for 50% and 37% of these emissions from the agricultural and forestry sectors, respectively (CRGE, 2011; FAO-NZAGRC, 2017). The livestock sector represents around 45 percent of Ethiopia's total agricultural production value, and supports the livelihoods of many Ethiopians (Shapiro et al., 2017; CSA, 2020). The subsector is also responsible for 40 percent of agriculture-related greenhouse gas emissions (GHG) (FAO, 2016d). The majority of emissions from the livestock sector come from enteric fermentation, feed production, and transportation, followed by manure management (FAO, 2016a; FAO-NZD, 2017).

In light of the fact that agriculture contributes substantially to GHG emissions, studies have shown that there is enormous potential to mitigate the emissions from the sector (Niggli et al., 2009; FAO, 2016b; FAO, 2022). Sustainable agricultural practices are therefore crucial for reducing emissions of greenhouse gases and improving food security (FAO, 2016b; FAO-

NZAGRC, 2017). As part of CSA, increased productivity and resilience are emphasized along with mitigation to ensure food security (FAO, 2010a). As part of CSA, climate-smart dairy farming (CSD) practices can increase animal productivity, help smallholders increase their income, and reduce the environmental footprints of animal agriculture by employing improved dairy cow breeds, better feed and forages, and better feeding conditions (Herrero et al., 2009; 2015; Van Dijk et al., 2015). This provides opportunities for smallholder farmers (SHF) to increase productivity through climate-smart livestock farming and use their animals as a vehicle out of poverty.

Ethiopia is endowed with a large livestock population and the most diverse and distinct livestock production systems in Africa (FAO, 2016a; CSA, 2020). In highland, lowland, and pastoral farming areas, livestock provides food, draught power, fuel, cash income, security, and investment opportunities (Tegegne et al., 2013; FAO, 2016a; 2018). Even though Ethiopia has a large population of cattle and a favourable production environment, per-animal productivity is still low because of inadequate feed quality and quantity, the low genetic potential of indigenous breeds, subpar animal health services, and subpar management techniques (Gizaw et al., 2016; Shapiro et al., 2017; Tegegne et al., 2013). The national average daily milk yield per cow, as well as per-capita consumption of beef and cow milk, are lower than most African countries (FAO-NZAGRC, 2017; FAO, 2019; CSA, 2020).

Even though a wide variety of stakeholders are trying to promote dairy technology adoption among smallholder farmers, it is extremely low and varies considerably from region to region (Duncan et al., 2013; Mekoya et al., 2008; Kebebe, 2019). Smallholder farmers often lack access to essential services, an understanding of the market system, and other necessities, which restricts their capacity to invest, increase their market surplus, and add value to their produce (Deininger et al., 2003; Dercon et al., 2012; Rivera et al., 2019). Understanding and characterizing factors affecting the uptake of dairy technologies and what motivates people to choose a specific package from the available options is an important area of research and policy development for years. Various conditions and circumstances can influence farmers' decisions about whether and how to adopt new technology Loevinsohn et al. (2013). For instance, perceptions, attitudes, and knowledge drive individual and collective adoption of sustainable

agriculture practices (Meijer et al., 2015; Sumane et al., 2018; Lucas et al., 2019), as well as social capital, which includes farmers' networks, community relations, norms and values (Rivera et al., 2019).

Although many studies have attempted to assess the factors that affect agricultural technology adoption, some of the studies either focused on extrinsic factors (Zander et al., 2013; Kebebe, 2019; Massresha et al., 2021) or overlooked the scale of agricultural technology that may be interrelated (Oremo et al., 2019; Chuang et al., 2020; Maina et al., 2021). There is, however, limited information on the intrinsic factors of farmers, i.e., their knowledge, attitudes, and perceptions, which affects their adoption decisions of CSD practices. Therefore, this study examines farmers' knowledge, attitude, and perceptions toward the economic and environmental impacts of CSD practices as well as the factors that influence adoption decisions.

2.2 Conceptual Framework

Adoption of improved agricultural technologies can enhance food security and environmental protection and subsequently promotes a sustainable and green economy (FAO, 2010a). The decision whether to adopt agricultural technology is not an overnight phenomenon, rather the process is influenced by the dynamic, intertwined characteristics of intrinsic and extrinsic factors (Loevinsohn et al., 2012; Meijer et al., 2015; Adnan et al., 2017). Understanding the factors preventing the adoption of more improved agricultural technologies requires knowledge of the relationships between and a characterization of the key interacting variables that take place during the adoption process. Accordingly, the possible link and relationship between intrinsic and extrinsic factors are illustrated in (Figure 2.1).

2.2.1 Extrinsic factors

Many extrinsic factors shape knowledge, attitudes, and perceptions in the decision-making process for adopting improved agricultural technologies, (Adesina and Seidi, 1995; Nguyen et al., 2006; Meijer et al., 2015). These extrinsic factors can be broadly grouped into characteristics of farmers, characteristics of the external environment, and characteristics of the technology that

help shape knowledge, attitudes, and perceptions of potential adopters (Meijer et al., 2015; Adnan et al., 2017). Accordingly, the possible links and relationships between intrinsic and extrinsic factors are illustrated in the (Figure 2.1).

Characteristics of farmers: The most important household-specific factors considerably influencing agricultural technology adoptions are age, gender, educational status, and family size (Solomon et al., 2014; Launio et al., 2018; Massresha et al., 2021). The education level of a farmer, for instance, has been assumed to have a positive influence on their decision to adopt new technology by increasing their ability to obtain, process, and apply information relevant to the adoption of new technology (Mignouna et al., 2011; Mwangi and Kariuki, 2015; Namara et al., 2003). A study by Massresha et al. (2021), Abay et al. (2016), and Challa and Tilahun (2014) on the adoption of improved agricultural technologies found that the level of education had a positive influence on the adoption of the technology. This is because higher education influences respondents' attitudes and thoughts; they become more open, rational, and capable of analyzing the benefits of new technology (Waller et al., 1998). Contrary to this, some authors have reported insignificant or negative effects of education on the up take of agricultural technology adoption (Kebeb et al., 2017; Wekessa et al., 2018).

Resources and market access: Total land holding, livestock ownership, off-farm income, and market access play a critical role in the adoption process of improved agricultural technologies. These are associated with wealth and increased availability of capital, making it more likely to invest in technologies that increase agricultural productivity and income (Kebeb et al., 2017; Wekessa et al., 2018; Hadush, 2021; Masresh et al., 2022). Access to input and the market has an enormous effect on agricultural technology adoption decisions and marketing agricultural yield. Many agricultural technology adoption studies have shown a negative association between market access and the decision to uptake agricultural technologies (Wekessa et al., 2018; Hadush, 2021; Masresh et al., 2022).

Institutional factors: Access to extension services, credit access, cooperative membership, and market linkage were found to play an important role in the adoption process of agricultural technologies (Kebeb et al., 2017; Wekesa et al., 2018; Feyiso, 2020; Masresh et al., 2022). The role of extension, training, and social capital is crucial in the development of knowledge,

perceptions, and attitudes about agricultural innovations (Meijer et al., 2015). Strong social networks serve as information hubs where farmers learn from one another and exchange ideas about new technologies, which is important for individual adoption decisions (Uaiene et al., 2009; Mignouna et al., 2011). New agricultural technologies require a substantial capital investment. Access to credit stimulates technology adoption (Mohamed and Temu, 2008) and promotes the adoption of risky technologies by relieving liquidity constraints and increasing households' risk-bearing capacity (Simtowe and Zeller, 2006).

Technology factors: The characteristics of the new technology are the most compelling in the process of technology adoption, shaping farmers' knowledge, attitudes, and perceptions (Mignouna et al., 2011; Mwangi and Kariuk, 2013; Banerjee et al., 2014). According to Adesina and Baidu-Forson (1995), farmers' subjective perceptions of the characteristics of new agricultural technologies influence their decision to adopt. Agricultural technology attributes, such as the benefits and costs of the new practice, influence knowledge, perceptions, and attitudes by influencing adoption decision (Meijer et al., 2015).

2.2.2. Intrinsic factors

Studies contend that assessing farmers' knowledge, perceptions, and practices regarding a new technology plays an essential role in developing management strategies that match farmers' aspirations and therefore are likely to sustain the new technologies (Rubia et al., 1996; Nyeko et al., 2002; Yang et al., 2005). Knowledge commonly refers to a body of information and understanding possessed by farmers about new technology. The development of knowledge about the innovation is the first stage in the decision-making process for adoption (Rogers, 1995), and it is critical in any innovation uptake process (Azman et al., 2013). Knowledge is often created through a combination of education and experiences obtained from other people and their environment (Geoghegan and Leyson, 2012), which helps farmers arrive at decisions that influence agricultural adoptions (Calvo-Iglesias et al., 2006). Farmers can learn about new technologies, how to use them, and what the outcomes are in terms of products, yield, potential environmental benefits, risks, and costs, which then form the basis of the perceptions and attitudes this individual develops toward the technology. Farmers' perceptions of innovation

depend on their felt needs as well as prior experiences, and they are closely related to the knowledge they have about it (Wessman, 2006). Attitude is defined as "a learned predisposition to consistently favour or oppose a given object" (Fishbein, 1977; Ajzen and Fishbein, 2000). It is an evaluative predisposition that influences how people act, what actions they take, and how those actions are carried out (Ajzen and Fishbein, 2000). Attitude refers to a positive or negative evaluation of an objective (Ajzen and Fishbein, 2000) and can be a strong predictor of behaviours or the acceptance of ideas (Dietz et al., 2005; Arbuckle et al., 2013).

Previous studies have identified the interconnection among knowledge, attitude, and perceptions (Pratkanis et al., 1994; Valente et al., 1998). Hungerford and Volk (1990) propose that knowledge and skills are necessary for behaviour change in the knowledge-practices relationship. In terms of the relationship between attitudes and practices, Ajzen (2011) proposed that if a person has a positive attitude and behaviors, she or he will have a more motivating intention toward an issue. Knowledge indirectly influences behaviour through its effect on attitudes and beliefs. Changes in individuals' levels of knowledge lead to modifications in their attitudes, behaviors, and practices within their environments (Blackmore, 2007). The knowledge and perceptions about innovation then, together, determine the attitude toward it and thus influence farmers' decisions about the innovation.

This study was based on the concept and essence of knowledge, attitude, and perception (KAP) of sustainable agricultural technology adoption, as suggested by Meijer et al. (2015) and Liao et al. (2022). Our conceptual framework, therefore, proposes that farmers' decisions to adopt improved dairy technology are shaped and influenced by knowledge, attitude, and perceptions, which are in turn influenced by external factors.

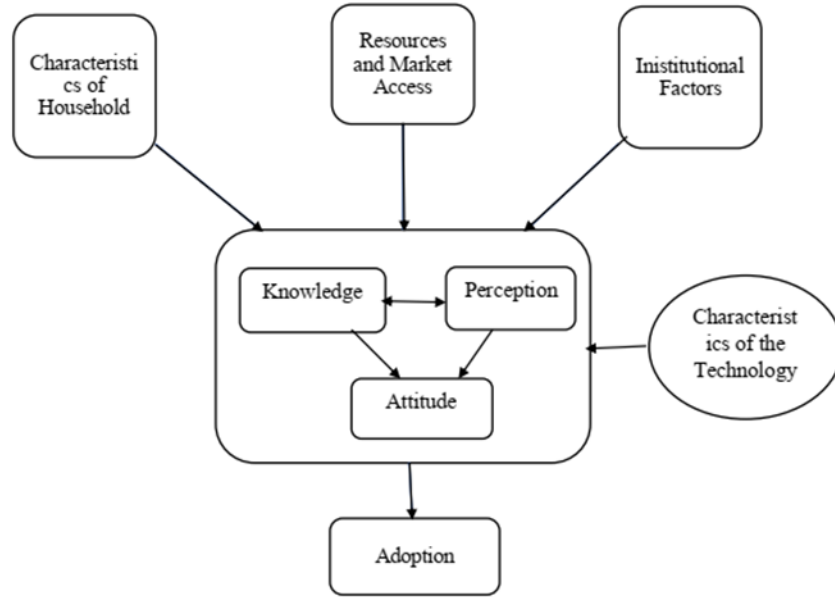


Figure 2.1 The linkages between extrinsic and intrinsic variables in the decision-making process

2.3 Materials and Methods

2.3.1 The study area

The study was conducted in the Selale highlands, the central highlands of Ethiopia (Figure 2). The study area lies at 38° 07' 60" E longitude and 9° 40' 60" N latitude and has an elevation of 1000 to greater than 3000 meters above sea level (Brandsma et al., 2013; Feyissa et al., 2018). The area receives an average annual rainfall of 1250 mm with an average minimum and maximum temperature of 7.9 °C and 21 °C, respectively (Brandsma et al., 2013). As a source of income and livelihood, dairy farming is an important part of the local economy in the study area. Selale highlands are primarily based on livestock farming, particularly dairy farming (Brandsma et al. 2013; Feyissa et al., 2018). In the study region, three smallholder dairy farming systems (rural, peri-rural, and urban) have been found and described (Yilma et al., 2011; Tegegne et al., 2013; Gizaw et al., 2016). Since the advent of modern dairy cows about 60 years ago, the Selale milk shed, the top dairy development in the nation, has a long history of dairy development (Shapiro et al., 2015; Tegegne et al., 2013; Zijlstra et al., 2015). Besides, the region is known to have suitable conditions for fodder production and the use of agricultural by-products. Farmers

have a high percentage of specialized dairy breeds and better access to artificial insemination (Zijlstra et al., 2015; CSA, 2020).

2.3.2 Data collection

Data collection was carried out between July 2020 and February 2021 in the four purposively selected districts. In each district, four peasant associations were selected by considering dairy cattle potential and accessibility. A total of 480 households were randomly selected to represent the three SHF (Tegegne et al., 2013; Gizaw et al., 2016). A KAP survey were designed to collect household characteristics data, farm inputs and outputs, and the knowledge, perception, and attitude of smallholder farmers towards CSD. The Knowledge, Attitudes, and Perceptions (KAP) is importantly used survey methodologies in social research (Vandamme, 2009). The KAP survey can be used to evaluate people's knowledge, attitudes, and perceptions about a particular topic, which can be used to ascertain how much people know about the technology, how important adopting it is to them, how positively and negatively they percieve it, and what they would do about it (Kaliyaperumal, 2004; WHO, 2008). A semi-structured questionnaire was employed to collect information from the randomly selected household.

In our study, “knowledge” refers to the understanding of the concepts of CSD practices, as described in FAO (2010). The responses of SHFs were cross-checked based on the pillars of climate-smart livestock production and rated on a Likert scale of 1 to 4, where 4 was ‘High level’, 3 was ‘Medium’, 2 was ‘Low, and 1 was ‘Poor’. A similar scale was used to assess respondents' perceptions of the environmental and economic significance of CSD technology adoption. The degree of CSD importance was assessed by asking, “How important is CSD technology to you?” (1 = Less important; 4 = very important) of SA technology. Whereas the respondent's attitude is defined as the willingness or likelihood to adopt improved practices, each respondent gave a Yes or No answer to the question about their attitudes toward CSD practices.

2.3.3 Analytical framework

In this study, we applied the KAP model used by Liao et al., 2022; Oremo et al., 2019; Tran et al., 2018, and Meijer et al., 2015 to analyze farmers' knowledge, attitudes, and perception

regarding sustainable agriculture adoptions and its determinant. Specifically, this study examines the determinants of extrinsic factors on KAP in adoption decisions of climate-smart dairy farming practices as well as the barriers to adoption. First, PCA was employed to group farmers' perceptions towards CSD practices into heterogeneous principal clusters. Utilizing the Varimax approach, the components were rotated orthogonally such that fewer strongly correlated practices were placed under each component, facilitating easier interpretation and group generalization. (Kaiser, 1974). PCA is a type of factor analysis that can reduce dimensions or uncover latent variables by extracting linear combinations that best describe the covariance among all elements (Chromy and Abeyasekera, 2005).

Farmers' perceptions were grouped based on PCA with iteration and varimax rotation in the model below.

$$\begin{aligned}
 Y_1 &= a_{11}x_{11} + a_{12}x_{12} + \dots + a_{1n}x_n \\
 Y_j &= a_{j1}x_{j1} + a_{j2}x_{j2} + \dots + a_{jn}x_n
 \end{aligned}
 \tag{1}$$

Where Y_1, \dots, Y_j = principal components which are uncorrelated, a_1 - a_n = correlation coefficient, x_1, \dots, x_j factors influencing farmers' perception. The current study, however, used general farmers' perceptions (economic and environmental importance) together in determinants of adoptions to compare the results with the existing literature and for consistency.

Econometric model: The binary and ordinal logistic regression models are frequently used in agricultural technology adoption and as factors determining adoption decisions. In this study, the logistic distribution function (logit) model was selected based on a previous KAP study to assess factors determining KAP in agricultural technology adoptions (Massresha et al., 2021; Ntawuruhunga et al., 2020; Tran et al., 2018; Oremo et al., 2019). The estimated coefficients indicate the effect of a change in the independent variables on the dependent variable (Greene, 2003). Binary and ordered logistic regression models were used for socio-economic (extrinsic) factors in determining the knowledge, attitude, and perceptions (KAP) of smallholder farmers (SHF) towards the adoption of climate-smart dairy farming practices (CSD). These models were used in modelling binary and ordered response KAP variables regarding CSD farming practices (Debara and Gebretsadik, 2016; Oremo et al., 2019).

Ordered logit model: Here farmers' knowledge and perception to climate smart dairy farm is a categorical variable, ordered as high, medium, low and poor level of understanding. Although an unordered multinomial model can estimate such data, a much more effective and sensible model takes this ordering into account. As a result, the ordinal logit model is a better fit than the multinomial model for addressing farmers' knowledge and perception to climate resilient agricultural practices (Gujarati, 2004). Greene (2003) and Liao (1994) specify the functional form of the ordinal logit model.

In ordered logit model, Y is an observed ordinal variable, which in turn, is a function of another a continuous latent variable (unmeasured) variable Y*, whose value determine what the ordinal variable Y equals. The continuous latent variable Y* various threshold points.

$$\begin{aligned}
 Y_i &= 1 \text{ if } Y_i^* \leq \mu_1 \\
 Y_i &= 2 \text{ if } \mu_1 < Y_i^* \leq \mu_2 \\
 Y_i &= 3 \text{ if } \mu_2 < Y_i^* \leq \mu_3 \\
 Y_i &= 4 \text{ if } Y_i^* \geq \mu_3
 \end{aligned} \tag{2}$$

Where Y* is equal to:

$$Y_i^* = \sum_{k=1}^k \beta_k X_{ki} + \varepsilon_i = Z_i + \varepsilon_i \tag{3}$$

$$Z_i = \sum_{k=1}^k \beta_k X_{ki} = E(Y_i^*) \tag{4}$$

Because of the random disturbance term the unmeasured latent variable Y* can be either *higher* or *lower* than Z. The K βs and the M-1 κs are parameters that need to be estimated.

$$Z_i = \sum_{k=1}^k \beta_k X_k \tag{5}$$

You then use the estimated M-1 cutoff terms to estimate the probability that Y will take on a particular value as follows.

$$\begin{aligned}
 P(Y_i > j) &= \frac{\exp(X_i\beta - K_j)}{1 + [\exp(X_i\beta - K_j)]}, j = 1, 2, \dots M - 1 \\
 P(Y_i = 1) &= \frac{\exp(X_i\beta - K_1)}{1 + [\exp(X_i\beta - K_1)]} \\
 P(Y_i = j) &= \frac{\exp(X_i\beta - K_{j-1})}{1 + [\exp(X_i\beta - K_{j-1})]} - \frac{\exp(X_i\beta - K_j)}{1 + [\exp(X_i\beta - K_j)]}, j = 2, \dots M - 1 \\
 P(Y_i = M) &= \frac{\exp(X_i\beta - K_{M-1})}{1 + [\exp(X_i\beta - K_{M-1})]}
 \end{aligned}$$

In the case of M = 4, these equations simplify to

$$P(Y = 1) = \frac{1}{1 + \exp(Z_i + K_1)} \quad (6)$$

$$P(Y = 2) = \frac{1}{1 + \exp(Z_i + K_2)} - \frac{1}{1 + \exp(Z_i + K_1)} \quad (7)$$

$$P(Y = 3) = \frac{1}{1 + \exp(Z_i + K_3)} - \frac{1}{1 + \exp(Z_i + K_2)} \quad (8)$$

$$P(Y = 4) = 1 - \frac{1}{1 + \exp(Z_i + K_3)} \quad (9)$$

The ordered logit model may therefore be used to calculate the likelihood that the unknown variable Y^* falls within the various threshold limits using the estimated value of Z and the assumed logistic distribution of the disturbance term.

Where: $P(Y = 1)$ if $Y_i^* \leq K_1$: Has poor knowledge and perception of the improved practices

$P(Y = 2)$ if $K_1 \leq Y_i^* \leq K_2$: Has low level knowledge and perception

$P(Y = 3)$ if $K_2 \leq Y_i^* \leq K_3$: Has medium knowledge and perception

$P(Y = 4)$ if $Y_i^* \geq K_3$: Has high knowledge and perception

Binary Logistic Regression (BLM): was employed to examine the association between dependent and independent variables and the directions they take when the response variable is dichotomous. A binary outcome variable coded as 1 for a yes response or 0 for a no response is used in the attitude components of a KAP study (Oremo et al., 2019; Ntawuruhunga et al., 2020).

The BLM aims at modeling the probability of the binary response variable using some of the potential explanatory variables, following the equations:

$$p_i = \frac{1}{1 + e^{-z_i}} \quad 1$$

Where: P_i is a probability of the binary response variable, by i^{th} household head

Z_i is a function of the explanatory variable (X_i).

The odds to be used can be defined as the ratio of the probability that farmers have a positive attitude towards the improved dairy farming practices, and $(1 - P_i)$ is with no response.

$$1 - p_i = \frac{1}{1 + e^{z_i}} \quad 2$$

$$\frac{p_i}{1 - p_i} = \frac{1 + e^{z_i}}{1 + e^{-z_i}} = e^{z_i} \quad 3$$

$$\frac{p_i}{1 - p_i} = \frac{1 + e^{z_i}}{1 + e^{-z_i}} = e^{B_0 + \sum B_i x_i} \quad 4$$

Taking the natural logarithm of the odd ratio of the equation will result in what is known as the logit model as indicated below:

$$\ln\left(\frac{p_i}{1-p_i}\right) = \ln[e^{B_0 + \sum B_i x_i}] \quad 5$$

$$Z = B_0 + \sum B_i x_i \quad 6$$

Hence, the logit model for the KAP parameter towards adoption of CSD practices is a function of households' socioeconomic and institutional characteristics. The model employed has the following form,

$$P_i(KAP) = Z = \beta_0 + \beta_1 \text{Age} + \beta_2 \text{income} + \beta_3 \text{education} \dots \beta_k X_k + \varepsilon_i$$

Where: β_0 is intercept

β_x = Parameter to be estimated

X_k = Hypothesized determinants of KAP

Description of variable

In addition to establishing the analytical framework, it is important to define the variables' measurements and symbols. Accordingly, the following extrinsic variables are expected to affect the KAP of smallholder farmers in adopting improved dairy farming practices.

The dependent variables: The household adoption decision of improved agricultural technologies merely depends on extrinsic and intrinsic factors. The dependent variable, KAP, is determined by external factors, an independent variable, which together influence the uptake of improved technologies (Meijer et al., 2015). In this study, we considered two ordinal variables, knowledge and perception, one binary response variable, attitude, and independent variables for regression analysis (Table 2.1). The knowledge and perception of SHF towards improved technologies are ordinal variables and were analyzed using ordinal logistic regression models, whereas the attitude of SHF was treated as a dichotomous variable, and analyzed using binary logistic regression models.

Independent variables: We hypothesized that demographic, socioeconomic, and institutional variables might influence KAP, and farmers' decisions to adopt climate-friendly dairy farming practices. Based on the adoption literature and past research findings, explanatory variables (Table 2.1) were considered in this study and examined for their effect on farmers' KAP for adoption decisions.

Table 2.1 Description and summary statistics of the variable used in the analysis

Variable	Description	Measurement	Mean	SD
Characteristics of the	Initial capital	Continuous	22560	111.2
Knowledge	Applicability	Dummy	0.62	0.57
	Rating the understanding of CSL farming practices on four point likert scale of good, average, and poor	Ordinal	1.61	0.881
Perceptions	Farmers' perceptions towards the importance of adopting CSD technology	Ordinal	1.667	1.032
Attitude	Does the respondents willing/like to undertake	Binary	0.744	0.437
Age	Age in years of the household head	Continuous	48.18	10.53
Gender	Gender of the household head	Dummy: 1= if female, 0 = male	0.05	0.227
Education	Educational status	Dummy literate = 1 illiterate = 0	0.69	0.51
Family size	Number of family	Continuous	5.23	1.78
DR	Dependency ratio	Continuous	0.42	0.34
LAND	Total land owned in acres	Continuous	3.02	1.29
TLU	Number of Livestock in TLU	Continuous	6.46	3.55
Credit	Access to credit	Dummy No= 0, Yes= 1	0.6	0.49
DNM	Distances to nearby market	Continuous km	3.24	2.41
DMC	Distance to milk collection center	Continuous walking minuets	29.03	18.01
Off-Farm	Participation in off-farm income	Dummy none= 0, yes= 1	0.14	0.34
EXS	Access to extension services	Dummy No= 0, Yes= 1	0.77	0.42

Table 5. 1 Description and summary statistics of the variable used in the analysis

*Distance is measured in walking minutes or hours.

The data were analyzed using Stata 17 statistical software, and the analysis included descriptive statistics for the respondents' socioeconomic characteristics. Pearson correlation was also used to examine the association among knowledge, practices, and attitudes regarding CSD practices and socioeconomic characteristics. Econometrics models were also used to assess the association between extrinsic factors and intrinsic factors. An index was calculated to provide an overall ranking: Index = Σ of [3 for rank 1 + 2 for rank 2 + 1 for rank 3] given for a particular reason, divided by Σ of [3 for rank 1 + 2 for rank 2 + 1 for rank 3] for all reasons.

2.4 Results and Discussion

2.4.1 Socioeconomic characteristics

The survey result showed that the majority (95%) of the households in the study area were headed by male, and most of them attended formal education (Table 2.1). The literacy level in the study area is higher than the national literacy level of 52% (WB 2017). The average age of the heads of the sampled households ranged from 30 to 79 years old. The sampled households' average dependence ratio was 0.291. Although mixed-crop-livestock farming is the dominant economic activity, about 20% of the respondents engaged in off-farm activity as a source of income. Livestock, particularly market-oriented dairy farming, is the dominant production and source of income in the study area. The mean reported livestock and land holding were 6.92 and 2.966, respectively. About 65% of the respondents had access to extension services and credit. Approximately 65 percent of the respondents were literate; 12% attended primary school or higher, and the rest could read and write. As suggested in a previous KAP study, the proportion of SHF having primary education would be an opportunity for the adoption of new and improved agricultural technologies (Oremo et al., 2019; Liao et al., 2022). Similarly, access to extension services influences farmers' knowledge and, as a result, their adoption of new technologies.

2.4.2 Climate-Smart Dairy Farming Practices

Various improved dairy technology packages have been identified and introduced to optimize the production and reproductive performance of both local and cross-bred dairy animals. The improved breed and breeding, improved feed production and utilization, improved health services, and improved manure management techniques are the main topics of these packages. Different types of smart-dairy technologies by smallholder farmers in the study area are depicted in the Table 2. 2. The main improved dairy farming practices used include: improved breeding, artificial insemination, improved feed and feeding conditions, and improved forage and health services. Some farmers engage in multiple interdependent CSD practices at the same time, indicating that the various CSD practices are linked. These findings are similar to the previous improved agricultural adoption study in Africa and India (Aryal et al., 2018; Kebebe et al., 2017;

Teklewold et al., 2013). The majority of smallholder farmers adopted improved breed, improved feed, and other supplementary technologies.

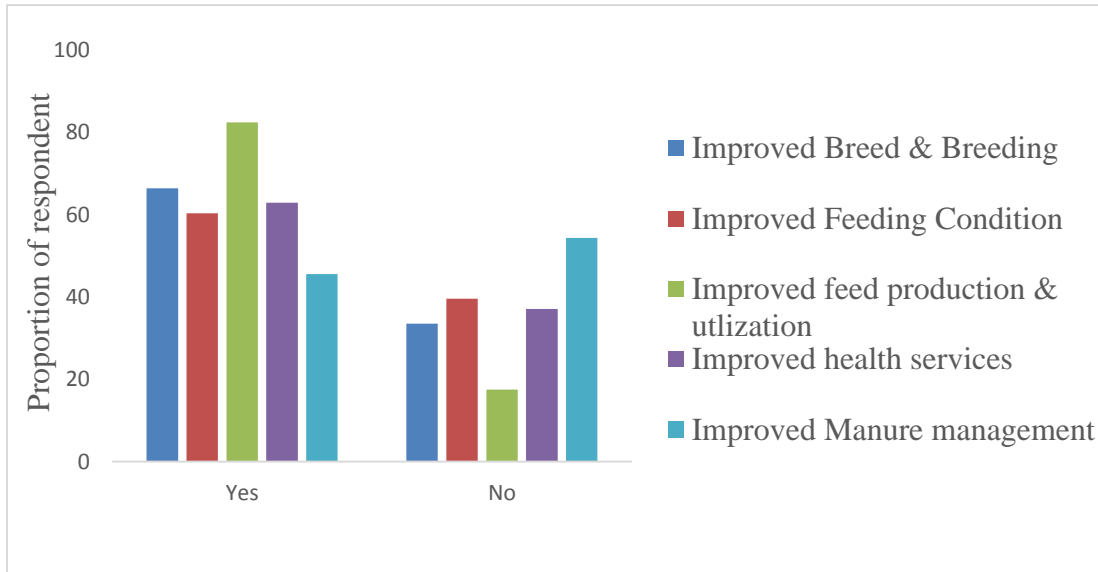


Figure 2.2. Climate Smart Dairy farming practices

Positive correlations were found among improved breed and AI, improved breed and feeding, improved breed and feeding condition, and improved breed and health services, demonstrating how dairy farming technologies complement one another. Similarly, improved feeding was significantly correlated with AI, feeding conditions, and improved forage (Table 2. 2). These results show that farmers adopt these practices primarily as complements. Consistent with our findings, Kebebe et al. (2017) indicated that multiple dairy technologies are significantly and positively correlated in Ethiopia and Kenya, which show the complementarity of the improved practices.

Table 2. 2 Correlation of improved farming practices

Variables	1	2	3	4	5
1 Improved breed & breeding	1.00				
2 Improved feed production & utilization	0.265***	1.00			
3 Improved feeding conditions	0.341***	0.24***	1.00		
4 Improved health services	0.393***	0.14***	0.22**	1.00	
5 Manure management	0.71***	0.27***	0.26***	0.13***	1.00

P value: *** Significant at P<0.01; **Significant at P<0.05% level; *Significant at P<0.1, feeding conditions (stall feeding, semi-grazing, and free grazing)

2.4.3 Farmers' knowledge, attitude, and perception

Perception

Perceptions of farmers were assessed using a likert scale and analyzed using PCA. The PCA analysis elicits two components that evaluate farmers' perceptions of the economic and environmental importance of CSD practices (Table 2.3). The two components of PCA explained 67.06 percent of the total variability in the farmers' perceptions data set. The first component explains 32.75 percent, while the second explains 25.34% percent of the total variation in the data on improved dairy technology perception. The first component was about farmers' perceptions of CSD practices in terms of their economic and social impacts, including CSD's ability to adapt to climate change impacts as well as enhance animal productivity. In the second component, CSD practices address environmental concerns, such as mitigating GHG emissions, using manure as fertilizer to boost crop production, and reducing the degradation of grazing lands.

Table 2.3 Loadings of the two components of farmers' perceptions

Perceptions	Comp 1	Comp 2	Communality
CSDF resilient to CCh impacts	0.820	0.257	0.337
CSDF enhance animal productivity	0.748	0.315	0.739
CSDF improve farmers income	0.710	0.302	0.658
CSDF reduce GHG emissions	0.367	0.489	0.595
Use of manure as fertilizer boost crop production	-0.377	0.898	0.947
CSDF improve grazing land productivity	-0.379	0.897	0.948
Eigen value	2.156	1.868	
Eigenvalues % contribution	35.93	31.13	
Cumulative	35.93	67.06	

Most farmers have a modest perception and understanding of what CSD practice is and the economic and environmental consequences it may have (Figure 2.). Farmers have a slight variation in perception between the environmental and economic importance of CSD practices. Most farmers in the study area believed that CSD practices had more economic and environmental importance than the traditional farming system. About 85 percent of SHF believes that improved dairy farming practices enhance animal productivity and farmers' income.

Significant proportions of respondents, about 60%, believe that the improved practices also contributed to environmental benefits.

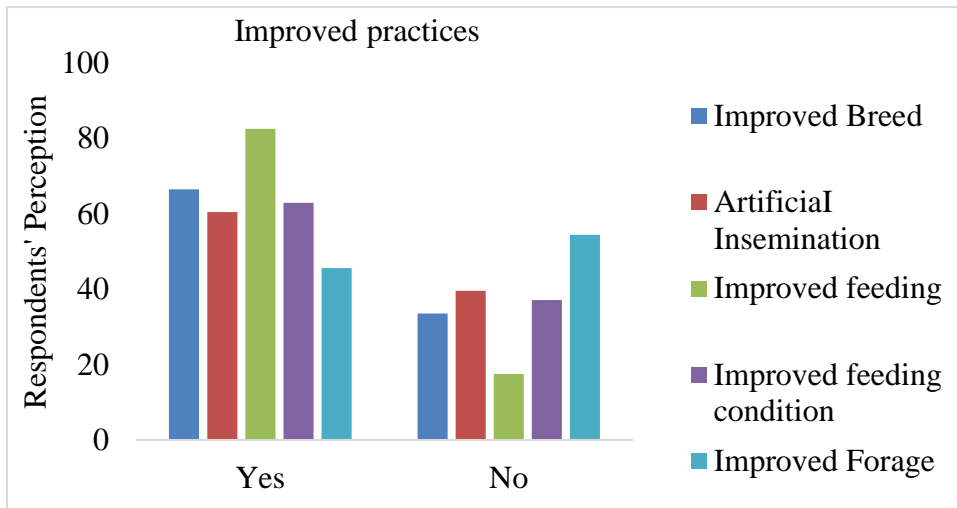


Figure 2.3 Improved dairy farming practices

Knowledge

Farmers' knowledge of CSD was assessed using a four-point Likert scale of high, medium, average and poor understanding (Figure 2.). According to our findings, nearly half of the respondents (40%) had a moderate level of knowledge of CSD practices, 20% had a high level of knowledge, and approximately 30% had a low level of knowledge. Most respondents' (85%) knowledge about CSD principles rated as medium and average.

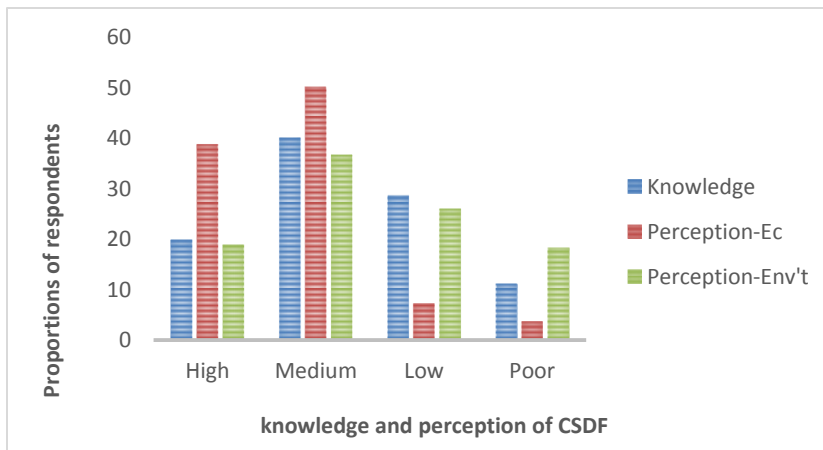


Figure 2. 4 Rating the knowledge and perceptions of CSD among respondents

According to Meijer et al. (2015), an individual's knowledge of a improved practices serves as the foundation for awareness that the individual develops toward the technology.

Attitude

According to Meijer et al. (2015), an individual's knowledge of a improved practices serves as the foundation for the awerness that the individual develops toward the technology. According to the results, 85% of respondents had a favourable opinion of the enhanced practises. Approximately 90% of farmers expressed a positive attitude toward reducing GHG emissions from animal agriculture and a willingness to adopt or promote climate-resilient dairy farming practices (Figure 2.). Although most farmers expressed support for sustainable agriculture, attitudes differ among smallholder farmers and are heavily impacted by external variables. This is consistent with the findings of Liao et al. (2022) and Zewelde et al. (2017), who found that most surveyed farmers have positive attitudes toward sustainable agriculture when it is used to achieve specific goals, such as increasing agricultural productivity, enriching biodiversity conservation, and improving their livelihoods and incomes. Similarly, Liao et al. (2022) found that the different attitudes of Thailand farmers towards sustainable agriculture generally reflect their different expectations of sustainable agriculture, and culture, values, and socioeconomic status also play important roles in attitude formation.

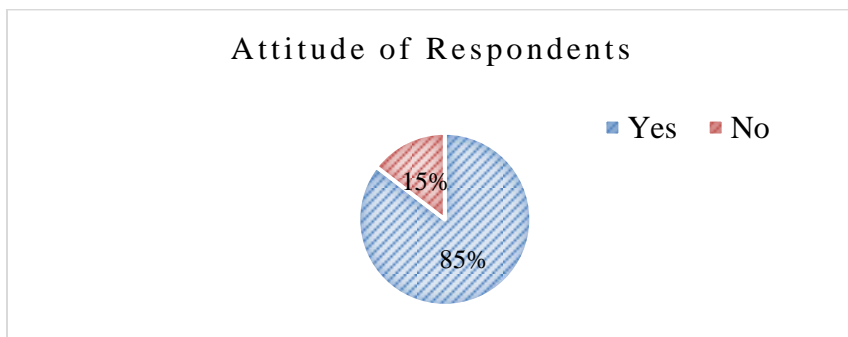


Figure 2.5 Farmers' attitude towards improved technology

2.4.4. Determinants of knowledge, attitude and perception

The adoption of improved dairy farming practices was significantly influenced by various extrinsic factors. The regression results indicated that age, education, access to information,

extension services, distance to market, and distance from the farmers' training center significantly explained all response variables, namely knowledge, attitude, and perceptions towards adoption of CSD practices.

Knowledge

The high level of households' knowledge about CSD practices was positively and significantly explained by age, education, access to information and extension services (Figure 2.). Whereas off-farm activity, distance from the district and farmers' training center negatively and significantly explained knowledge about the improved technology. For a one unit increase in education, access to information and extension services, i.e., from 0 to 1, the probability of having high level of knowledge of the improved practices is increased by 18.7, 19% and 7.7% respectively, but decreased by 1%, 7%, 6.6%, and 6% respectively. Likewise, for a year increase in household age, the probability of having medium to high level knowledge of the improved practices increased by 1.2%. This might be because education, age (farming experiences), and extension services allow farmers to have more experience, practical knowledge, and skills than their younger counterparts. Our findings are consistent with the previous KAP study by Dean et al. (2016), Oremo et al. (2019), and Tran et al. (2018), which found a positive and significant association between education, age, and extension services with knowledge. Similarly, Meijer et al. (2015), indicated that extension and training are crucial in the development of knowledge, perceptions, and attitudes about agricultural innovations. Most importantly, Farmer-led extension, in which farmers are the primary agents of change in their community and help disseminate new technology to other farmers, has become increasingly popular (Franzel et al., 2004; Franzel et al., 2001; Kiptot et al., 2006). This is presumably because, farmers greatly value local experiential knowledge as they see it as having practical, personal, and local relevance. Similarly, the work of Wolf (2010) has acknowledged the importance of linking agricultural research to farmers' knowledge in agricultural technology up-take and dissemination. On the other hand, off-farm activity, distance to the nearest market and farmers' training centers (FTC) negatively and significantly correlated to the high level of knowledge of smallholder farmers, which influence the adoption decision. The FTCs serve as extension hubs, and extension agents serve as the channel for knowledge flow, to promote new agricultural technologies to reach farmers. The local market is important for remote rural farmers because it

allows them to exchange information with other farmers and facilitates technology adoption. Although membership in an agricultural cooperative is not statistically significant, participation in a network can improve knowledge and understanding of improved agricultural technologies and influence new technology uptake.

Table 2.4 Marginal effects for the farmers' knowledge

Variables	Level of knowledge			
	1	2	3	4
Gender	-0.06* (0.031)	-0.02 (0.01)	0.0001(0.01)	0.08* (0.04)
Age	-0.001*** (0.001)	-0.003***(0.001)	0.001(0.001)	0.02*** (0.001)
Education	-0.14*** (0.02)	0.04*** (0.01)	0.001(0.012)	0.14***(0.03)
ICT	-0.01***(0.001)	0.002***(0.0001)	0.00004(0.001)	0.01***(0.002)
Off-farm	0.023*(0.012)	0.023*(0.011)	0.021*(0.01)	0.07*(0.03)
Extension service	-0.07***(0.015)	-0.065***(0.014)	-0.06***(0.014)	0.191***(0.04)
Distance	0.0045***(0.001)	0.064***(0.0014)	0.0036*(0.015)	-0.012***(0.004)

P value: *** Significant at $P < 0.01$; **Significant at $P < 0.05$ level; *Significant at $P < 0.1$; *FTC* = *Farmers training Center (in walking minutes)*, *ICT* = *Initial capital for the technology*, *BT* = *Benefits of the technology*

Perception

Age, educational status, extension services, and distance to market and farmers' training centers were found to play a significant role in determining farmers' perception of CSD practices (Table 2.5). High level of farmers' perception was found to be positively influenced by age, educational status, extension services, but negatively influenced by off-farm activity, distance to market, and FTC. For every unit increase in household education and extension services, the probability of farmers having high level climate smart dairy perception increase by 18.7% and 19% respectively. On the other hand, age, education, and extension services had inverse relation with medium to low level of farmers' perception. In the same way, an increase in one more year of farmers' age resulted in increase the probability of farmers' perception by 1.2%. In line to our findings, a study of farmers' perceptions of tree mortality, pests, and pest management practices in agroforestry found that farmers' perceptions are influenced by education, experience, and gender (Sileshi et al., 2008). Similarly, Massresha et al., (2021) indicated that age, education, TLU, and access to extension services influenced farmers' perceptions of agricultural technology adoption. According to Massresha et al. (2021), farm experiences, level of education, TLU, and family size influence farmers' perception and thus adaptation to climate change.

Table 2.5 Marginal effects of farmers' perception

Variables	Level of knowledge			
	1	2	3	4
Age	-0.01*** (0.001)	-0.003***(0.001)	0.001(0.006)	0.012*** (0.001)
Education	-0.07*** (0.014)	-0.064*** (0.015)	-0.06***(0.014)	0.187***(0.037)
Of farm activity	0.023*(0.011)	0.023*(0.011)	0.021*(0.01)	-0.067*(0.03)
ICT	-0.012*(0.01)	-0.012*(0.01)	-0.0112(0.01)	0.036 (0.018)
Extension service	-0.066***(0.015)	-0.065***(0.014)	-0.06****(0.014)	0.19****(0.037)
Access to info	-0.06*(0.031)	-0.017(0.01)	0.0003(0.01)	0.077(0.04)
Member of coop.	-0.01(0.014)	-0.003(0.004)	0.0001(0.0001)	0.012(0.018)
Distance mark	0.004***(0.001)	0.004***(0.0014)	0.0036*(0.015)	-0.012***(0.004)
Distance milk	0.006***(0.004)	0.002***(0.001)	0.001*(0.001)	-0.005***(0.001)

P value: *** Significant at P<0.01; **Significant at P<0.05% level; *Significant at P<0.1

FTC = Farmers training Center (in walking minutes), ICT = Initial capital for the technology, BT = Benefits of the technology

Attitude

Age, education, and extension services have significant effects on farmers' attitudes toward the adoption of improved dairy farming practices (P<0.05) (

Table 2. 6). All of these variables positively contribute to the willingness of farming households to engage in CSD program, but to different magnitudes. On the other hand, distance to market and the FTC have negatively explained farmers' attitudes toward improved dairy farming practices. An increase in age (years) been associated with 108% in odds of willingness to participate in improved farming activities, respectively, whereas having a higher level of education and access to extension services are associated with 8.82 times and 3.48 times higher odds of willingness. Our present findings are consistent with previous KAP studies on the role of age, education, and income in the causes of land use and land cover change, as well as water resource management (Tran et al., 2018; Oremo et al., 2019). Similarly, in South Africa and Kenya, the role of extension services in increasing understanding and support for sustainable agricultural practices and water resource management is well documented in Oremo et al. (2019) and (Oremo et ., 2019; Ntawuruhunga et al., 2020).

Table 2. 6 Marginal effects for the farmers' attitude

Variables	Attitude		
	Coefficient	SE	Odd ratio
Gender	0.91	0.7	2.49
Age	0.075***	0.02	1.08
Education	2.11***	0.34	8.82
Family size	0.13	0.086	1.16
Dependency ratio	1.32	1.55	3.23
Farm size	-0.75	0.12	1.1
TLU	-0.028	0.04	0.97
Off-farm	0.18	0.32	1.17
Extension service	1.22***	0.32	3.48
Distance 2 woreda	-0.69**	0.32	0.54
Credit access	0.19	0.34	0.83
Member coopera	0.18	0.31	1.23
Access to info	0.053	0.04	1.05
FTC	0.002	0.014	0.99
FTO	0.01	0.18	1.01
BT	0.026	(.024	1.03

P value: *** Significant at P<0.01; **Significant at P<0.05% level; *Significant at P<0.1; *FTC = Farmers training Center (in walking minutes), ICT = Initial capital for the technology, BT = Benefits of the technology*

2.4.5 Associations between knowledge, attitude, and perception

The correlation between knowledge, perception, and attitude in the adoption decision of CSD practices (Table 2. 7). Knowledge, attitude, and perception of improved dairy farming practices were found to have positive and significant associations. In addition, the predictors of attitude and perception in CSD practices were similar to those that determine knowledge towards CSD practices. This shows the interdependence of intrinsic factors in the process of adoption decisions. A similar observation was reported in a previous KAP study (Oremo et al., 2019; Meijer et al., 2015). Consistent with our findings, Meijer et al. (2015) indicated that farmers' perceptions of innovation are very closely related to their knowledge, which together determines their attitude toward it.

Table 2. 7 The correlation between KAP

No	KAP	1	2	3
1	Knowledge	1.000		
2	Attitude	0.6517***	1.000	
3	Perception	0.7533***	0.6478***	1.000

*** Indicate significance at $P < 0.01$

Similarly, the correlation output revealed that knowledge and perception of the technologies were significantly correlated with all improved technologies except improved forage (Table 2. 8). This indicated that a good understanding of CSD practices appears to be a prerequisite for the uptake and implementation of improved technologies. These findings are consistent with previous research, which found a positive and statistically significant relationship between improved technology and knowledge and perception (Chuang et al., 2020; Tran et al., 2018). According to Chuang et al. (2020), households with higher levels of knowledge and perceived importance of technology would adopt more innovative farming practices.

Table 2. 8 Correlation between improved farming practices and KAP

KAP	Improved breed & breeding	Improved feed production & utilization	Feeding conditions	Manure management	Animal health
Knowledge	0.3018***	0.1182**	0.1853***	0.361***	0.15***
Perception	0.184***	0.112**	0.087*	0.205***	0.168***
Attitude	0.5163***	0.248***	0.213***	0.541***	0.24***

P value: *** Significant at $P < 0.01$; **Significant at $P < 0.05$ level; *Significant at $P < 0.1$

AI = artificial insemination, feeding conditions (stall feeding, semi-grazing and free grazing)

2.4.6 Barriers to adoption of improved practices

Studies have shown that it is important to understand barriers to adoption, and the design of mitigation measures must take these barriers into account (Van Dijk et al., 2016, FAO-NZRC, 2017). Figure 2. depicts the barriers of adoption to climate smart dairy farming practices in the study area. Lack of initial capital, feed problems, lack of market linkage, and the rise of production input, scarcity of land, inadequate services, and lack of information on dairy management are the main barriers

to the adoption and implementation of CSD practices. Smallholder farmers have noted that the feed problem (quality and quantity) is the most important problem to adaptation and implementation of improved dairy farming practices. Ethiopian livestock productivity and production are adversely affected by a lack of feed, both in quantity and quality, seasonal fluctuations, and the poor quality of the available feed (Tolera, 2012; Gizawu et al., 2017). It is more difficult to ensure feed supplies during the dry season in rural and peri-urban areas than in urban areas, where the best resources for feed are crop residues and concentrates (Gizawu et al., 2017; Tegegn et al., 2013). The most important constraints encountered by producers and smallholder dairy cooperatives are access to input and output delivery systems and market linkage to access affordable inputs and services and to sell liquid milk to the major urban market in the study area. The condition is exacerbated by market access during the fasting period, low product prices, less demand for processed dairy products like cottage cheese, and frequent maintenance requirements of cream separators in cooperative dairy plants (Gizawu et al., 2017; Tegegn et al., 2017). Inadequate access to health services and poor herd health management, as well as poor AI service delivery and efficiency, are also the main constraints for improved dairy development in the study area. Consistent with our observation, Mutoko et al. (2015) reported similar barriers to the adoption of improved fodder crops in Kenya and the promotion of sustainable cattle ranching in Brazil (Ermgassen et al., 2019).

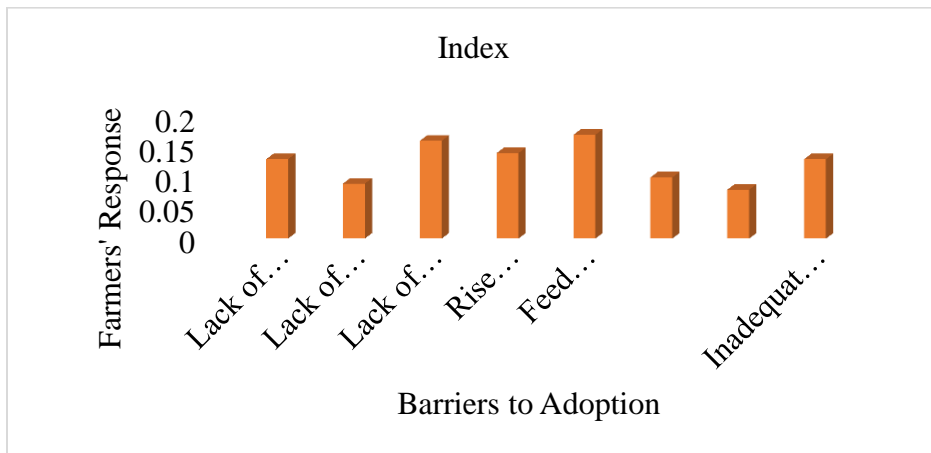


Figure 2.6 Barriers to adaptation of improved farming practices

2.4.7 Conclusions

The study was designed to investigate the knowledge, attitude and perceptions of farmers towards improved dairy farming practices and their determinants. The study findings revealed that there was a positive and strong correlation among knowledge, attitude, and perception (KAP) towards improved dairy farming systems. The predictive factors towards climate smart dairy farming practices were similar for all knowledge, attitude, and perception (KAP). Age, education, and extension services positively explained knowledge, attitude and perceptions, whereas distance to the farmers training center, and districts' markets negatively explained KAP. Smallholder farmers have a better understanding of CSD if they are well educated, older and have access to extension services. Greater endowments and better access to input services and the output market will have an impact on smallholder farmers' KAP toward new technology. Resource constraints, supply chain bottlenecks and market linkages, inadequate services, and a scarcity of information on dairy management have been reported as hindering improved dairy technology adoption and implementation in the study area. Therefore, interventions that overcome the constraints related to access to farm resources and the supply chain for technological inputs and services and output markets could facilitate the uptake of dairy technologies. Market access constraints could be alleviated through infrastructure improvements and targeted institutional arrangements for the distribution of technological inputs and services could improve technology adoption and productivity in dairy.

Chapter Three

3. Effects of improved smallholder dairy farming practices on farmers' food security

Abstract

Sustainable livestock farming practices have the potential to improve productivity and high income, reduce greenhouse gases, and improve household food security. Despite previous efforts to disseminate these technologies, the rate of adoption has remained very low in Ethiopia. In this study, we investigate the determinants of adoption and the impact of improved dairy farming practices (IDFP), which include improved breed, improved feed, and improved feeding conditions, on household food security in the central highland of Ethiopia. A multi-stage stratified random sampling technique was used to select 480 smallholder farmers from four districts. The study employed principal component analysis (PCA) to group IDFPs, and the endogenous switching regression model (MESR) was used to examine household food security status. Our findings showed that IDFP adoption had a significant and positive impact on per capita food consumption and increases the likelihood of smallholder farmers being food secure compared to non-adopters. The adoption of integrated IDFP had a greater impact on household food security when smallholder farmers used a package that incorporates improved breeds, feeds, and feeding systems (B₁F₁S₁). The implementation of this package increased food security by 31% in terms of household food consumption score (HFCS) and 26% in terms of household diet diversity score (HDDS). Additionally, the size of livestock holdings, off-farm income, extension services, and milk collection centers all influenced the adoption decision of this package. It has been confirmed that improving dairy farming practices for sustainable development can significantly contribute to the food security of smallholder farmers when used in combination. Interventions that address access to farm resources, the supply chain for technological inputs and services, and output markets may assist in the adoption of dairy technologies.

Keywords: Adoption, Dairy farming, Food security, Improved Technologies, Selale, Smallholder farmers

3.1 Introduction

Global livestock production is at a crossroads in terms of adapting to climate change and reducing greenhouse gas emissions while ensuring sustainable development goals (FAO, 2011). To achieve food security, reduce poverty, and address climate change without depleting natural resources, livestock production must undergo a major transformation in the coming decades. The sector is a significant source of livelihood and employment opportunities for millions of smallholder farmers around the world. For instance, in sub-Saharan Africa (SSA), livestock is a primary source of livelihood for many low-income rural farmers (Muehlhoff et al., 2013). Livestock is an integral part of agriculture in Ethiopia, accounting for about 45 percent of the total value of agricultural production and supporting the livelihoods of a large share of the population (CSA, 2020). About 70% of the Ethiopian population rear livestock, including many poor people, for their source of livelihood (FAO, 2019b). On the other hand, livestock supply chains are significant sources of global greenhouse gas (GHG) emissions, accounting for up to 14% of total GHG emissions (Gerber et al., 2013). In addition to land and forest degradation effects (Barona et al., 2010), animal products are often less efficient at utilizing nutrients and have a large water footprint than other foods (Bouwman *et al.*, 2011; Mekonnen and Hoekstra, 2012).

The growing demand for livestock products as a result of population growth and diet changes will allow smallholder farmers (SHFs) to improve animal productivity by improving breeds, improving feed and feeding conditions, improving animal health services, and using animals as a vehicle to escape poverty. Smallholder dairy farming is one of the leading agricultural industries in Ethiopia. A sector is a viable option for improving farmers' household income and food security (FAO, 2018a; FAO, 2019b). Ethiopia possesses one of the most diverse and distinct livestock production systems in Africa. About 65 million cattle are estimated to be found and kept under different farming systems and production objectives (CSA, 2020). Despite Ethiopia's large cattle population and favorable development environment, per-animal productivity is significantly lower than its potential owing to inadequate feed quality and quantity, the low genetic potential of indigenous breeds, poor animal health services, and poor management practices (Tegegn et al., 2013; Gizaw et al., 2016). The national average daily milk yield per cow

is 1.49 liters (CSA, 2020), and per-capita consumption of beef and cow milk is 6.5 kg and 43.3 liters per year, respectively (FAO, 2019b), lower than the per-capital consumption of most African countries (FAO-NZAGRC, 2017). As a result, Ethiopia is a net importer of dairy products to satisfy the increasing demand for dairy products (FAO-NZAGRC, 2017).

Recently, sustainable intensification of the agricultural system has been proposed as a strategy to increase agricultural productivity and resource efficiency (McDermott et al., 2010; Smith, 2012). In light of this, several technologies that involve the use of improved technologies in breeding (e.g., artificial insemination, selection, and cross-breeding), feeding (e.g., planting improved forage and fodder trees and using agro-industrial by-products), and management (e.g., vaccination and anti-parasitic medicaments) have been promoted (Mekoya et al., 2008; Duncan et al., 2013). These improved dairy technologies can be viewed as sustainable strategies for increasing animal productivity, productive capacity, and farmers' food security, thereby improving smallholder farmers' resilience and adaptation to climate variability and change. Furthermore, improved dairy farming practices are important in reducing greenhouse gas emissions and degrading ecosystem services (Gerber et al., 2013; Opio et al., 2013). Despite the multiple benefits of improved dairy technologies and deliberate efforts of the government and development partners to encourage smallholder farmers, the uptake rate of dairy technologies is very low and varies significantly across the country (Mekoya et al., 2008; Duncan et al., 2013; Kebebe, 2019).

In spite of numerous successful pilot projects on agricultural products, technologies, and models, scaling them up has proved challenging, especially in the livestock sector, due to incompatibility with local farming (Kebebe, 2018; Kathage et al., 2015). Understanding why smallholder farmers do not adopt improved technologies and what motivates people to select a specific package from the options is a critical area of inquiry and policy development. According to Loevinsohn et al. (2013), the dynamic interaction between a technology's characteristics and varying conditions and circumstances influences farmers' decisions about whether and how to adopt a new technology. Individual decisions often result from comparing the uncertain benefits and costs of adopting a new technology (Hall and Khan, 2003). Similarly, smallholder farmers often have varying access to basic services, information, and basic knowledge of the market system, all of

which limit their ability to invest, expand their market surplus, and add value to their produce (Deininger et al., 2003; Dercon et al., 2012).

Several studies have been conducted to evaluate the effects of improved dairy technology on farmers' food security and the factors that determine adoption (Chelkeba et al., 2016; Kebebe, 2017; Hadush, 2021). Some of these studies, however, either ignored the scale of technology adoption, which is potentially inter-related and may provide better outcomes when adopted jointly (Melesse and Jemal, 2013; Hadush, 2021); or the analytical model failed to account for differences in welfare outcomes between adopters and non-adopters of improved dairy technologies caused by unobservable differences among smallholder farmers (Chelkeba et al., 2016; Kebebe et al., 2017). Ignoring the unobservable difference between adopters and non-adopter smallholder farmers could lead to wrong conclusions (Heckman et al., 2001). Furthermore, using logit or probit models to assess factors influencing the adoption of dairy technology fails to control for unobserved heterogeneity effects on farmers' technology adoption decisions. When subjects in non-experimental studies cannot be randomly assigned to "treatment" and "control" groups, these regression methods may be less effective in dealing with the sample selection problem (Heckman et al., 1998; McKenzie et al., 2010). Hence, we use a multinomial endogenous switching regression approach to control for selection bias while considering the impact of IDFPs on food security.

The present study attempts to fill this knowledge gap by using an endogenous switching regression model to identify factors that influence the choices of improved dairy technologies and investigate the impact of improved dairy technologies on farmers' food status.

3.2 Dairy farming system and technology use in Ethiopia

Recent data estimates 65 million cattle, of which 97.76% are local breeds with low genetic potential for milk production, and the remaining are hybrid and exotic (CSA, 2020). Approximately 97% of cattle milk is produced by indigenous cattle, while 3% is produced by pure exotics and crossbreeds (FAO-NZAGRC, 2017). Most of the cattle are kept by smallholder farmers who raise low-productivity indigenous breeds and feed them with natural pastures and

crop residues. They also follow an underdeveloped market for inputs and outputs (Tegegn et al., 2013; Gizaw et al., 2016). By-products from the flour and oil industries, as well as brewery residues, are the main supplementary feeds. Smallholder farmers who keep improved dairy cows also cultivate improved forage crops such as elephant grass, oats, vetch, and alfalfa to supplement grazing (A Tegegne et al., 2013; Gizaw et al., 2016; Feyissa et al., 2018).

In Ethiopia, three smallholder dairy farming systems (urban, peri-urban, and rural) are identified and characterized based on agro-ecology, production objectives, sources of feed and feeding system, breeds and genotypes kept, and integration with crop production (Tegegne et al., 2013; Gizaw et al., 2016). Dairy farming systems distinguish between breeds and genotypes kept and the feeding conditions (Tegegn et al., 2013). Urban and peri-urban smallholder farming systems are more likely to keep medium-high grade cows with exotic blood and use stall feeding and semi-grazing. Rural smallholder farmers keep low-grade cross-bred cows with exotic blood levels and multi-purpose local zebu breeds (Gizaw et al., 2016).

In response to the growing demand for animal-sourced foods, SHFs are anticipated to make investments that increase production and productivity (FAO-NZAGRC, 2017). Various dairy technology packages have been identified and introduced to optimize the production and reproduction performance of both local and cross-bred dairy animals. These improved packages, which focus on breeding, feed and feeding management, and improved husbandry, can increase animal productivity while also improving smallholder livelihoods, household income, and improving nutrition. Despite many years of effort, smallholders do not use these technologies widely, and dairy cow productivity remains low (Boichard and Brochard, 2012; Duncan et al., 2013).

We identified and classified the existing improved dairy farming practices based on their relative economic and environmental importance, as well as their interdependence and complementarity of practices. The technologies were categorized using principal component analysis into three categories (IDFPs): improved breed, improved feed and forage, and improved feeding system.

Improved Breeds: Increased milk production is one of the leading dairy breeding goals worldwide (Bařłowska et al., 2009). However, new breeding goals, particularly in milk composition, have recently been identified in response to the demands of a healthier human diet

(Boichard and Brochard, 2012). An efficient, systematic, and operational breeding strategy is necessary to improve the dairy sector and increase milk production. Initial dairy development efforts focused on introducing high-yielding dairy cattle (Friesian and Jersey) to the highlands and around major urban areas, where they were crossed with indigenous breeds to improve the production potential of local breeds (Ahmed et al., 2004; Tegegne et al., 2010; Ayenew et al., 2011). Crossbreds have longer lactation periods, and shorter calving intervals and calves are younger than indigenous breeds (Galukande et al., 2013). This has encouraged farmers to adopt improved breeds, resulting in higher milk yields and economic returns. Hence, SHFs with a cross or highbred dairy cows are considered an indicator of dairy technology adopters.

Improved feed production and utilization: Feed is the primary input in milk production, and the performance of the dairy industry is primarily hampered by low quality and quantity, as well as seasonal fluctuations of feed resources in the central highlands (Yilma et al., 2011; Brandsma et al., 2012). Without the adoption of improved feed and forage production for livestock-rearing households in the highlands of Ethiopia, grazing land shortages and degradation will have devastating effects on food security and the environment (Klitzing et al., 2014). Improved forage, feed conservation practices, and industrial by-products have been promoted to alleviate the shortage of livestock feed. Using improved feed and forage by SHFs is considered an adopter of improved practices.

Stall feeding/ zero-grazing (ZG): this management practice is believed to have economic and environmental importance compared to extensive grazing systems. It improves animal performance and fodder productivity and minimizes land degradation, disease prevention, and manure management (Hadush and Hagos, 2018; Hadush, 2021). Recent studies in Ethiopia's highlands indicated that farmers benefit by earning a higher income from milk and meat and having higher traction power under ZG than traditional grazing (Hadush and Hagos, 2018; Hadush, 2021). Hence, the use of stall feeding by SHFs is considered an adoption of improved practices.

3.3 Materials and Methods

3.3.1 Description of the study area

The study was carried out in the Selale milk shed in Ethiopia's central highlands (Figure 2). The Selale milk shed covers a wide territory, extending from Kuyu districts in the north to Bahirdar, the Amahara regional state, and from Suluta, on the outskirts of Addis Abeba. Livestock, particularly dairy farming, is the integral agricultural enterprise and source of income in the Selale highlands (Eba, 2012). The subsistence mixed crop-livestock farming system dominates the smallholder agricultural production system in the study area (Eba, 2012). Smallholder dairy farms dominate the dairy industry in the area (Brandsma et al., 2013), and three smallholder dairy farming systems (urban, peri-urban and rural) were identified and characterized by Tegegn et al. (2013), and Gizawu et al. (2016).

The study area was selected due to its high milk production potential and the importance of dairy farms in the local economy as a subsistent agriculture. The Selale milk belt, the leading dairy development in the country is known for having a long history of dairy development ever since the introduction of modern dairy cows some 60 years ago (Tegegn et al., 2013; Zijlstra et al., 2015). Besides, the region/area is known to have suitable conditions for fodder production and the use of agricultural by-products. Farmers have a high percentage of specialized dairy breeds and better access to artificial insemination (Gizaw et al., 2016; CSA, 2020. CSA's (2020) annual report shows that the region/area holds the largest cross-bred dairy cow population.

3.3.2 Sampling and data collection

This study employed a multi-stage stratified random sampling technique to select SHFs. The first four districts (Sululta, Wuchale, Girar Jarso, and Degem) were purposively selected from Selale milk belt to represent the mixed crop-livestock farming system and suitability for dairy farming. Four kebeles (the smallest administrative units in Ethiopia) were purposively selected from each district by considering dairy cattle potential and road accessibility. In each kebele, SHFs were stratified into adopters and non-adopters of improved farming practices based on dairy

technology adoption indices, such as improved breed, improved feeds and forage production, and feeding conditions (stall feeding, free grazing) promoted through the extension system.

A total of 480 SHFs were randomly selected to represent adopters and non-adopters based on (Arsham, 2007). A survey questionnaire was designed to collect data on farm household characteristics, farm input-output, feed sources, feeding practices, and productive and reproductive performance. Three enumerators, experts in livestock production, were selected from each district and were given orientation and refresher training on the household survey. Data collection was held between July 2020 and February 2021. The first author supervised the survey. The survey data was triangulated using a transect walk and group discussion.

3.3.3. Analytical framework

This study used the methodology of (Kassie et al., 2015; Wekesa et al., 2018), which used a multinomial endogenous switching regression model to assess how individual and alternative combinations of improved dairy farming practices (IDFP) affect household food security. Specifically, this study examines the impacts of multiple IDFPs, such as improved breeding, improved feeds and forage, and feeding systems, on farmers' livelihoods.

First, Principal Component analysis was employed to group improved dairy farming practices into heterogeneous principal clusters. The components were rotated using the orthogonal rotation (varimax method) (Kaiser, 1974) so that a smaller number of highly correlated practices were put under each component for easy interpretation and a generalization about a group. Principal Component Analysis is a type of factor analysis that can reduce dimensions or uncover latent variables by extracting linear combinations that best describe the covariance among all elements (Chromy and Abeyasekera, 2005).

In the model below, IDFP practices were grouped based on PCA with iteration and varimax rotation (Field, 2009).

$$Y_1 = a_{11}x_{12} + a_{12}x_{12} + \dots + a_{1n}x_n$$

$$Y_j = a_{j1}x_{j1} + a_{j2}x_{j2} + \dots + a_{jn}x_n \quad (1)$$

Where Y_1, Y_j = principal components which are uncorrelated, a_1 - a_n = correlation coefficient, x_1, \dots, x_j factors influencing choices of a particular strategy. The output of previous studies guided the selection of these practices in the study area (Wekesa et al., 2018; Hadush, 2021).

Multinomial endogenous switching regression (MESR) was used to model determinants of IDFPs' adoption and effects of improved practices after grouping them into "n" heterogeneous groups. Then household food consumption scores (HFCS) and household dietary diversity scores (HDDS) were used to measure a household's food security status.

Modeling the adoption of multiple technologies

In a multiple-adoption framework, the adoption of a combination of IDFPs may not be random. Decisions about adoption or non-adoption are likely influenced by unobservable characteristics that are correlated with the outcomes of interest rather than observable characteristics (Kassie et al., 2015). The MESR model framework has the advantage of evaluating combinations and individual practices while controlling for self-selection bias caused by both observed and unobserved heterogeneity and the interactions between choices of combinations of practices (Wu and Babcock, 1998; Mansur et al., 2007). This can be done simultaneously in two steps. In the first stage, farmers' choices of individual and combined IDFPs are modeled using a multinomial logit selection model while recognizing their inter-relationships. In the second stage, the MESR econometric model is used to investigate the effect of different IDFP practices on food security status.

Stage 1: A Multinomial adoption selection model

A multinomial logistic model was used to assess the determinants of the choice of IDF practices. The model is the analytical approach that is commonly used in an adoption decision study involving multiple choices (Chromy and Abeyasekera, 2005; Seo and Mendelsohn, 2007). This method can also be used to examine crop and livestock (Seo and Mendelsohn, 2007) choices as a means of adapting to the negative effects of climate change. The MNL has the advantage of allowing the analysis of decisions across more than two categories and determining choice

probabilities for different categories [62, 63] (Maddala, 1987; Tse, 1987), as well as being computationally simple (Tse, 1987).

Farmers are assumed to maximize their food security status, Y_i by comparing the revenue provided by "M" alternative IDFPs. The requirement for farmer i to choose any strategy j over other alternatives M is that $Y_{ij} > Y_{iM}$ $M \neq j$, that is, j provides higher expected food security than any other strategy. Y_{ij}^* is a latent variable that represents an expected food security level influenced by observed household characteristics, and unobserved characteristics expressed as follows:

$$Y_{ij}^* = X_i\beta_j + \varepsilon_{ij} \quad (2)$$

Where X_i captures the observed exogenous variables (household and institutional characteristics), while the error term ε_{ij} captures unobserved characteristics. Covariate vector X_i is assumed to be uncorrelated with the unobserved stochastic component ε_{ij} , so $E(\varepsilon_{ij}/X_i) = 0$, with error terms ε_{ij} assumed to be similarly Gumbel distributed and independent, under the independent irrelevant alternatives hypothesis (IIA).

The selection model (2) leads to a multinomial logit model (McFadden, 1973) where the probability of choosing strategy j (p_{ij}) is:

$$p_{ij} = p(\varepsilon_{ij} < 0|x_i) = \frac{\exp(X_i\beta_j)}{\sum_{k=1}^j \exp(X_i\beta_m)} \quad (3)$$

Stage 2: Multinomial endogenous switching regression model

To determine the impact of a combination of improved livestock farming practices on the outcome variable (food security), endogenous switching regression (ESR) is used by applying the selection bias correction model (Bourguignon et al., 2007). Farm households face a total of "M" regimes $j=1$ being the reference category (non-adopter). The food security status equation for each possible regime j for $j=1 \dots 6$ is defined as follows:

$$\left\{ \begin{array}{l} \text{Regime 1 } Q_{i1} = z_i\alpha_1 + \mu_{i1} \text{ if } i = 1 \\ \quad \quad \quad \cdot \\ \quad \quad \quad \cdot \\ \text{Regime 2 } Q_{ij} = z_i\alpha_j + \mu_{ij} \text{ if } i = j \end{array} \right. \quad j = 2, \dots, 6 \quad (4)$$

Food security status with adoption/usage

$$E(Q_{i2}|i = 2) = z_i\alpha_2 + \delta_2\lambda_2 \quad (7a)$$

$$E(Q_{ij}|i = j) = z_i\alpha_1 + \delta_1\lambda_j \quad (7b)$$

Food security status without adoption (counterfactual)

$$E(Q_{i1}|i = 2) = z_i\alpha_1 + \delta_1\lambda_2 \quad (8a)$$

$$E(Q_{i1}|i = j) = z_i\alpha_1 + \delta_1\lambda_j \quad (8b)$$

ATT can be defined as the difference between (7a) and (8a) which is given by:

$$\begin{aligned} \text{ATT} &= E(Q_{i2}|i = 2) - E(Q_{i1}|i = 2) \\ &= z_i(\alpha_2 - \alpha_1) + \lambda_2(\delta_2 - \delta_1) \end{aligned}$$

Measurement of food security

WFP (2009) developed the Household Food Consumption Score (HFCS) and Household Dietary Diversity Scores (HDDS), which are widely used to measure farmers' food security status (Wekesa et al., 2018). HFCS is a weighted score based on dietary diversity, food frequency, and the nutritional importance of food groups consumed. HFCS and HDDS are similar, with slight differences in the food cluster components. HDDS considers food items consumed within the last 24 hours, while HFCS takes into account food items consumed within the last 7 days.

Empirical specification

The model specification and selection of explanatory variables were based on researchers' knowledge of a review of theoretical work and previous similar empirical adoption and impact studies (Jaleta et al., 2018; Wekesa et al., 2018; Hadush, 2021). In this regard, 16 explanatory variables that are believed to influence and explain farmer technology adoption and, therefore, food security were identified and explained. These factors were broadly categorized under household, institutional, resource, and market access factors (Table 3.1).

Table 3.1 Explanatory variables and expected sign

Variable	Description and variable type	Variable type	Sign
Household characteristics			
Age	Age of household head: Years	continuous	+
Gender	Sex of household head: Female= 1, Male = 0	Dummy	+/-
Family size	NA number of a family:	continuous	+
Education	Educational status (illiterate = 1, Literate = 0)	Dummy	+
Dependency ratio	The ratio of non-active/ active family member	dummy	-
Resource and market access			
Farm size	Total land size (ha)	continuous	+
TLU	Number of Livestock in TLU	continuous	+
Credit access	Access to credit (No= 0, Yes= 1)	Dummy	+
Social network	Social network (No= 0, Yes= 1)	Dummy	+
DNM	Distances to a nearby market	Continuous	-/+
Off-farm income	Off-farm income (none= 0, yes= 1)	Dummy	+/-
Institutional factors			
Ext. services	Access to extension services (No= 0, Yes= 1)	Dummy	+
Frequency of extension	Frequency of extension: no	Continuous	
Cooperative member	Member of social cooperatives (No =0, Yes = 1)	Dummy	+/-
Health	Animal health facilities (No=0, Yes=1)	Dummy	+/-
Access to information	Access to climate information	Dummy	+

3.4 Results and Discussion

3.4.1 Improved dairy farming practices

The principal component analysis (PCs) and the coefficients of linear combinations (loadings) is presented in (Table 3.2). The result indicated that the three PCs showed 69.4 of the total variability in the data set. The first component showed 32.75%, while the second and third explain 25.34% and 11.31% of the total variation in the data of improved dairy technology adoption, respectively. The first component was associated with concentrate feed, supplementary feed (local feed), and improved forage and was named feed-related intervention. These improved practices were the most commonly adopted, with 79.19% of smallholder farmers (SHF) using at least one of these components. The second PC was improved dairy cows and artificial

insemination, used by 53% of SHF. The last PC was associated with the feeding system, using stall feeding and semi-grazing/seasonal grazing, which were only used by 29.79% of SHF (Table 3.2). Following MacCallum et al. (1999), the total amount of each variance in the three components was over 0.60, or an average commonality of 0.7 for a small sample size to undertake a PC analysis (Table 3.2).

Table 3.2 Loading of the three components for improved practices

Farming practices	Comp 1	Comp 2	Comp 3	Communalities
Highbred	0.736	0.370	-0.286	0.769
Crossbred	0.020	0.835	-0.22	0.838
Artificial insemination	0.731	0.495	0.105	0.784
Use of concentrate feed	0.708	0.636	0.124	0.912
Improved forage	0.172	0.781	0.144	0.620
Supplementary feed (local)	0.100	0.450	-0.46	0.277
Stall feeding	0.825	-0.197	-0.051	0.768
Semi-grazing/ Seasonal grazing	0.122	8.460	0.154	0.765
Eigenvalues	2.947	2.280	1.018	
Eigenvalues % contribution	32.75	25.34	11.31	
Cumulative %	32.745	58.081	69.394	

The use of PCA is justifiable given the sample size of 480 and the communalities reported in (Table 3.3) as it fulfills the minimum criterion. For the interpretation of PCs, variables with high factor loading and communalities were taken from the maximum likelihood method (Mignouna et al., 2011; Goswami et al., 2012).

Table 3.3. Lists of improved dairy farming practices

Group	Percentage of users	Components
Improved breed & AI	53.13	Use of highbred cow Crossbred cow Use of AI
Feed related intervention	79.17	Use of concentrate feed Supplementary feed
Feeding condition	29.79	Improved forage Stall feeding Semi-grazing (seasonal)

AI: Artificial Insemination

3.4.2 Determinants of adoption of improved dairy farming practices

Determinants of improved dairy farming technologies can be categorized in a variety of ways, which have an impact on a household's food security. In the study, SHF adoption choices were influenced by various demographic, socioeconomic, and institutional factors. Table 3. 4 presents a combination of different packages, of which SHFs used 6 out of 8 possible packages/ combinations. The majority of SHFs (21%) used a package (B₁F₁S₀) with the improved breed and feed management. About 20% of households used package B₁F₁S₁, containing all three groups of improved dairy farming practices, whereas non-adopters of package B₀F₀S₀ comprise 21% of SHF in the study area.

Table 3. 4. Specification of improved dairy farming practices

Choices	Binary quadruplicate	Improved breeds		Improve feeding		Feeding system		Frequency	Percentage
		B ₁	B ₀	F ₁	F ₀	S ₁	S ₀		
1	B ₁ F ₁ S ₁	✓		✓		✓		100	20.83
2	B ₁ F ₁ S ₀	✓		✓			✓	102	21.25
3	B ₀ F ₁ S ₁		✓	✓		✓		43	8.96
4	B ₁ F ₀ S ₁	✓			✓	✓		0.00	0.00
5	B ₁ F ₀ S ₀	✓			✓		✓	53	11.04
6	B ₀ F ₁ S ₀		✓	✓			✓	82	17.08
7	B ₀ F ₀ S ₁					✓		0.00	0.00
8	B ₀ F ₀ S ₀		✓		✓		✓	100	20.83
Total									100

The binary quadruplicate defines the IDF packages. For each IDF combination, each element in the quadruplicate is a binary variable: improved breed (B), enhanced feeding (F), and feeding condition (S), with subscript 1 indicating adoption and 0 indicating non-adoption.

The MNL results show six sets of parameter estimates, one for each mutually exclusive combination of practices (Table 3.5). Non-adoption (B₀F₀S₀) of all practices was the base category for comparing the other five packages used by farmers. The wald test, that all regression coefficients are jointly equal to zero, is rejected [$\chi^2(65) = 255.34$; P = 0.000].

Table 3.5 Marginal effects estimates for the determinants of IDFs packages by MNL

Variables	B ₁ F ₁ S ₁		B ₁ F ₁ S ₀		B ₀ F ₁ S ₁		B ₁ F ₀ S ₀		B ₀ F ₁ S ₀	
	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE
Gender	0.603	0.122	0.325	0.276	0.016	0.205	0.0564	0.220	0.215	0.180
Age	0.012	0.010	0.049	0.084	0.096	0.074	0.0126*	0.010	0.013*	0.007
Education	0.285	0.290	0.284	0.186	0.28**	0.130	0.415**	0.140	0.1869	0.123
Family size	-0.260	0.100	0.126	0.063	-0.110	0.058	-0.150	0.060	0.185	0.057
Dependency Ratio	0.760	0.752	0.591	0.426	-0.036	0.372	0.701**	0.374	0.99***	0.315
Farm size	0.049	0.086	0.085	0.063	0.075	0.049	0.026	0.052	0.099**	0.047
TLU	-0.16**	0.060	-0.057**	0.025	-0.065**	0.021	-0.066**	0.020	-0.58*	0.195
Off-farm income	1.772**	2.626	1.32**	2.530	2.387	2.326	2.202	2.400	1.77	2.288
Extension service	0.79**	0.260	0.462**	0.157	0.266*	0.122	0.286**	0.126	.233**	0.118
Cooperative member	0.900	2.820	0.32**	0.810	0.100	0.365	1.18**	0.570	0.235	0.341
Credit access	0.214	0.223	0.456***	0.143	0.34**	0.115	0.34**	0.120	0.294*	0.111
District market	-1.18***	0.570	-0.376***	0.072	-0.234**	0.055	-0.31***	0.057	-0.23***	0.054
Milk collection	-0.221***	0.640	-0.0284	0.018	0.010	0.008	0.011	0.087	0.02**	0.083

B₀F₀S₀ = base category

Number of obs = 480

Prob > chi2 = 0.0000

Log pseudo likelihood = 362.284

Pseudo R² (McFadden) = 0.784

Age of Household Head: The age of the household head was positively and significantly ($p < 0.05$) associated with the use of $B_1F_0S_0$ and $B_0F_1S_0$ (Table 3.5). This means that an increase in the age of the household head by one year increases the likelihood of the household's decision to use $B_1F_0S_0$ by 1.26% and 1.3% more than a non-adopter, respectively. In other words, as the age of the household heads increases by one year, the likelihood of the household heads choosing a smaller package increase. It is most likely that older farmers are more experienced and thus less risk averse than younger SHFs. In support of this finding, previous studies indicated that older farmers are assumed to have gained knowledge and experience, may have accumulated more physical and social capital over time, and are better able to evaluate technical information than younger farmers (D B Mignouna et al., 2011; Kariyasa and Dewi, 2013; Wekesa et al., 2018). On the contrary, a negative relationship has been found between age and technology adoption, which can be explained by the fact that as farmers get older, their risk aversion increases, and their interest in long-term farm investment decreases (Mauceri et al., 2006).

Education: The education level of the household was found to positively and significantly influence farmers' decision to adopt improved breeds only ($B_1F_0S_0$). As the educational level of the household increased, the probability of using $B_1F_0S_0$ and $B_0F_1S_1$ increased significantly. The level of education of farmer improves his ability to obtain, process, and apply information relevant to adopting a new technology (Kariyasa and Dewi, 2013; Loevinsohn et al., 2013) and tends to build farmers' innovativeness and ability to assess risks for proper farm adjustments (Gido et al., 2015). Similarly, a study by Okunlola et al. (2011) on fish farmers' adoption of new technology and Ajewole (2010) on organic fertilizer adoption found that the level of education significantly influenced adoption. Education influences respondents' attitudes and thoughts (Waller et al., 1998), easing the introduction and adoption of innovations (Adebiyi and Okunlola, 2013). On the other hand, some authors have reported an insignificant or negative effect of education on the rate of technology adoption (Chromy and Abeyasekera, 2005; Zezza et al., 2010). Wekesa et al. (2018) argue that a higher level of education enables farmers to avoid using improved practices that do not offer risk-reduction measures.

The dependency ratio: is used as a measure of labor availability. Many working age groups in the family could positively influence the adoption of labor-intensive new technologies. The dependency ratio positively and significantly explained the adoption of $B_1F_0S_0$ and $B_0F_1S_0$. This

is because households with a higher dependency ratio have a lower workforce to apply the intensive work of improved dairy practices. A low dependency ratio within a household may increase labor availability (Zezza et al., 2011), easing labor constraints when introducing new technologies (Mignouna et al., 2011). This shows that SHF with a low dependency ratio is more likely to adopt than non-adopters.

Farm size: Having a large farm size negatively and significantly explains the use of the improved package $B_1F_1S_1$. This means that as farmland size increases, the likelihood of using $B_1F_1S_1$ decreases by 26.9% more than non-adopters. This is most likely due to households with small farm sizes adopting land-saving and labor-intensive technologies such as small numbers of productive animals and stall feeding/zero grazing to increase animal productivity. According to key informants, due to urbanization and cropland expansion to vast grazing land, farmers are switching from traditional dairy production systems to improved ones to increase dairy profitability. Several studies, however, have found a positive relationship between farm size and agricultural technology adoption (Chromy and Abeyasekera, 2005; Kariyasa and Dewi, 2013). Farmers with larger farm sizes are more likely to adopt new technology because they can afford to devote a portion of their land to experimenting with new technologies and influence the use of large packages as opposed to those with smaller farm size (Chromy and Abeyasekera, 2005; Moll et al., 2007). Other studies have found an insignificant or neutral relationship between adoption and farm size (Zezza et al., 2011; Kebebe, 2017; 2019).

Livestock holding (TLU): having a large livestock holding had a negative and significant impact on the adoption decisions of all $B_1F_1S_1$, $B_1F_1S_0$, $B_0F_1S_1$, $B_1F_0S_0$, and $B_0F_1S_0$ improved practices. This is most likely due to adopters of improved dairy technology reducing the number of low- yielding animals and keeping a few improved breeds for milk production. According to Moll et al. (2007), due to limited grazing land, farmers cannot maintain a large number of livestock holdings, so they keep only a few productive animals. In contrast, Wekesa et al. (2018) stated that resource-endowed farmers can absorb the risks associated with failure and the time it takes before realizing the meaningful effects of using CSAs.

Off-farm income: Off-farm income had a positive and significant impact on technology adoption ($B_1F_1S_1$, $B_1F_1S_0$). This is because off-farm income diversifies income sources and serves as an essential strategy for overcoming financial constraints, allowing farmers to invest in

technology adoption. Similarly, a growing body of evidence indicates that employment in off-farm occupations positively impacts agricultural technology uptake and adoption (Abunga et al., 2012; Diro, 2013). Diro (2013) states that off-farm income provides farmers with liquid capital for purchasing productivity-enhancing inputs like fertilizer and seeds.

Access to extension services positively and significantly influenced the usage of almost all dairy farming technologies. The service would help farmers be better informed about the existence of new technologies and how to use and benefit from them. Several authors have reported a positive relationship between extension services and technology adoption (Chromy and Abeyasekera, 2005; Mohamed and Temu, 2008). The diffusion of new technologies may also be influenced by agricultural extension agents' visits to farmers (Kebebe, 2017). Similarly, Wekesa et al. (2018) suggest that extension services play a crucial role in implementing development technologies by farmers.

Access to credit: This positively and significantly explained the likelihood of using dairy technologies such as $B_1F_1S_0$, $B_0F_1S_1$, $B_1F_0S_0$, and $B_0F_1S_0$. Credit access allows SHF to cover the costs of implementing expensive technologies that require a large initial investment, such as improved dairy breeds. Several similar results reported a positive correlation between credit access and agricultural technology adoption (Mohamed and Temu, 2008; Kebebe, 2017). Credit availability, according to Mohamed and Temu (2008), has stimulated and increased technology adoption. In addition, Shiferaw et al. (2015) reported that households experiencing credit constraints are less likely to adopt CSA technologies requiring cash expenditures.

Member of a cooperative: Similarly, agricultural group membership positively and significantly explained the usage of $B_1F_1S_0$ and $B_1F_0S_0$. Membership in a social group allows for the exchange of ideas, information, and trust (D B Mignouna et al., 2011), facilitating technology adoption. Members of group networks can exchange ideas, get market information, handle farm demonstrations, and connect to the dissemination of important research findings (Wekesa et al., 2018). Ward and Pede (2015) also noted that learning from peers' experience increases the likelihood of technology adoption because farmers trust the practical experiences demonstrated by their peers because they share many things in common, including shared labor.

Distance to the nearest district market: Distance negatively influences the likelihood of SHF usage of all improved dairy technologies. This is possible because access to markets allows the household to purchase inputs and sell their goods. Proximity to the market is an essential determinant of technology adoption, presumably because the market serves as a means of exchanging information with other farmers and facilitating buying and selling activities. Teklewold et al. (2013) observed that, in addition to affecting market access, the distance could also affect the accessibility of new technologies, information, and credit institutions, resulting in a negative relationship. Similarly, distance to the milk selling point had a negative and significant influence on the adoption of $B_1F_1S_1$ but a positive influence on the use of $B_0F_1S_0$. This is possible due to a lack of or weak linkage between producers and consumers, exacerbated by poor road infrastructure to transport fluid milk to the selling point. Lack of well-established market linkage, infrastructure, transportation facilities, and the value chain for collecting, cooling, processing, and marketing milk and milk products are the main limiting factors for dairy development in Ethiopia (Duncan et al., 2013).

3.4.3 IDF practices impact on household food security

This section presents the conditional effects of adopting improved dairy production technology on rural household food security. Following the identification of factors influencing IDFP package selection in the first stage, treatment effects were determined in the second stage to investigate the impact of package usage on household food security. The predicted outcomes of the ESR models were used to calculate the average treatment effect on the treated (ATT) and the average treatment effect on the non-treated (ATU). Then the ordinary least squares regression of the households' food consumption scores (HFCS) and household diet diversity scores (HDDS) was estimated for each combination of improved practices, taking into account the selection bias correction terms from the first stage. For interpretation and comparison with existing literature, HFCS was preferred over HDDS because the latter only captures meals consumed within 24 hours, which may exclude occasional meals consumed on specific days such as market days within a week (Appendix II Table 5).

Table 3.6 depicts the average adoption effects of HFCS and HDDS in actual and counterfactual conditions. The result showed that adopting either individual IDFPs or a combination of them provides a significant food security effect compared to non-adopters. The SHFs that adopted the

entire technology package, namely improved breed, forage, and stall feeding ($B_1F_1S_1$), had a more significant overall effect on HFCS and HDDS than the others. This is most likely due to the complementarity between the adoption of improved breeds and the feed and feeding system, which are crucial in boosting dairy productivity and the farmer's income. In all combinations of adoptions, the adopters' average per capita food consumption would have decreased if they had not adopted.

Table 3.6. Impact of use and non-use of IDF practices on farmers' food consumption score

Package	Status	HFCS		
		adoption status		Effects
		Adopting	Non-adopting	
$B_1F_1S_1$	Adopters	75.6 (0.52)	60.81(0.33)	14.79 (0.61)***
	Non-adopters	71.71 (0.09)	59.79 (0.27)	11.92 (0.27)***
$B_1F_1S_0$	Adopting	65.38 (0.795)	50.41 (0.30)	17.98 (0.85)***
	Non-adopting	65.590 (0.52)	50.81 (0.33)	17.78 (0.61)***
$B_1F_0S_0$	Adopting	52.38 (0.53)	50.81 (0.39)	1.57 (0.62)***
	Non-adopting	51.23 (0.26)	49.20 (0.33)	2.03 (0.41)***
$B_0F_1S_1$	Adopting	57.51 (0.62)	54.44 (0.48)	2.75 (0.26)***
	Non-adopting	56.28 (0.43)	50.81 (0.33)	5.47 (0.54)***
$B_0F_1S_0$	Adopting	52.48 (0.14)	50.81 (0.33)	1.68 (0.36)***
	Non-adopting	49.47 (0.15)	47.85 (0.47)	1.72 (0.5)***

On the other hand, if non-adopters had adopted IDFs, their HFCS would have increased significantly higher than the benefit adopters would have lost due to non-adoption. For non-adopters, for example, the average probability of food security increases by 40% if the entire package is implemented ($B_1F_1S_1$). These findings are consistent with previous technology adoption studies, showing that adopting new technologies can improve farmers' food security and reduce poverty. These include the adoption of improved agronomic practices on net crop income and agrochemical use in Malawi (Kassie et al., 2015); the adoption of improved breeds of dairy cows and improved forages on household nutrition and income (Kebebe, 2017); the adoption of improved maize varieties on household food security (Jaleta et al., 2018); and the

adoption of stall feeding on household welfare in Mekele milk shed (Hadush, 2021). This is because improved agricultural technology is expected to increase farmer income while decreasing food insecurity and poverty. Along with food security effects, improved dairy farming technologies have biophysical and environmental benefits in mitigating greenhouse gas emissions and grazing land management (Opio et al., 2013; Hadush, 2021).

3. 5 Conclusions

Enhancing food production without compromising a healthy agro-ecosystem has become an increasingly global challenge. An improved smallholder dairy farming system aims to enhance livestock productivity and resilience, reducing food insecurity and poverty while improving natural resource management. The study investigated the adoption of improved dairy technology and its effects on household food security as factors influencing its uptake using the multinomial endogenous switching regression approach in a counterfactual framework, where selectivity is modeled as a multinomial logit model. It was found that households adopting dairy technologies have better off-farm income, better access to complementary inputs and services, and broader market opportunities than households not adopting dairy technologies. Agricultural research, extension services, and credit access appear to be successful in disseminating improved dairy technologies. The distance to the nearest market and milk collection center had a negative ($P < 0.05$) impact on adopters of improved technology. The empirical results indicated that adopting either individual IDFPs or a combination of them provides a significant food security effect compared to non-adopters. Whereas, a larger package comprised of improved breed, improved feeding, and feeding condition ($B_1F_1S_1$) had the highest overall effects in HFCS and HDDS than the others. This package is comprehensive as it addresses a wider spectrum of breed improvement, improved feed and forage, and improved feeding conditions. The economic impacts of improved dairy technology suggested in this study would be an input for the ongoing efforts in transforming livestock production, and efforts aimed at enhancing widespread adoption in Ethiopia will generate significant benefits. Resource constraints, supply chain bottlenecks, an incomplete value chain for input and output, and institutional barriers have been hindering improved dairy technology adoption. Interventions that overcome the constraints related to access to farm resources and the supply chain for IDF practice inputs and services and output markets could facilitate the uptake of dairy technologies.

Chapter Four

4. Variability in the Carbon Footprint of Smallholder Dairy Farms in the Central Highlands of Ethiopia

Abstract

Smallholder dairy farms face enormous challenges in increasing milk production while mitigating greenhouse gas (GHG) emissions, thereby enhancing climate resilience. The carbon footprint (CF) of smallholder milk production is expected to increase with increasing demand for dairy products under the business-as-usual scenario. This study estimates the carbon footprint of smallholder milk production and examines variation across farms using data from 480 households to identify viable options for mitigating GHG emissions. We applied a cradle to farm-gate Life Cycle Assessment (LCA) approach to examine the effects of farming systems on GHG emission intensities across intensification gradients of smallholder farms (SHF) from four potential dairy districts in the central highlands of Ethiopia. According to our findings, enteric fermentation was the primary source of GHG emissions, and methane (CH₄) emissions from enteric fermentation and manure management accounted for the majority of total emissions across farms. The estimated average CF varies depending on farming systems, Global Warming Potential (GWP), and allocation methods used. When GHG emissions were allocated to multiple products using economic allocation and based on IPCC (2007) and IPCC (2014) GWPs, the overall average CF of milk production was 1.91 and 2.35 kg CO₂e/kg fat and protein corrected milk (FPCM), respectively. On average, milk accounted for 72 percent of total greenhouse gas emissions. In terms of farm typology, rural SHF systems produced significantly more CF per kg of milk than urban and peri-urban SHF systems. Variations in milk yield explained more than half of the variation in GHG emission intensity at the farm level. Feed digestibility and feed efficiency had a negative and significant ($P < 0.01$) association with CF of SHF. Our findings suggested that improving feed digestibility and feed efficiency by increasing the proportion of concentrate and improved forage, as well as improving straw and crop residue, could provide an opportunity to both increase milk yield and reduce the CF of milk production in the study area. Interventions at several levels of the dairy production value chain are required to support SHF's efforts to implement climate-resilient dairy strategies.

Keywords: Carbon footprint, Dairy cattle, Greenhouse gas emission, Life Cycle Assessment, Selale, Smallholder farmers

4.1 Introduction

Global livestock production in general, and the Ethiopian dairy sector in particular, are at the crossroads of mitigating greenhouse gas (GHG) emissions as well as enhancing resilience to climate change to meet the increasing demand for livestock products (FAO, 2010b; Shapiro et al., 2015). With 65 million cattle, 39.89 million sheep, and 50.5 million goats, Ethiopia has the largest livestock population in Africa (CSA, 2020), and it is also blessed with a variety and abundance of livestock species (FAO, 2018b, 2019a). Smallholder farmers represent about 85% of the population and account for 98% of milk production in the country. Selale milk shed of the central highland of Ethiopia is one of the country's largest and most developed milk sheds, with a large number of smallholder producers (Brandsma et al., 2013). The milk shed is known for its high production potential and serves as the major milk supplier to the more affluent population in the capital, Addis Ababa (Brandsma et al., 2012; Zijlstra et al., 2015). Despite its potential for stimulating growth, reducing poverty, and achieving food security, the sector is not able to produce enough products to meet the country's growing demand due to feed problems, poor health services, and low genetic potential of indigenous breeds (Zijlstra et al., 2015).

On the other hand, cattle are the main contributors to GHG emissions in Ethiopia. Methane emission from enteric fermentation and manure management accounts for 45 % of the total national methane emission (CRGE, 2011; FAO and NZAGRC, 2017) (CRGE, 2011). The rural mixed crop-livestock system, and the pastoral/agro-pastoral system, contribute 96% of national milk production but, at the same time responsible for 56% and 43% of the total greenhouse gas (GHG) emissions associated with milk production, respectively (de Vries et al., 2016; FAO and NZAGRC, 2017).

Given the expected increase in demand for dairy products, the Ethiopian dairy sub-sector faces tremendous challenges in increasing milk production while mitigating associated GHG emissions (Shapiro et al., 2015; FAO and NZAGRC, 2017). More importantly, the Ethiopian green growth pathway aims to foster economic growth and development while limiting GHG emissions to 150 million tonnes (CO₂ eq-) by 2030 under the business as usual (BAU) scenario. As part of the green growth strategy, the dairy sector has been identified and prioritized for fast-track implementation to reduce GHG emissions while improving milk production (CRGE, 2011;

Shapiro et al., 2015). Emission reduction through reduced emission intensity while improving smallholder farmers' livelihoods is consistent with Ethiopia's livestock development strategy (CRGE, 2011; Shapiro et al., 2015). For this purpose, estimation of GHG emissions and identifying an emission hotspot from smallholder dairy farms helps to generate baseline information that could serve as an input to national emission inventory and design subsequent national mitigation strategies. Furthermore, studies at the local level are important for assessing the effects of specific farm management practices on the CF performance of SHF milk production, so that knowledge of improved practice can be promoted.

In spite of the sector's significant contribution to national GHG emissions and the country's large cattle population, only a limited effort has been made to investigate the CF of the smallholder dairy farming system and how variation in the farming system affects the CF of SHF milk production. Some of the CF studies conducted so far have either focused on evaluating the GHG emissions of milk production at the regional or national level (FAO and NZAGRC, 2017) or assumed characteristics of typical farms and actual data from small samples of the farm (Woldegebriel et al., 2017; de Vries et al., 2016). As a result, the findings of those studies are highly aggregated and are of little help in addressing the local peculiarities of production characteristics and intervention measures. Moreover, despite the multiple functions of dairy cattle in the livelihoods of smallholder farmers in the study area, the vast majority of CF studies are based solely on the base of main products (milk or meat) (De Varis et al., 2017; FAO and NZAGRC, 2017; Opio et al., 2013) . The results of mono-dimensional analyses do not adequately reflect the complexity of dairy production characteristics; as a result, it leads to biased conclusions.

Therefore, this study was designed to estimate cradle to farm-gate GHG emissions from SHFs in Selale highlands and examine variation in CF of milk production across different farming systems using actual data from a large size of SHF and a large number of dairy cows.

4. 2. Materials and Methods

4. 2.1. Description of the study area

The present study was conducted in Selale milk shed in the central highlands of Ethiopia (Figure 2). The study area lies at 38° 07' 60" E longitude and 9° 40' 60" N latitude and has an elevation

of 1250 to greater than 3000 meters above sea level. According to Brandsma et al. (2012), 42% of the area falls under tropical highlands similar to that of temperate region climate, and almost a quarter of the land in the zone is typical tropical dry land. Livestock, especially dairy farming, is the dominant agricultural enterprise and source of income in the Selale highlands.

4. 2.2. Sampling and data collection

A multi-stage stratified random sampling technique was employed to select SHF for this study. The first four districts (Sululta, Wuchale, Girar Jarso, and Degem) were purposively selected from Selale milk shed to represent different agro-ecologies and farming systems. Girar Jarso district was selected to represent urban SHF, where dairy farming is practiced to support family income in addition to off-farm activities. Sululta and Wuchale districts represent mid-land agro-ecology and peri-urban dairy farming systems where crop and livestock production are closely integrated. Degem district is typical highland agro-ecology where crop and livestock (dairy) production are closely integrated. In each district, SHFs were stratified into urban, peri-urban, and rural dairy farming systems based on the scale of production, production resources, feeding systems, breeds, and genotypes kept, and the contribution of dairy to livelihoods (Gizaw et al., 2016; Tegegne et al., 2013). Four kebeles (the smallest administrative units in Ethiopia) were purposively selected from each district by considering dairy cattle potential, road accessibility, and SHF registered under the national dairy cattle database. A total of 480 (urban = 120, peri-urban = 180, and rural = 180) SHF were randomly selected to represent all farming systems following Arsham (200) and Wilkes et al. (2019) smallholder dairy methodology. A survey questionnaire was designed to collect data on farm household characteristics, farm input-output, sources of feed, feeding practices, productive and reproductive performance, and manure management systems. Three enumerators, experts in livestock production, were selected from each district and were given orientation and refresher training on the household survey. The survey was supervised by the first author. The survey data was triangulated using a transect walk and group discussion. Additional data were extracted from the national dairy cattle database of Addis Ababa, Ethiopia. Data collection was held between July 2020 and February 2021, during which the SHFs were visited three times to observe seasonal variations in feed resources and cross-check the data.

Field measurements: The body weights of different animal categories were estimated using heart girth (HG) measurements of individual animals (FAO, 2012). The HG measurements were converted to an estimate of live weight (LW) in kg by using the regression equation developed for Ethiopian Zebu and cross breed cattle and African cattle by Taylor and Galal (1980) and Goopy et al. (2018), respectively.

Milk yield and Chemical Composition: Milk yield data from the 2019-2020 lactation period were extracted and analyzed from the national dairy cattle database. The standard 305-d milk yield for each animal was estimated from test date (TD) milk yield records by using the test interval method described by Sargent et al. (1968) and Meseret et al. (2015). In rural areas, farmers allow calves to suckle before and after milking. Thus the average daily milk yield considers the milk suckled by calves. Calf milk consumption was estimated following the methods and assumptions of NRC (2001) and converted to kg/day. NRC (2001) provides methods to estimate net energy intake by calves for maintenance and growth based on calf live weight and weight gain (Haile et al., 2011; Dadi et al., 2021). Cows' milk yield was calculated as the sum of milk off-take and estimated calf milk consumption. Milk samples were collected in the morning and afternoon from a total of 70 SHF (U = 27, PU = 21, Rural = 21) using standard procedures and analyzed for chemical compositions such as fat percent (Gerber method) and milk density (Kg/L at 20°C) (Van Marle-Köster et al., 2000). Richmond's formula (Bector and Sharma, 1980) was used to calculate milk solid not-fat (SNF) as follows:

$$\text{SNF}\% = \left(\frac{\text{milk density (Kg/L)}}{4} \right) + (0.22 * \text{BF}(\%)) + 0.72 \dots \dots \dots (1)$$

Energy-corrected milk yield (ECM) was calculated following the equation developed by Tyrrell and Reid (1965):

$$\text{ECM(MJ/kg)} = 0.0386\text{BF(g/kg milk)} + 0.0205 \text{SNF (g/kg milk)} - 0.236 \dots \dots \dots (2)$$

Secondary data collection: Secondary data was collected from various sources. The nutrient content and nutritional characteristics of common feedstuffs specific to the study area were taken from ILRI database and various scientific publications. The standard crop yields, fertilizer use, pesticide use, and market price of 2020 production year were calculated using CSA (2020) data and information gathered from SHF. IPCC guidelines (IPCC, 2014; Refined, 2019) were used to

collect data and calculate emissions from animals, feed, and manure. GLEAMi databases (Opio et al., 2013; FAO, 2016c; IPCC, 2019) and Feed Print (Vellinga et al., 2013) were used for feed emission-related calculations.

4. 2.3 Carbon footprint estimation method

An attributional LCA approach was employed to assess GHG emissions of 480 SHF over one year. Global warming potentials (GWP) from the IPCC assessment report (IPCC, 2007a; IPCC, 2014a) were used to calculate carbon dioxide equivalent (CO₂e) units for carbon dioxide, methane, and nitrous oxide. The Global Livestock Environmental Assessment Model-*interactive* (GLEAM-*i*) FAO (2020) was used to estimate GHG emissions, and the CF was expressed in kg CO₂e per kg FPCM (fat and protein corrected milk).

4. 2.3.1 System boundaries

A cradle-to-farm gate system was determined using the protocols of Opio et al. (2013) and FAO (2016), which include all on-farm and off-farm processes related to dairy production. On-farm processes mainly were related to farm activities, such as management of dairy cattle, feed production and processing, and manure management practices. The off-farm process included energy used for production, processing, and transporting feeds. As indicated in the schematic diagram below (Figure 4.1), the system boundary included on-farm processes (feed production and processing, farm management practices, and manure management) and off-farm processes.

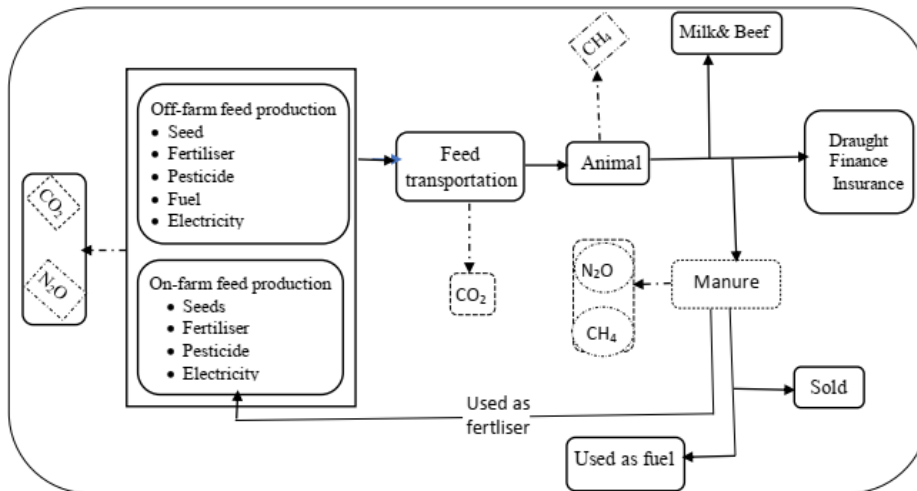


Figure 4.1 Cradle to farm gate system boundary (—) indicating process (→) and emissions (---) flows

4. 2.3.2. Functional units and allocation methods

As recommended in global CF studies, the functional unit used is kg CO₂e/kg FPCM (FAO, 2016a). The milk yield (litre) was converted to kg using a standard density of 1.031 kg/L and corrected to kg CO₂e/kg FPCM, following the equations described by Opio (2013), assuming the overall average of 4.18% fat and 3.25% protein content of laboratory analysis of the study area (Table 4.1). The dairy sector plays multiple roles in livelihoods of farmers, providing milk and meat, income (sale of animals and animal products), draft power, insurance, and security for future financial needs, social and cultural services in Ethiopia (Moll et al., 2007; Behnke and Muthami, 2011; Woldegebriel et al., 2017). Hence in this study, the burden of GHG emissions was shared by a kg of raw milk, a kg of beef, an hour of draught power, and a kg of manure used, with finance and insurance. Emissions were attributed to milk production using three methods: economic allocation based on product and co-product prices; mass allocation based on protein content in milk and meat produced at the farm level, and all GHG emissions were attributed to milk production at the farm level. However, to compare the result with the existing literature and for consistency, the present study used economic allocation for each product and co-product.

Table 4.1. Chemical composition of milk in the study area

Milk composition (%)	Urban	Peri-urban	Rural
Fat	3.79 ± 0.09	3.79 ± 0.12	4.49 ± 0.43
Protein	3.05 ± 0.063	3.2 ± 0.034	3.5 ± 0.41
SNF	8.2 ± 0.15	8.2 ± 0.33	8.56 ± 1.56
Density	29.9 ± 0.29	30.5 ± 0.29	31.15 ± 1.65
Lactose	4.36 ± 0.9	4.66 ± 0.1	4.34 ± 1.43

In the economic allocation approach, GHG emissions generated in milk production are allocated to products and co-products according to their economic values (FAO, 2010b; Opio et al., 2013). In the current study, milk and meat have a direct market value, as stated in a previous study, whereas the economic value of finance and cattle as a means of insurance and manure as fertilizer can only be assessed indirectly (Moll et al., 2007; Weiler et al., 2014). The current milk price per kg reported was 21.65 Birr. The economic value of animals sold was based on the selling prices of different categories of animals. The local rent value of an ox per year was used to determine the economic value of an animal used for draught purposes. The quantities of manure produced (Refined IPCC, 2019), used as fertilizer for on-farm crops, forage, sold as fertilizer, and used as fuel in the form of dung cakes were collected and observed during the survey. The economic value of manure as fertilizer was determined based on synthetic nitrogen fertilizer equivalents (Alary et al. (2011). The economic value of nitrogen in manure used for fertilizer was determined by multiplying the amount of manure applied to crops by the nitrogen content of cattle manure, which was 1.4 percent in this study (Alary et al., 2011; Weiler et al., 2014). The amounts of manure applied to crops and forage were estimated based on farmers' recall. Similarly, as described in the study of Woldegebriel et al. (2017), the economic value of dung cake sold and used as a fuel source was determined based on the local market.

Valuing the role of cattle as finance and insurance is well documented in previous studies (Moll et al., 2007; Behnke and Muthami, 2011). The financing value in the study area was estimated at 8%, based on commercial interest rates for Ethiopia's short- and medium-term credit. Similarly, the economic value of cattle as insurance was calculated as a product of the economic value of the herd and the insurance premium, i.e., the cost that farmers would need to pay to

purchase insurance coverage equal to the capital value of their herd (Moll et al., 2007; Weiler et al., 2014). The insurance premium of 10% in the rural system was estimated based on national insurance rates. Economic allocation was also used to allocate the share of GHG emissions for crop residue production, where the proportion of economic importance of crop residues was computed (Woldegebriel et al., 2017).

4. 2.3.3 Inventory Analysis

Four hundred eighty (480) SHFs were selected to represent the three SHF systems in the study area. GHG emissions were estimated for a total of 1365 cattle (515 in urban, 515 peri-urban, and 350 rural) SHF systems, while about 235 dairy cattle were dropped from the analysis because of incomplete milk test dates and data inconsistency before data analysis (Table 4.2).

Methane emissions from enteric fermentation: Enteric methane emissions were estimated based on gross energy intake (GEI) and 6.5% conversion factors using the IPCC Tier 2 model (IPCC, 2006; IPCC, 2019). Average daily feed intake, expressed as gross energy intake, was calculated from diet of cattle (cow, replacement, and male). The emission factor for each animal category was calculated following Marquardt et al. (2020), a protocol for a Tier 2 approach to generate region-specific enteric methane EF.

Emissions from manure management: Direct and indirect N₂O and CH₄ emissions from manure management were calculated using the IPCC Tier 2 method for each animal category. The new refined spreadsheet was used to calculate the methane emission factor from manure management. Methane conversion factors (MCF) were estimated considering the study area's average annual mean air temperature (° C). The primary step in the N₂O emission calculation using Tier 2 is estimating the nitrogen excretion rate from managed manure. Nitrogen intake rates were calculated following the refined IPCC (2019) equation using input data on GE intake and CP content of major feeds. Nitrogen excretion was estimated by subtracting nitrogen retention from nitrogen intake in IPCC (2019). Due to a lack of country-specific data, the IPCC default emissions factor (for direct N₂O emissions from manure management systems (EF₃) for African farming systems was adapted from IPCC.

Emissions from feed production and transportation: Emissions related to on-farm feed production were calculated by surveying various factors such as synthetic fertilizer application, manure and pesticide use, seeds sown, draught power, and modes of transportation. Framers use animal traction for crop production and harvesting, and no SHFs reported using farm machinery in the study area. Following Feyissa et al. (2018), the amount of hay, crop residue, and improved forage per hectare was estimated based on farmers' recall and CSA (2020) data. Emissions related to off-farm feed production and transportation were estimated from the amount of feed purchased from outside. The emission intensities of by-products were considered zero when calculating the CF for concentrate ingredients by attributing the entire emission potency to main products (Reddy et al., 2019a). There were no country-specific emission factors available in Ethiopia. Hence, feed emission factors ($\text{kg CO}_2\text{e kg DM}^{-1}$) were obtained from FAO and LEAP (2015); Wilkes et al. (2020a), and feed print Vellinga et al. (2013) in the Netherlands.

4. 2.4 Data analysis

Both descriptive statistics and one-way ANOVA were used to analyze quantitative data. One-way ANOVA was employed to analyze the variation of GHG emissions per kg of milk among the three farming systems. A posthoc test was used for means comparison. The association between GHG emissions and milk yield, digestible energy, and feed efficiency was estimated using regression analysis. Because CF and the other input variables were not normally distributed, we used a logarithmic function to convert to a linear function to improve the precision of the regression.

Analyses were made by using STATA version 17 computer software and the Microsoft Excel computer program. Uncertainty analysis was conducted using Monte Carlo simulation implemented in an excel spreadsheet. Uncertainty was estimated as the margin of error (MOE) with a confidence interval of 95%. The margins of error were calculated using a z-score of 1.96, which corresponds to α value of 0.05.

4. 3. Results

4. 3.1 Characteristics of dairy farming systems

Table 4.2 illustrate herd structure, breed composition, and production performance in the study area. All cows in urban and peri-urban SHF were either pure exotic breeds or crossbreeds with medium to high-level exotic blood. On the other hand, dual-purpose indigenous cattle were dominantly kept in rural SHF. All the animals in the urban SHF were stall-fed as they did not have land for grazing. Stall feeding with limited grazing in restricted areas and private pasture was a common feeding practice in peri-urban farming systems.

In contrast, the rural SHF followed free grazing of natural pasture and crop aftermath throughout the year with a minimum supplementation to milk cows. A significant variation was reported in average lactation milk yield and body weight across farming systems. Milk production per cow per year and adult cows' body weight was significantly higher ($P<0.01$) in urban than in peri-urban and rural SHFs. Selling fluid milk to urban markets was the main production objective of urban and peri-urban SHFs. Dairy farming was the sole source of income and livelihood for the majority of urban and peri-urban SHFs.

Table 4.2 Farm characteristics, herd structure, and production performances of SHF (mean \pm SD)

Parameters	Farming system			Overall Mean \pm SD
	Urban Mean \pm SD	Peri-Urban Mean \pm SD	Rural Mean \pm SD	
Breed & genotype				
Cattle breed	High-grade Holstein Friesians	High grade & Crossbred	Pure indigenous breeds	
Herd structure				
Cattle holding	5.85 \pm 2.58	5.91 \pm 2.97	6.43 \pm 3.57	5.73 \pm 3.1
Adult female	3.02 \pm 1.39	2.55 \pm 1.329	2.31 \pm 1.11	2.63 \pm 1.15
Adult male	NA	1.20 \pm 0.56	1.57 \pm 0.18	1.43 \pm 0.34
Heifer	2.16 \pm 1.38	1.76 \pm 1.09	1.62 \pm 0.781	1.85 \pm 1.06
Young Female	1.95 \pm 1.21	1.72 \pm 1.14	1.36 \pm 0.672	1.68 \pm 1.05
Growing male	1.46 \pm 0.61	1.46 \pm 0.755	1.43 \pm 0.693	1.44 \pm 0.71
Herd Performance				
Age at 1 st calving (year)	3.1 \pm 0.40	3.27 \pm 0.551	3.79 \pm 0.66	3.51 \pm 0.49

Lactation length (months)	9.56±0.91	8.43 ±1.059	6.77 ± 0.948	8.12 ± 0.98
Calving interval (months)	13.3 ± 0.86	13.7 ± 0.78	24.5 ± 0.27	13.06 ±0.54
MY FPC kg/year	3750.7 ^a ± 511.4	3226.46 ^b ± 452.67	785.74 ^c ± 98.57	2587.64 ± 35.42
Adult cow BW (kg)	429.12 ^a ± 43.72	423.26 ^a ± 42.02	284.16 ^c ± 34.46	374.02 ± 34.17
Average Agricultural Land holding (ha)				
Agricultural land (ha)	1.5 ± 0.59	2.87 ± 1.2	3.38 ± 0.9	2.58 ± 0.86
Crop land (ha)	0.93 ± 0.44	2.21 ± 0.862	2.14 ± 0.95	1.79 ± 0.75
Pasture land (ha)	0.35 ± 0.156	0.69 ± 0.620	1.23 ± 0.88	0.86 ± 0.58

Adult cows (≥3years), growing female (1-3 years), growing male (1-3 years), Calves (≤1year), calves (≤ 6 months), and adult male (≥3 years). Means with different superscript letters in the same row indicate significant differences at $p<0.05$; MYFPC = fat and protein corrected milk yield per year; NA = not applicable.

Natural pasture hay, crop residues, and pasture grazing constitute the dominant sources of basal feed resources in the study area. Crop residues, dominantly cereal straws, are produced and used as animal feed in peri-urban and rural farming systems, especially during the dry season when pasture and hay supplies are depleted (Table 4.3). The most commonly used agro-industrial by-products for supplementation were wheat bran, wheat middling, and noug (*Guizotia abyssinica*) seed cake. At the same time, oats grain/hull and grass pea hull were also used as local supplements (Table 4.3). The average feed digestibility (DMD) in a rural farming system was significantly ($p<0.05$) lower than in an urban farming system.

Table 4.3 Feed type, diet composition, and dry matter digestibility % in the three farming systems

Feed type (%)	Farming systems			References	
	Urban (N = 120)	Peri-urban (N = 180)	Rural (N =180)		
Natural pasture (Native)	NF	8.77	32.17	58.49	Feyissa et al., 2014; Derara and Bekuma, 2021
Grass hay	18.98	13.05	1.78	59.30	Bediye et al., 2019; Feyissa et al., 2014
Commercial concentrate	2.11	2.11	NF	70.28	Feyissa et al., 2015
Wheat bran	7.83	6.76	1.42	71.15	Feyissa et al., 2015
Wheat middling	7.11	4.74	1.98	79.03	::
Oats grain	2.28	1.52	1.90	76.03	::
Noug cake	7.10	4.97	NF	70.99	::

Cottonseed cake	0.85	0.85	NF	84.67	::
Desho grass (<i>Pennisetum glaucifolium</i>)	0.75	1.32	1.09	52.68	Faji et al., 2020
Napier grass (<i>Pennisetum purpureum</i>)	NF	NF	0.51	50.50	Kebede et al., 2016
Vetch (<i>Vicia</i> species)	NF	1.00	1.00	66.47	Kebede, 2016
Alfalfa	NF	0.77	1.15	76.63	Geleti et al., 2014
Oats (<i>Avena sativa</i>) straw	0.47	0.46	0.70	46.89	Kebede et al., 2020
Wheat straw	3.08	3.69	3.28	41.00	Feyissa et al., 2015
Barley straw	3.53	2.69	2.48	41.32	Derara and Bekuma, 2021
Teff straw	2.76	2.76	2.30	46.01	Feyissa et al., 2015
Grass pea hull	NF	0.61	1.54	61.42	Feyissa et al., 2015
Faba bean hull	0.92	0.31	0.92	61.42	::
Brewer residue	3.18	3.18	1.04	69.46	::
Atela (traditionally home-made liquor residue)					::
	0.74	0.74	2.21	73.66	
Feed digestibility	62.28 ± 3.44 ^a	60.29 ± 3.25 ^b	57.46 ± 3.83 ^c		

Means with different superscript letters in the same row indicate significant differences between seasons of the ear at ($p < 0.05$); DMD = dry matter digestibility; SD = standard deviations; NF: not fed

The manure management system was similar across different farming systems in the study area (Table 4.4). In urban and peri-urban SHF systems, about two-thirds of the total manure is used for making dung cakes and stored in dry lot systems. Many farmers used manure as fertilizer and dung cake, while a few urban and peri-urban SHFs used it for biogas production. About 40–50% of the total animal manure or dung cake is used as a source of domestic fuel for home consumption or income generation.

Table 4.4 Manure management systems

Manure management systems (%)	Farming systems		
	Urban	Peri-urban	Rural
Pasture/Range	0.00	10.76 ± 1.79	41.5 ± 7.05
Daily spread	1.69 ± 0.50	4.60 ± 1.21	4.54 ± 1.21
Solid storage	37.57 ± 8.07	30.71 ± 3.56	17.23 ± 1.75
Dry lot	31.35 ± 5.91	26.00 ± 1.62	14.23 ± 1.74
Liquid/Slurry	1.77 ± 0.70	1.29 ± 0.64	0.00
Burned for fuel	25.29 ± 3.88	23.18 ± 1.6	12.40 ± 0.82

Composting	1.58 ± 0.87	2.96 ± 0.76	10.10 ± 1.38
Anaerobic digester	0.75 ± 0.44	0.5 ± 0.50	
Total	100	100	100

4. 3.2 Greenhouse gas emissions and emissions hotspot

Enteric fermentation (CH₄) was the primary source of GHG emissions, accounting for about 67% of the total GHG emissions, followed by GHG emissions from manure management (CH₄ and N₂O) and feed production and transportation (CO₂, CH₄, and N₂O), which contributed about 16% and 15% of total emissions, respectively (Table 4. 5). Greenhouse gas emissions from enteric fermentation were significantly higher ($p < 0.05$) in rural SHF than in urban and peri-urban SHFs. However, no significant ($p < 0.05$) difference was observed between the urban and peri-urban farming systems. Greenhouse gas emissions from feed production and processing were significantly higher ($p < 0.05$) in urban than in rural SHF. Similarly, emissions from manure management were significantly lower ($p < 0.05$) in rural SHFs than in urban and peri-urban SHFs. Methane emission from enteric fermentation (73.2%) and N₂O emission (22.9%) from manure management, feed production, and transportation were the two major hotspots of SHFs. Carbon dioxide from feed production, processing, and transportation contributed the least, accounting for about 4.0% of total emissions. Adult and replacement females contributed most farm GHG emissions in urban and peri-urban SHFs. However, the male stock contributed about 31% of total GHG emissions in rural SHF.

Table 4. 5 Sources of GHG emissions and emission hotspots across farming systems

Sources of GHG emissions (%)	Urban	Peri-urban	Rural	Average total
Enteric fermentation (%)	66.20 ^a	67.60 ^a	69.80 ^b	67.90
Manure management (%)	16.90 ^a	16.70 ^b	15.80 ^c	16.50
Feed production & processing (%)	16.90 ^a	15.70 ^{ab}	14.50 ^b	15.70
Contribution of GHG emissions				
CH ₄ (%)	74.50 ^a	72.10 ^a	72.90 ^a	73.20
N ₂ O (%)	20.60 ^a	23.50 ^b	24.50 ^c	22.90
CO ₂ (%)	4.90 ^a	4.40 ^a	2.60 ^b	4.00

Means with different superscript letters in the same row indicate significant differences between farming systems at ($p < 0.05$).

4. 3.3 Carbon footprint of milk production

4. 3.3.1 Carbon footprint of milk production and its association

The CF of milk production (kg CO₂/kg FPCM) was estimated for each farm by using different allocation methods and global warming potential (GWPs) (Table 4. 6). Our findings show that CF varies across allocation methods and GWPs. Allocating a single product (100% allocation to milk) using the GWPs equations of IPCC (2007) and IPCC (2014) resulted in an overall weighted mean CF of 3.54 and 3.65 kg CO₂e/kg FPCM, respectively. When GHG emissions were allocated to multiple products using economic allocation, to kg of milk, kg of beef, kg of manure, finance, and insurance, the weighted mean of CF of milk was 1.91 and 2.35 CO₂e/kg FPCM for GWPs of IPCC (2007) and IPCC (2014), respectively. On average, milk accounted for 72% of the total greenhouse gas emissions (urban = 88%, peri-urban = 82%, rural = 45%). A significant ($p < 0.01$) variation of CF among the three smallholder farming systems was found. Rural SHF was reported to have significantly ($p < 0.05$) higher CF per kg of milk than urban and peri-urban SHF systems (Table 4. 6). When estimated using economic allocation, the CF was significantly lower ($p < 0.01$) in urban than in peri-urban and rural SHFs. The remaining analysis uses the IPCC (2014) GWPs and economic allocation approach for consistency and comparison with existing knowledge of CF in milk production.

Table 4. 6 Carbon footprint (kg CO₂e/kg FPC) of milk production (\pm SD) using different GWPs and allocation approaches

Allocation	IPPC (2014) GWPs			IPCC (2007) GWPs		
	Urban	Per-urban	Rural	Urban	Per-urban	Rural
100% to milk	2.6 ^a \pm 0.35	2.8 ^b \pm 0.39	5.56 ^c \pm 0.89	2.1 ^a \pm 0.30	2.26 ^a \pm 0.32	5.36 ^b \pm 0.73
Mass allocation	2.10 \pm 0.32	2.36 \pm 0.33	3.68 \pm 0.42	1.92 \pm 0.26	1.91 \pm 0.27	2.97 \pm 0.34
Economic allocation	2.14 ^a \pm 0.29	2.30 ^b \pm 0.32	2.62 ^c \pm 0.30	1.73 \pm 0.26	1.86 \pm 0.26	2.15 \pm 0.25
All farming system	IPPC (2014) GWPs			IPCC (2007) GWPs		
100% allocated to milk	3.65 \pm 0.56			3.54 \pm 0.45		
Mass allocation	2.69 \pm 0.29			2.27 \pm 0.29		
Economic allocation	2.35 \pm 0.26			1.91 \pm 0.27		

Means with different superscript letters in the same row indicate significant differences between farming systems at (< 0.05).

4. 3.3.2 Carbon footprints and its association with milk yield and feed digestibility

A significant and negative relation was reported between milk yield per farm and GHG emissions per kg of milk and milk yield, which explained more than half of the variability at the farm level (69%) (Table 4. 7). Similarly, the magnitude of CF was also significantly influenced by feed dry matter digestibility (Table 4. 7). Feed digestibility had a negative and significant ($P < 0.01$) association with emission intensity at the animal level. It was observed that GHG emissions consistently decreased with increasing feed digestibility across all farming systems.

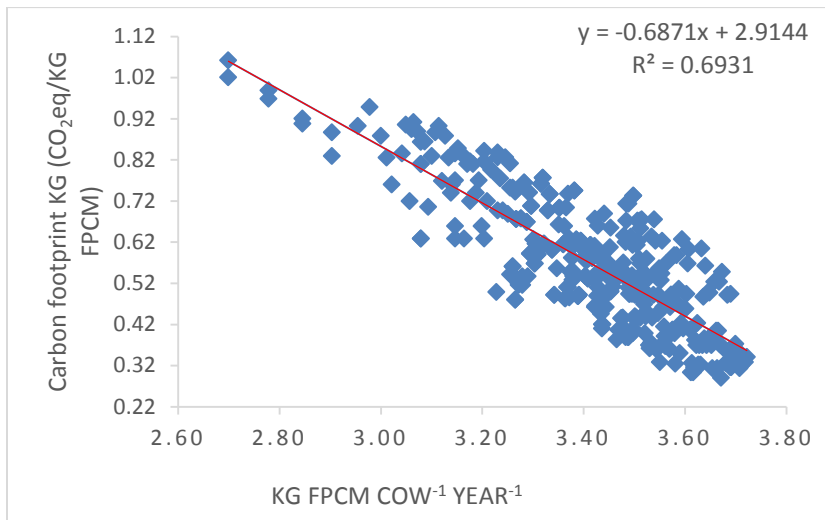


Figure 4. 2 Relationship between milk yield and carbon footprint of milk of SHF

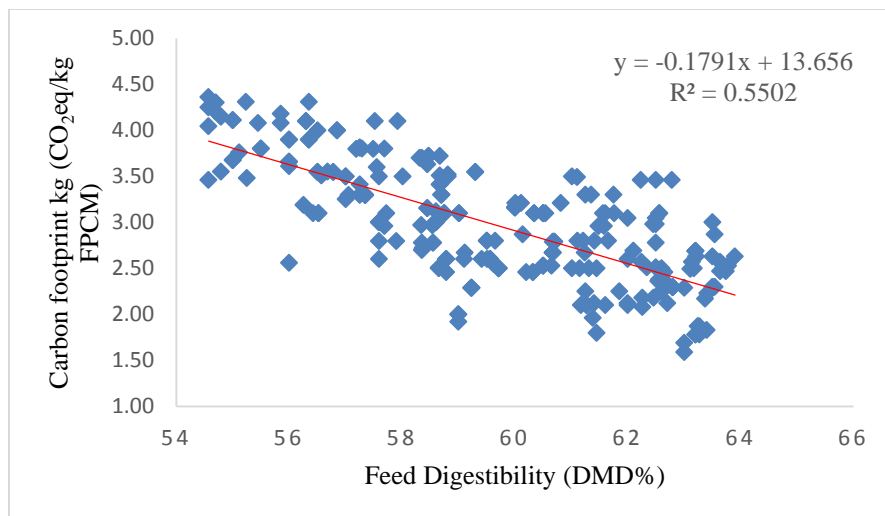


Figure 4.3 Relationship between feed digestibility and carbon footprint of milk production

4. 4. Discussions

4. 4.1 Smallholder dairy farming systems

Like the smallholder farming system in Ethiopia, the highland dairy system represents a mixed crop-livestock system in which farmers mainly depend on crop by-products and residue for livestock feeding (Tegegne et al., 2013; Gizaw et al., 2016). The significant differences in milk yield and body weight observed across farming systems could be attributed to differences in intensification and production input. This result is consistent with earlier findings, which found that the major differences among smallholder dairy farming systems in Ethiopia are production objectives, levels of inputs, and breeds and genotypes kept by farmers (Yilma et al., 2011; Tegegne et al., 2013; Gizaw et al., 2016; FAO-NZAGRC, 2017). The average herd size, breed (genotype) composition, age at first calving, and calving interval reported in this study are consistent with the comprehensive characterization of smallholder dairy farming systems in the central highlands of Ethiopia (Tegegne et al., 2013; Gizaw et al., 2016; Shibru et al., 2016). The average milk yield per cow per year reported in this study is higher than the values reported in CF study in Mekele milk shed of northern Ethiopia (Woldegebriel et al., 2017) and SHFs of Kenya's central highlands (Wilkes et al., 2020a). On the other hand, the average milk production per cow was significantly lower than the average milk yield reported in a meta-analysis of CF studies in developed countries (Lorenz et al., 2019).

Like in other tropical countries, cattle are kept to fulfil both tangible and non-tangible benefits for smallholder farmers in Ethiopia (Weiler et al., 2014; Garg et al., 2016; Woldegebriel et al., 2017; Wilkes et al., 2020a). For the majority of urban SHF, dairy farming was the sole source of livelihood and income. This result is consistent with the findings of Gizaw et al. (2016), who indicated that livestock production is the most important activity and the sole source of livelihood for nearly 100% of urban dairy farmers in the central highlands of Ethiopia. Similar findings were reported in the CF study in Kenya (Weiler et al., 2014; Wilkes et al., 2020a). On the other hand, milk production and draught power were given a high priority in rural smallholder farming systems where animals are also kept for manure (fertilization of the soil and fuel production) while castrated males are used for fattening. Because of limited access to urban centers where fresh milk is highly demanded, rural SHF processes milk into butter and other dairy products for sale or home consumption (Ghilu et al., 2012; Tegegne et al., 2013; Gizaw et al., 2016).

Grass hay from the natural pasture was the dominant basal feed resource, followed by crop residue and pasture grazing in the study area (Tegegne et al., 2013; Gizaw et al., 2016; Feyissa et al., 2018). The share of these feed ingredients in animal diets varied considerably across the farming systems and seasons. Accordingly, crop residue and green grass from natural pasture constituted 90% of rural SHF's total feed basket throughout the year. The overall feed digestibility and the proportion of supplementary feed in the daily feed ration reported in the present study are similar to the LCA studies of smallholder dairy farming systems in Ethiopia and of Kenya (Woldegebriel et al., 2017; Wilkes et al., 2020a), but much lower than those of developed countries (IPCC, 2019). This is primarily due to the high cost and inadequate supply of agro-industrial by-products in the study area.

The management system and the percentage of animal manure used as dung cake for fuel are similar to the earlier reports (de Vries et al., 2016; FAO and NZAGRC, 2017; Woldegebriel et al., 2017). According to key informant interviews, small ruminant faeces replaced cattle manure as fertilizer. This is primarily because dung cake is used as a year-round source of income in all farming systems. In light of these findings, Mekonnen and Kohlin (2008) proposed that dung cake as manure is limited, partly because a significant portion of dung is used as a source of

household fuel. An earlier CF study in Ethiopia discovered that approximately 40% of animal manure is used as a fuel source, implying that valuable nutrients are lost from the farm and regional nutrient cycle (de Vries et al., 2016).

4. 4.2 GHG emissions hotspot

The most important sources of GHG emissions were rumen enteric fermentation, manure management, feed production, and transportation. This could be attributed to feed digestibility, animal feed conversion efficiency, physical and chemical properties of feed, and the high proportion of low-quality (roughage) feed in the total feed basket. Emissions from manure management (CO₂, CH₄, and N₂O) contribute about 16.45% of the total GHG emissions in peri-urban and rural SHFs. This might be because of a considerable amount of N₂O emission from direct manure deposition by grazing animals (FAO, 2013) (Opio et al., 2013). Moreover, during the rainy season, a significant portion of manure was collected and stored in an open heap for 3-4 months, which may have been responsible for the production of potential CH₄ emissions from anaerobic fermentation. In contrast to these findings, feed production and transportation emissions were the second-largest sources of GHG emissions (Garg et al., 2016; Woldegebriel et al., 2017; Wilkes et al., 2020a). In urban SHF, emissions from feed production and processing were the second-largest GHG emission. The differences in GHG emissions from feed production observed across farming systems were due to the type and quality of feed used in the daily ration. In urban SHF, for instance, the significant GHG emissions from feed production were mainly attributed to the large proportion of concentrate or processed feed in the daily ration relative to peri-urban and rural SHF.

The significant differences in enteric fermentation reported in rural SHF might be due to the lower average feed digestibility and crude protein content reported in rural SHF than in peri-urban and urban SHFs. The DMD and crude protein contents in the daily ration fed in rural SHF were below the crude protein (CP) requirements of productive dairy cows, which range from 12–18% CP in the diet (Moran, 2005). The association of low digestible feeds with high enteric CH₄ and GHG emissions was reported earlier (Archimède et al., 2011; Opio et al., 2013; Reddy et al., 2019b). The GHG emissions related to feed production in urban SHF were significantly higher

than in rural SHF. This could be because more emissions related to feed production are emitted off-farm in urban SHFs than in peri-urban and rural SHFs, as a significant amount of supplementary feed is produced off-farm in urban SHFs. Similar results were reported in the CF study by Garg et al. (2016) in India and Wilkes et al. (2020a) in Kenya. On the other hand, the low proportion of total GHG emissions from feed production and transportation in rural and peri-urban SHF indicated that a large proportion of animal feed (pasture hay, crop residue) in the daily ration was produced on-farm.

4. 4.3. Carbon footprint and its uncertainties

Using economic allocation, the overall average CF of milk production estimated in this study (2.35 ± 0.27 kg CO₂e/kg FPCM) was much lower than the CF value reported by FAO and NZAGRC (2017) in Ethiopia and the explorative global study in SSA (FAO, 2010b; Gerber et al., 2013). However, other studies reported higher CF in India (Garg et al., 2016) and South Africa (Reinecke and Casey, 2017). The lower CF in urban systems than in peri-urban and rural farming systems is mainly due to the differences in intensification and production objectives. The wide range of variation among different authors in the CF findings could be due to differences in allocation methods (Rice et al., 2017), study methodology (Reddy et al., 2019b), management practices (Garg et al., 2016; Woldegebriel et al., 2017; Reddy et al., 2019b), and region-specific emission factors (Wilkes et al., 2020a).

According to the reports of Wilkes et al. (2020a), feed conversion efficiency negatively correlates to CF. Emission intensity increases with milk yield and decreases per kg output (FPCM) per lactation. Similar trends were observed in CF studies in India (Garg et al., 2016) and Kenya (Wilkes et al., 2020a). A previous study by Gerber et al. (2011) stated that GHG emissions increase with a higher yield, whereas the emissions per kg FPCM decline substantially as animal productivity increases. Furthermore, Gerber et al. (2011) concluded that increasing productivity could be a viable mitigation option, especially in areas where milk yields are below 2000 kg per year per cow. Feed digestibility had a strong but inverse relationship with milk yield per lactation. Low feed digestibility was mainly attributed to the large proportion of crop residue and pasture hay in the study area. As suggested by Gerber et al. (2011), low-quality feed takes a

long time in the rumen, leading to high enteric methane emission and high emission intensity, consequently resulting in low animal productivity. The value obtained in this study is similar to the value reported in CF studies of India and Kenya (Garg et al., 2016; Wilkes et al., 2020a). Therefore, the significant association between emission intensity and feed digestibility reported in the present study will contribute to designing effective GHG emission mitigation strategies.

The standard deviations of the mean of CFs reported in our study had a margin of error of about 20 at a 95% CI (Table 4. 7). This value is larger than the margin of error reported in the CF study in Kenya and India (Garg et al., 2016; Wilkes et al., 2020a). Similarly, a wide range of secondary data estimates was reported in Ethiopia (Wilkes et al., 2020b). The uncertainty range of +26 and +18.75 was reported for the weighted mean of farms. A Monte Carlo simulation of uncertainty in input parameter values found that feed digestibility and feed emission factor (EF) were essential sources of uncertainties in all feeding systems. Hence, these are the key potential areas to reduce uncertainty and improve accuracy.

Table 4. 7 Milk yield, dry matter (DM) intake, feed efficiency (FE), and carbon footprint (CF) of milk production (mean values with S.D).

Parameter	All farms N = 480	Urban N = 120	Peri-urban N = 180	Rural N = 180	P value
FPCM (kg/year)	2587.64 ± 354.2	3750.7 ^a ± 511.4	3226.46 ^b ± 452.67	785.74 ^c ± 98.57	
Total DM intake (kg/year)	7130.41 ± 47.41	8427.65 ^a ± 51	7808.34 ^b ± 51.24	4969 ^c ± 27.16	≤0.05
Feed efficiency (FE)	0.367 ± 0.13	0.44 ^a ± 0.14	0.41 ^b ± 0.10	0.14 ^c ± 0.12	≤0.05
CF (Economic allocation)	2.35 ± 0.26	2.14 ^a ± 0.29	2.30 ^b ± 0.32	2.62 ^c ± 0.30	≤0.05

Means with different superscript letters in the same row indicate significant differences among farming systems.

4. 4.4 Mitigation of GHG emissions and policy implications

The CF in the present study varied with methodological choices, dry matter digestibility, feed conversion efficiency, and increasing animal productivity. The GHG emissions from enteric

fermentation reported in this study pinpoint the importance of enteric fermentation as a hotspot for identifying mitigation options in the study area. By considering the main drivers of emissions intensity, the following mitigation options are identified as having the potential to reduce on-farm GHG emissions and improve productivity while considering the feasibility of implementation and their potential economic benefit at the farm level.

Improved feeding by increasing the proportion of concentrate in the daily ration at the expense of straw and crop residue will be an important area of intervention. Supplementation with leguminous shrubs, silage making, and urea treatment of crop residue is expected to address feed scarcity and quality constraints, improve the quality of the diet, and increase intake and digestibility. The manure management system is another potential mitigation intervention prioritized next to improved feeding. By shifting the manure into fertilizer, the amount of organic manure on farmland will increase, which will reduce the need for synthetic N-fertilizers. In urban and peri-urban SHFs, biogas or anaerobic digestion is very helpful in replacing dung cake used for fuel. Improving the genetic potential of indigenous breeds by cross breeding or introducing crossbred heifers that can withstand feed and disease problems in the herd will improve production and reproductive performance. This, in turn, increases average milk production per animal and maximizes the overall herd productivity, reducing GHG emissions intensity. Culling unproductive and retired dairy animals from the herd increases herd productivity and reduces GHG emissions at the farm level.

4. 5. Conclusions and Recommendations

Smallholder farming systems in Selale milk shed differ in terms of intensification, production objectives, and production inputs and output. Enteric fermentation and CH₄ emissions from enteric fermentation and manure management were the primary sources of GHG emissions and emissions hotspots. The main sources of CF variability in milk production were the farming system, allocation approach, and GWPs used. The average CF ranged between 2.14 and 2.62 kg CO₂-eq/kg FPCM, using economic allocation, and was significantly higher in rural smallholder farmers than in peri-urban and urban farming systems. A significant and inverse relationship was reported between CF and milk yield (FPCM) per kg output. Feed digestibility and feed conversion efficiency had a strong negative relationship with emission intensity. Improved

feeding by increasing the proportion of concentrate and improve forage crops, as well as chemically treating crop residue and pasture hay, could help to reduce enteric CH₄ emissions, improve animal productivity, and, as a result, lower milk CF. Adding the desired amount of feed additives to the ration also improves feed efficiency, rate of gain, and disease prevention, thereby improving animal productivity and reducing greenhouse gas emissions. Using organic manure for fertilizer instead of fuel will increase the amount of organic manure on-farm, thus improving nutrient use efficiency for sustainable dairy farming in the long run. The study recommends supporting SHF to realize strategies contributing to climate-resilient dairy development, which requires interventions at several levels in the dairy value chain.

Chapter Five

5. Developing Country Specific Enteric Methane Emission Factors and Its Response to Farming Systems Dynamics in Selale Highlands

Abstract

Following global pledges to reduce greenhouse gas (GHG) emissions by 30% by 2030 compared to the baseline level in 2020, improved quantification of GHG emissions from developing countries has become crucial. However, national GHG inventories in most sub-Saharan Africa countries use default (Tier I) emission factors (EF_s) generated by the intergovernmental panel on climate change (IPCC) to estimate enteric CH₄ emissions from animal agriculture. The present study provides an improved enteric CH₄ emission estimate (Tier II) based on animal energy requirements derived from animal characteristics and performance data collected from about 2500 cattle in 480 households from three smallholder farming systems to represent the common dairy farming in the central highlands of Ethiopia. Using average seasonal feed digestibility data, we estimated daily methane production by class of animal and farming system and subsequently generated improved EF. Our findings revealed that the estimated average EF and emission intensities (EI) vary significantly across farming systems. The estimated value of EF for adult dairy cows was 73, 69, and 34 kg CH₄/cow/ year, for urban, peri-urban, and rural farming systems, respectively. Rural dairy farming had significantly higher EI estimated 1.78 (CO₂-eq kg-1MY) per kg of milk than peri-urban and urban 0.71 and 0.64 (CO₂-eq kg⁻¹MY) dairy farming systems, respectively. For both stall-fed high-productivity and dual-purpose low-productivity cows, the EF estimates in this study are lower than the IPCC's (2019) default value. The current findings can be used as a baseline for the national emission inventory, which can be used to quantify the effects of future interventions, potentially improving the country's commitment to reducing GHG emissions. Similarly, this study suggests that increased animal productivity through improved feed has a considerable mitigation potential for reducing enteric methane emissions in smallholder dairy farming systems in the study area.

Keywords: Enteric methane emission, Emission Factor, Emission intensity, Intergovernmental Panel on Climate Change, Smallholder Farmer.

5.1 Introduction

Enteric methane (CH₄) is the second largest source of greenhouse gas (GHG) emissions from agriculture and represents 14% of all agricultural, forestry, and other land-use emissions (FAO, 2017). In Africa, agricultural emissions dominate the GHG emissions profile, of which 70% comes from livestock production, where CH₄ emissions from enteric fermentation dominate (Tubiello et al., 2014). Some estimates show that GHG emissions from enteric fermentation, manure management, and managed soil account for the largest share (60%) of Ethiopia's total agricultural GHG emissions (CRGE, 2011; Shapiro et al., 2015). In addition, the estimates indicated that methane emissions from the enteric fermentation of livestock in Ethiopia have shown an increasing trend in enteric methane emissions (Shapiro et al., 2017; Wasse et al., 2022). Ruminant enteric fermentation accounted for a large portion of livestock methane emissions in 2018, accounting for 85 percent of total emissions (Wassie et al., 2022).

Because of the rising demand for animal products, the cattle population is expected to grow, hastening the rise in enteric methane emissions caused by population growth, urbanization, and dietary changes. Given the current demand for livestock products, for instance, the cattle population is likely to increase from today's around 65 million (CSA, 2020) to more than 90 million in 2030 CRGE (2011), thereby doubling emissions from the livestock sector. In a business-as-usual scenario, emissions from cattle are projected to increase as a function of cattle population growth, low animal productivity, poor animal health, and low-quality feed, mainly driven by an increase in methane emissions from enteric fermentation.

On the other hand, the dairy value chain provides opportunities for low-cost mitigation and widespread social and economic benefits (Herrero et al., 2012), as there is a strong correlation between increased animal productivity and reductions in enteric methane emissions (Garg et al., 2018). There is considerable agreement that increasing efficiency in resource use is a crucial component of improving the sector's environmental sustainability. Improving animal and herd productivity is one of the key pathways to reducing enteric CH₄ emissions per unit of product (FAO, 2016a; FAO-NZAGRC, 2017). Improved practices and technologies such as strategic

supplementary feeding, diet quality, adequate animal health control, and genetic improvement of animals can improve dairy productivity and reduce emission intensity (FAO-NZAGRC, 2017).

To contribute to global efforts to reduce methane emissions across all sectors of the economy, the livestock sector must be integrated into national climate actions. East African countries, including Ethiopia, have been signatories to the global methane pledge since 2021 and have committed to reducing global methane emissions by 30% by 2030 compared to baseline levels in 2020 (FAO, 2022). Furthermore, countries have submitted updated national determined contributions (NDCs) covering methane to the United Nations (UN) Framework Convention on Climate Change (UNFCCC) in 2020, with mitigation actions for the livestock sector included in these submissions (Crumpler et al., 2021). The effectiveness of any national or regional mitigation measure depends on the accuracy, transparency, and comparability of country-specific national GHG inventories (IPCC, 2006). In light of this, countries should adopt a high-tier method to generate baseline information that could be an input to the national emission inventory to quantify the effects of future interventions (Malley, 2023). Using a Tier II method for enteric methane emission estimates would improve accuracy and reduce uncertainties caused by the IPCC Tier I method (IPCC, 2019).

So far, only a few attempts have been made to estimate the enteric methane emissions of smallholder dairy cattle in Ethiopia in general and the central highlands in particular. Selale milk shed is one of the potential mixed farming systems of the central highlands of Ethiopia where crop-livestock farming is the predominant practice (Brandsma et al., 2013). Some previous studies have either estimated enteric CH₄ emissions at the regional/national level (Wilkes et al., 2020; FAO & NZAGRC, 2017) or used assumed characteristics of typical farming systems and actual data from small samples of farms (Girma et al., 2018; Tadesse et al., 2022). As a result, the findings of those studies are highly aggregated and provide little assistance in addressing local differences in production characteristics and intervention measures.

Moreover, in various agro-ecologies and production systems, ruminant livestock have access to different types and quantities of feed, causing varying levels of production and GHG emissions (Herrero et al., 2008; Opio et al., 2013). Herrero et al. (2008) noted that the spatial distribution of GHG produced by ruminant animals varies significantly depending on their location due to

agro-ecology and the type of production system. Due to the dynamic nature of livestock husbandry practices and feed resources, animal and feed characteristics data can provide valuable insight into additional mitigation strategies for reducing enteric CH₄ emissions.

Therefore, the objective of the present study was to generate improved enteric methane emission factors (EF) using the tier II method based on animal energy requirements derived from animal characteristics and performance data and to evaluate the variations in enteric CH₄ emissions among farming systems in the central highlands of Ethiopia.

5. 2. Literature Review

5.2.1 Smallholder farming systems

Like most dairy systems found in the tropics, the smallholder dairy farming systems can be classified into three categories: urban, peri-urban, and rural. These systems are classified depending on the scale of production, production resources, breeding and marketing objectives, management practices, and the contribution of dairying to livelihoods (Tegegne et al., 2013; Gizaw et al., 2016). According to Gizaw et al. (2016), variables that significantly contributed to classification included the breeds and genotypes kept, daily milk production, income from livestock, and cow feeding practice. However, the peri-urban and urban farming systems might share some similar characteristics. The significant variation in milk yield across the smallholder farming system can be attributed to differences in exotic gene levels of crossbred animals and management (Tegegne et al., 2013; Gizaw et al., 2016). These characteristics also play an important role in the variation in enteric methane emissions across the farming system in the study area.

Urban farming systems are concentrated in major cities and towns. The system is market-oriented, based on improved breeds (crossbreds or high-grade), and operated under stall feeding conditions with little or no land resources. As compared to other systems, they have relatively better access to inputs (e.g., feeds) and services (e.g. artificial insemination) provided by the public and private sectors than others and use intensive management. The primary farm output is fluid milk, which is sold to the most affluent urban markets. Farmers dominantly raise exotic or

the cross of exotics blood with local breeds, and agro-industrial byproducts and purchased roughage are the important sources of feed (Asrat et al., 2016; Duguma and Janssens, 2016; Gizaw et al., 2016).

Peri-urban dairy systems: the systems are located mainly near towns and cities. Production is market-oriented and specifically targets consumers in urban areas, and some local butter products are the main production objectives in this system (Tegegne et al., 2013; FAO-NZAGRC, 2017). Farmers have access to land and usually practice mixed crop-livestock farming, which produces part of the feed in the form of crop residues and grazing. Similar to urban dairy, in this system too, milk production, in general, is mainly based on cattle (both cross and highbred) and uses semi-grazing and stall feeding using roughage and agro-industrial by-products. The major sources of feed include hay from private grazing land, concentrates, improved forage, and communal grazing land (Gizaw et al., 2016).

Rural farming systems are part of the subsistence farming systems that are primarily concentrated in the highlands and are dominated by cereals and cash crops (A Tegegne et al., 2013). The system is traditional and based on low-productive multipurpose indigenous cattle breeds for milk, manure (to fertilize the soil and fuel production), and castrated male animals for draught power (A Tegegne et al., 2013; Gizaw et al., 2016). Milk is mostly consumed at home or sold to neighbors because rural farmers have limited access to inputs and services, as well as the urban market where fluid milk is demanded (Tegegne et al., 2013; Gizaw et al., 2016; FAO-NZAGRC, 2017). The animals mainly graze natural pastures of non-arable or fallow land between crop fields and are additionally fed crop residues.

A variety of factors impede smallholder dairy production, the nature and magnitude of which vary depending on production systems and agro-ecologies. Some are system-specific, affecting specific dairy production systems regardless of agro-ecology whereas, others are cross-cutting (Tegegne et al., 2013). Among the major constraints are feed shortages in terms of quality and quantity, low genetic potential of indigenous breeds, poor access to inputs and services, undeveloped market linkage, land shortage, and policy support for dairy development (Tegegne et al., 2013; Gizaw et al., 2016). In all farming systems, farmers' ability to realize the genetic potential of improved breeds and increase output is limited by the non-genetic constraints.

Natural pastures, crop residues, and other available forage, for instance, have lower energy digestibility and protein content, limiting milk yield and increasing enteric methane emissions (Archimède et al., 2011). Variation in livestock management system (feed quantity and quality, feeding level, and livestock activity and health) also have a wide range of impacts on enteric CH₄ emissions (Shibata and Terada, 2010; Jo et al., 2015). In light of this, examining variations in enteric methane emission across smallholder farming systems will be essential to evaluating baseline information used for the national CH₄ emissions inventory and future climate actions that integrate livestock into global efforts to reduce CH₄ emissions.

5. 3. Materials and Methods

5. 3.1 Description of the study area

The present study was conducted in the Selale highland in the Central Ethiopia (Figure 2). The study area is located at 38°07'60" E longitude and 9°40'60"N latitude, and about 42% of the area falls under tropical highland resembling that of temperate regions climate and almost a quarter of the land in the zone is typical tropical dry land (Brandsma et al., 2013). The area includes diverse topographical features ranging in altitude from 3500 metre above sea level (masl) at the tip of mountainous to 1200 masl across most plains. The area experiences bimodal rainfall during summer (June-September) and spring (February-April). Livestock, especially dairy farming, is the dominant agricultural enterprise and source of livelihood. Agricultural production in the Selale highlands primarily consists of subsistence mixed crop-livestock farming, and Smallholder dairy farms dominate the dairy industry (Brandsma et al., 2012).

The study area was chosen because of its high milk production potential and the importance of dairying in the local subsistence agriculture economy. The Selale milk shed, the leading area for dairy development in the country is known for having a long history of dairy development ever since the introduction of improved dairy cows some 60 years ago (A Tegegne et al., 2013; Zijlstra et al., 2015; Shapiro et al., 2017). Besides, the region/area is known to have suitable conditions for fodder production and the use of agricultural by-products, and farmers have a high percentage of improved dairy breeds and better access to artificial insemination (Zijlstra et al., 2015). According to the CSA (2020) report, the study area has the largest population of crossbred dairy cows in Ethiopia.

5. 3.2 Sampling and data collection

We collected first-hand information about dairy production, feed resources, and related matters through a quick survey and discussions with agricultural extension offices. The information was used to identify focal villages (Kebeles) and individual farmers registered under the national dairy cattle database, using a multi-stage purposive sampling technique. Four potential mixed farming districts (Suluta, Wuchale, Girar Jarso, and Degem) were purposively selected to represent the diverse agro-ecology and smallholder dairy farming systems of the study area. Girar Jarso district was selected to represent urban SHF, where dairy farming is practiced to support family income in addition to off-farm activities. Sululta and Wuchale districts represent mid-land agro-ecology and peri-urban dairy farming systems where crop and livestock production are closely integrated. Degem district is a typical highland agro-ecology where crop and livestock (dairy) production are closely integrated. Smallholder farmers were then stratified to urban, peri-urban, and rural dairy farmers. Four kebeles (the smallest administrative units in Ethiopia) were purposively selected from each district by considering smallholder farmers (SHF) registered under the national dairy cattle database and proximity to the road. In the third stage, 30 households were randomly selected from each of the selected kebeles. Subsequently, a total of 480 respondents were selected from the 16 kebeles. The study adopted the sample size rule of Arsham (2007) for sample size determination and Wilkes et al. (2019) smallholder dairy methodology.

5. 3.3 Data collection

This study relied on farm household surveys, activity data from national dairy cattle databases, and secondary sources.

5. 3.3.1 Household survey

A household survey was carried out between July 2020 and February 2021. The SHFs were visited three times to observe seasonal variations in feed resources and cross-check the data. Under the close supervision of the first author, a team of enumerators with expertise in livestock production administered the questionnaire to randomly selected household heads. The questionnaire was designed to obtain information on household characteristics, livestock holding,

dairy cattle herd management, reproductive and production performance, major feed available in the area and feeding system, disease prevalence, marketing, and major production constraints. Farmers and village leaders participated in 6- to -8-person focus group discussions to validate the information gathered through individual farmer interviews. Besides, secondary data on human and livestock populations, feed chemical composition, agro-ecology, and climate were gathered from zonal and district agriculture and rural development offices.

5. 3.3.2 Animal characteristics and performance data

Herd composition: For this study, a total of about 3000 cattle of various ages and sex were used (Table 5. 2). Then the animals were classified into four age groups: adult animals (3-10 years); growing animals (1-3 years); calves (6m-1year), and male and female calves (< 6m). To refine this information further, we traced back to the owner's profile and individual cattle records for more details, and animals that were culled or missing during the farm visit were excluded. The cattle population comprises pure Holstein Friesian, East African shorthorn zebu, and their crosses. In the urban and peri-urban farming systems, pure Holstein cattle and their crosses are kept, while in the rural farming system, indigenous cattle (East African shorthorn zebu breed) are kept.

Live weight measurement and average daily weight gain

Live weight (LW), mature weight, and average daily weight gain data were extracted from the national dairy cattle database found in the Livestock Development Institute (LDI). The LW of animals was then estimated from the heart girth measurements using the regression equation by Goopy et al. (2018). Due to the unreliability of our calculated value, we relied on secondary sources Haile et al. (2011) and Dadi et al. (2021) for average daily weight gain (ADG). Body condition score (BCS) was subjectively assessed and scored using the 5-point scale 1-5 scale by following Edmonson et al.(1989).

Milk yield and its chemical composition

Data for milk yield and reproductive performances (age at first calving, calving interval, calving date, milk yield per day, milk test date, and dry date) were extracted from the national dairy

cattle database. The standard 305-d milk yield for each animal was estimated from test date (TD) milk yield records by using a test interval method described by Sargent et al. (1968) and Migose et al. (2020). Milk samples were collected from a total of 70 SHF (urban = 27, peri-urban = 21, and rural = 21) in the morning and afternoon and analyzed for chemical composition such as butterfat (% BF) by Gerber method and milk density (Van Marle-Köster et al., 2000) (Table 4.1). Richmond's formula (Bector and Sharma, 1980) was used to calculate milk solid not-fat (SNF) as follows:

$$\text{SNF}\% = \left(\frac{\text{milk density (Kg/L)}}{4} \right) + (0.22 * \text{BF}(\%)) + 0.72 \quad (1)$$

The milk energy content (ECM) was calculated using the following equation (Tyrrell and Reid, 1965):

$$\text{ECM(MJ/kg)} = 0.0386\text{BF(g/kg milk)} + 0.0205 \text{SNF (g/kg milk)} - 0.236 \quad (2)$$

5. 3.3.3 Feed characterization and seasonal diet composition

A recent carbon footprint study indicated that the IPCC Tier 2 approach is sensitive to changes in input parameters such as methane conversion factors (Y_m) and diet digestibility (DMD) (Wassie et al., 2022; Feyissa et al., 2022). The data on seasonal feed type and feed proportion were collected on the farm and seasonal weighted DMD values were computed to reduce uncertainty in the assessment of EF and to account for seasonal feed baskets (Appendix II Table 8). We first identified the common feed resources used for dairy cattle and grouped them into six major types in the study area, namely: Natural pasture (grazing), pasture hay, crop residue, and cereal grain, agro-industrial by-products, and local brewery residues (Table 5.1). The digestibility of these feedstuffs was derived from previously published work and the extensive characterization of livestock feed resources, Lidetewolde et al., (2022) (unpublished data) in the study area (Table 5.3). The seasonal DMD content and the proportion of feedstuff given for the different categories of animals in the farming systems were considered in our analysis. The average weighted seasonal value of digestible energy was estimated for the wet season (9 months) and dry season (3 months) (FAO, 2018b). Accordingly, the DMD of natural pasture, forage crops, and crop residues during the dry and wet seasons were estimated, and the weighted average was used to calculate EFs.

In rural farms, cattle herds spend most of their time grazing on stubble after harvest and during the dry season, when natural pasture is depleted. The proportion of crop residues in the total diet increases in the dry season compared to the wet season (Table 5. 3). To simulate the seasonal diet composition and the average apparent DMD values, the percentage of each feedstuff and their nutritional values were used. Finally, the calculated weighted value of DMD was used to estimate MEF for each category and farming system. Feed digestibility was calculated for each feed, season, and farming system using an equation developed by Oddy et al. (1993).

$$\text{DMD} \left(\frac{\text{g}}{100} \text{g DM} \right) = 83.58 - 0.824 * \text{ADF} \left(\frac{\text{g}}{100} \text{g DM} \right) + \left(2.626 * n \left(\frac{\text{g}}{100} \text{g DM} \right) \right) \quad (3)$$

5. 3.3.4 Activity/Walking data

The IPCC emphasized the importance of animal feeding conditions in estimating the net energy dissipated by animals for grazing (IPCC, 2019). However, default values for the coefficient for activity (Ca) corresponding to the animal's feeding situation were provided in the IPCC guidelines without a detailed description of the feeding situation. Hence, Ca was estimated using the equation given in NRC (2001) and the East African dairy methodology (Wilkes et al., 2019). Due to relatively high population density and the expansion of crop production, grazing cattle are mostly kept in small paddocks (private pasture and roadside) and expend very little energy to obtain feed. The average grazing distance (2-3 km) was estimated using survey data and triangulated using secondary data from East Africa (Ndung'u et al., 2019; Ndao et al., 2020).

The National Research Council (NRC) classifies the net energy required for activity into two components: energy requirements for walking and energy requirements for grazing or eating activity (NRC, 2001). According to NRC (2001), the energy associated with eating is 0.0012 MJ/kg body weight; walking in a flat area is 0.00045 MJ/kg per km; and cows grazing on hilly terrain is 0.006 MJ/kg per km.

Where NEm is net energy for maintenance, calculated using IPCC (2006) Equation 10.3, Mcal was converted to MJ by multiplying by 4.20.

Based on the above premise, Ca was evaluated for different animal categories.

$$\text{Annual average km walked per day} = (\text{km in wet season} * (\text{months of wet season}/12)) + (\text{km in dry season} * (\text{months of dry season}/12)) \quad (1)$$

If the proportion of feed obtained from grazing per day > 0, then C_a is calculated as follows

$$C_a = \frac{(0.00045 * LW * \text{annual average km per day}) + (0.0012 * LW) * 4.1868}{NE_m} \quad (2)$$

The energy cost for cows grazing hilly topography is higher than that for cows grazing relatively on flat pastures, so the energy requirements for maintenance increased by 0.006 Mcal of NEm/kg body weight. To convert ME to NEM, an efficiency of 0.7 was used (CSIRO, 2007).

$$C_a = ((0.00045 * LW * \text{annual average km per day}) + (0.0012 * LW) + (0.006 * BW) * 4.1868) / NE_m \quad (3)$$

In Ethiopia, energy expenditure for traction or plowing is not well documented. As a result, an estimate of work hours was collected during the survey for the current study. Accordingly, in rural smallholder farming systems, oxen are assumed to plow for 3.5 months of the year (not including Sundays) and 7.5 hours per day and thresh for one month (not including Sundays and other holidays). For Brahman cattle, values for energy expenditure from traction or plowing were calculated using Lawrence and Stibbards (1990), who suggest an energy expenditure for walking of 2.1MJ/kg LW and work efficiency for plowing of 0.3. Cattle maintain traction efforts equivalent to 12% of their LW at a speed of 0.6-1.0 m/s, which indicates an additional energy expenditure of 0.4j/m/kg LW. Hence, plowing requires (at 0.8 m/s velocity) 0.002 MJ/h/kg LW. Thus, energy expenditure from plowing was calculated as:

$$MER_P \text{ (MJ)} = \text{Work hours (h/d)} * \text{Days}_{\text{work}} * \text{MLW (kg)} * 0.002 \text{ (MJ)}$$

5. 3.4 Estimation of total energy expenditure of animal

The total energy expenditure for each animal (category) was calculated by adding the metabolizable requirements (MER) for maintenance (MER_M), growth (MER_G), lactation (MER_L) for lactating animals, and wading (MER_W) or plowing/traction, if applicable. Energy expenditure was calculated by using equations derived from CSIRO (2007).

Estimation of energy requirements for maintenance (MER_M)

$$MER_M \text{ (MJ/day)} = K * S * M(0.26 * LW^{0.75} * \frac{\exp(-0.03A)}{(0.02 * M/D) + 0.5}) \quad (4)$$

Where: K= 1.3 (the intermediate value for *Bos Taurus/Bos indicus*)

S= 1 for females

M= 1

MLW= Mean live weight for each season. However, live weight lost during the dry season is expected to be compensated in the wet season, with no weight loss or gain for adult animals (FAO, 2018b).

A= age in years

M/D = metabolizable energy content (ME MJ/DM KG) where;

$$\frac{M}{D} = 0.172 \text{ DMD} - 1.707 \quad (5)$$

Estimation of energy requirements for Growth (MER_G)

$$MER_G \text{ (MJ/d)} = \left(\frac{LW_{change} * 0.092 * EC}{0.043 * M/D} \right) \quad (6)$$

Where: EC (MJ/kg) = energy content of the tissue (18mj/kg) [40]

Estimation of energy requirements for lactation (MER_L)

$$MER_L \left(\frac{MJ}{day} \right) = [(MY(L)) * ECM(MJ)] / ((0.02 * M/D) + 0.4) \quad (7)$$

$$MER_L = \frac{(DMY * ECM)}{((0.02 * \frac{M}{D}) + 0.04)}$$

$$\text{Where: } MY \left(\frac{1}{d} \right) = \frac{\text{Total milk recorded per season (L)}}{\text{Number of days in season (L)}} + DCMC (L) \quad (8)$$

ECM (MJ/kg) = Energy content of milk MJ/kg

Milk consumed by pre-ruminant calves ($DCMC_L$) was estimated following Radostits and Bell (Radostits and Bell, 1970). The growth rate of (0.340 and 0.362 kg/d) for high grade and the multipurpose breed was taken and calculated DCM as follows:

$$DCM(L) = (LW_{calves}(kg) * 0.107L/kg) + (154L/0.1kgLWG) \quad (9)$$

Estimation of ENERGY requirements for walking/grazing (MER_W)

$$MER_T(MJ/day) = Dist(km) * LW(KG) * 0.0026 \quad (10)$$

Where: DIST= average distance covered

LW = live weight

0.0026 = the energy expended (MJ/LW kg).

Estimation of energy requirements for plowing (MER_P)

$$MER_P (MJ) = \text{Work hours (h/d)} * \text{Daywork} * \text{MLW (kg)} * 0.002 (MJ) \quad (11)$$

The daily total energy expenditure (MER_{Total}) for each animal category in each production system/season was then calculated as:

$$MER_{Total} \text{ (MJ/day)} = MER_M + MER_G + MER_L + MER_T \quad (12)$$

5.3.5. Computation of daily methane production and emission factor

The daily methane production (DMP) was estimated as a factor of dry matter intake DMI (Radostits, O. M. Bell, 1970).

$$DMI \text{ (kg/d)} = \frac{MER_{Total} \text{ (MJ/day)} / (GE \text{ (MJ/kg)} * (DMD/100))}{0.81} \quad (13)$$

Where: GE = gross energy of the diet assumed to be 18.1MJ/kg DM

0.81 = the factor to convert metabolizable energy to digestible energy.

Then the estimated DMI was used to calculate DMP by using an equation developed by Charmley et al. (2016)

$$DMP \text{ (g)} = 20.7 * DMI \text{ (kg/day)} \quad (14)$$

The mean DMP for each class of animal was calculated. This was then used to calculate annual enteric methane EF (CH_4 kg/head/year):

$$EF = \frac{(DMP_{Wet \ season} + DMP_{Dry \ season}) * 365}{2 * 1000} \quad (15)$$

$$EI = \frac{DMP}{MY} \quad (16)$$

Where EI = Emission Intensity, $g \text{ kg}^{-1} \text{ LW}$

DMP = Daily methane production, $g \text{ CH}_4/\text{day}$

MY = Milk yield in kg

Enteric methane emission intensity in $kg \text{ CO}_2\text{-eq}$ per kg milk yield:

$$EI_{CO_2\text{-eq}} = (DMP/MY * 1000) * 34$$

Where: $EI_{CO_2\text{-eq}}$ = emission intensity, $kg \text{ CO}_2\text{-eq} \text{ kg}^{-1} \text{ LW}$

5.3.6 Data analysis

Both descriptive statistics and one-way ANOVA were used to analyze quantitative data. One-way ANOVA was employed to analyze the variation of EF among the three farming systems. The post-hoc test was used for means comparison. Analyses were made by using the Statistical

Package for Social Studies (SPSS) (2003) version 26 and the Microsoft Excel computer program. A Monte Carlo Simulation (MCS) was applied to estimate the uncertainties in the enteric methane emissions factor for different classes of cattle across the three farming systems using the Intergovernmental Panel on Climate Change (IPCC) methodology. Uncertainty was estimated as the margin of error (MOE) with a confidence interval of 95%. The margins of error were calculated using a z-score of 1.96, which corresponds to α value of 0.05. Using Spearman's ranked correlation coefficients, the contribution of each variable to total uncertainty was calculated (Appendix II Table 9).

Table 5.1 Dry matter digestibility (DMD %) of the major feed available in the study area

Feed type	Season		References
	Wet	Dry	
Natural pasture (Native)	58.49	49.50	(Daba et al., 2009; Feyissa et al., 2013; Namera et al., 2017; Yalew et al., 2020)
Grass hay	59.3	51.91	(Feyissa et al., 2015; Bediye e al., 2019; Yalew et al., 2020)
Commercial concentrate	72.28	72.28	(Feyissa, Kitaw, et al., 2015)
Wheat bran	71.15	71.15	(Feyissa, Kitaw, et al., 2015)
Wheat middling	79.03	79.03	(Feyissa, Kitaw, et al., 2015)
Oats grain (<i>Avena sativa</i>)	76.03	76.03	(Feyissa, Kitaw, et al., 2015)
Noug cake	70.99	70.99	(Feyissa, Kitaw, et al., 2015)
Cotton seed cake	84.67	84.67	(Feyissa, Kitaw, et al., 2015)
Desho grass (<i>Pennisetum glaucifolium</i>)	52.68	49.36	(Asmare et al., 2017) (Faji et al., 2019)
Napier grass (<i>Pennisetum purpureum</i>)	50.5	47.87	(Kebede et al., 2019)
Vetch (<i>Vicia species</i>)	66.47	66.47	(Kebede et al., 2013)
Alfalfa	76.63	76.63	(Geleti et al., 2014)
Oats straw	46.89	46.19	(Daba et al., 2009)
Wheat straw	41	39.12	(Feyissa, Kitaw, et al., 2015) (Daba et al., 2009)
Barley straw	41.32	41.32	(Derara and Bekuma, 2021)

			(Bediye et al., 2019)
Teff straw	46.01	44.36	(Daba et al., 2009)
			(Feyissa, Kitaw, et al., 2015);
Grass pea hull	61.42	61.42	(Feyissa, Kitaw, et al., 2015)
Chick pea straw	50.16	50.16	(Daba et al., 2009);
			(Feyissa, Kitaw, et al., 2015)
Faba bean hull	61.42	61.42	(Derara and Bekuma, 2021)
			(Bediye et al., 2019)
Brewery residues	69.46	69.46	(Feyissa, Kitaw, et al., 2015)
Atela (local brewery)	73.66	73.66	(Feyissa, Kitaw, et al., 2015)

DMD = Dry Matter Digestibility

5. 4. Result

5. 4.1 Smallholder dairy farming systems

Three types of smallholder dairy farming systems were identified and characterized (Table 5. 2). Cattle were categorized into five classes based on age and sex. Herd composition varied across farming systems, and the largest female cattle were reported in the urban farming system. All cows in urban and peri-urban SHF were either pure exotic breeds or cross breeds with medium to high exotic blood levels (the cross of Holstein and *Bos-indicus*). Dual-purpose indigenous cattle were dominantly kept in rural SHF. A significant ($P < 0.05$) variation was reported in the average daily milk yield across different farming systems (Table 5. 2). The average daily milk yield per cow was significantly higher in urban than peri-urban and rural farming systems. Similarly, all cattle categories in the rural farming system had lower live weight (LW) than in peri-urban and urban farming systems.

Table 5. 2 Herd structure, breed composition, mean live weight (kg \pm SD), and animal performances for the three farming systems

Farming system	Urban		Per-Urban		Rural	
	Mean \pm SD	Observation	Mean \pm SD	Observation	Mean \pm SD	Observation
Breed & genotype	Pure/high-grade		High-grade		Local zebu	
Adult dairy cows	429.2 \pm 43.7 ^a	508	423.3 \pm 42.0 ^a	545	294.2 \pm 34.5 ^b	159

Adult male	435.3 ± 47.3	10	425.3 ± 57.2	32	351.1 ± 28.3	84
Growing female	271.4 ± 44.0	270	265.7 ± 39.9	352	198.3 ± 42.9	56
Growing male	288.1 ± 55.9	25	280.1 ± 45.9	33	234.6 ± 17.5	34
Calf (≤12m) male and female	141.2 ± 25.0	144	134.4 ± 25.9	144	113.4 ± 14.4	76
Calf (≤6m) male and female	75.1 ± 11.2	241	72.6 ± 12.0	220	57.5 ± 7.3	130
Breeding bull	NA		NA		346.3 ± 38.5	54
Fattening	NA		NA		375.7 ± 35.5	54
Herd Performance						
MY L/day	10.4 ± 0.9 ^a		9.0 ± 1.1 ^b		1.8 ± 0.2 ^c	
ECM (MJ/KG)	3.0 ± 0.6 ^a		3.0 ± 0.6 ^a		3.7 ± 0.5 ^b	
Working hrs /day			7.80 ± 1.0		7.99 ± 0.8	

Adult cows (≥ 3 years); Adult male (≥3); growing female (1-3 years); growing male (1-3 years); Calve (≤1); calve (≤ 6m). Means with different superscript letters in the same row indicate significant differences at $p < 0.05$; ECM = energy content of milk; ADWG = average daily weight gain; MY = milk yield per day; NA = not applicable. Working hrs = Working hours per day for draught oxen.

5. 4.2 Diet composition and estimate of feed digestibility

The feed proportion and estimated dry matter digestibility (% DMD) values are presented in (Table 5. 3). Natural pasture hay, crop residues, and pasture grazing constitute the dominant sources of basal feed resources in the study area. The most commonly used agro-industrial by-products were wheat bran, wheat middling, and noug (*Guizotia abyssinica*) seed cake, while oats grain/hull and grass pea hull were used as local supplements. The share of these feed ingredients in animal diets varied considerably across farming systems and seasons of the year. All animals were stall-fed on the urban farm, whereas stall feeding with limited grazing on restricted areas and private pasture was the common feeding practice in the peri-urban farming system. On the other hand, grazing is the main feeding system throughout the year for the rural SHF with a minimum supplementation for milking cows. Our estimated value of the weighted mean DMD of the feed basket varied among farms and seasons of the year. The DMD % of the total diet was higher ($P < 0.05$) in the urban smallholder dairy farm followed by the peri-urban dairy farm, and the least in the rural smallholder dairy farms.

Table 5. 3 Estimated major feed resources and its proportion and weighted digestible values (DMD %) based on the three farming systems sourced from the study

Feed type	Feed proportion (%)					
	Urban SHF		Peri-urban SHF		Rural SHF	
	Wet season	Dry season	Wet season	Dry season	Wet season	Dry season
Pasture grazing	NF	NF	10.0	3.00	52.0	40.0
Grass hay	37.0	33.0	23.0	24.0	4.00	8.00
Crop residues and hulls	19.1	16.42	24.02	28.5	24.5	31.50
Cultivated forage	1.42	1.00	4.92	3.50	6.00	2.50
Compound dairy ration- concentrate	4.00	4.50	3.00	3.50	NF	NF
Bran, middling & other cereal grain mill by-products	19.5	20.0	16.0	18.0	7.00	8.50
Oil seed cake and middling	13.0	16.0	11.0	11.0	NF	2.00
Agro-industrial by-product	6.00	8.10	7.00	7.00	3.50	4.50
Local beverage residue (Atela)	NF	1.00	1.00	1.50	3.00	3.50
Diet DM digestibility %	62.58	61.89	60.69	59.82	57.46	54.08
Average DMD % (Mean \pm SD)	62.3 \pm 3.44 ^a		60.3 \pm 3.25 ^b		55.8 \pm 3.83 ^c	

Note: Means with different superscript letters in the same row indicate significant differences between seasons of the ear at ($P \leq 0.05$).

DMD = dry matter digestibility; SD = standard deviations; NF: not fed

5. 4.3 Daily methane production, emission factor, and emission intensity

Metabolizable energy requirement (MER_T) and weighted average annual methane emission factors for different categories of animals across the farming systems are presented in Table 5. 4. Metabolizable energy requirement for lactation (MER_L) was the largest component of MER for milking cows on urban and peri-urban farms, whereas metabolizable energy requirement for maintenance (MER_M) was the major component of MER for all classes of cattle on the rural farm. Daily methane production (DMP) (Table 5. 5), emission factors (EF), and emission intensities (EI) vary considerably across the smallholder farming systems. DMP and EFs showed significant differences among the different production systems with the highest ($P<0.05$) DMP and EF observed in urban farms and the lowest ($P<0.05$) in rural farms, with an intermediate value in the peri-urban dairy production systems. The estimated EFs were higher (72.71 and 69.43 kg per head per year) for lactating cows, followed by growing males in urban and peri-urban farming systems, respectively (Table 5. 6). In contrast, the largest EF was reported for fattening males, followed by adult females in rural SHF. This is most likely due to the large body weight of fattening animals and the metabolic energy requirements for plowing. The EI (CO_2 .eq kg^{-1} MY) was highest ($P<0.05$) in rural and lowest ($P<0.05$) in urban farms with an intermediate value in the peri-urban dairy production system (Table 5. 7). Emission intensity (CO_2 .eq kg^{-1} MY) was significantly higher in rural than in peri-urban and urban SHFs. The uncertainty of CH_4 emission factors for adult dairy cows was $\pm 21\%$, 19% , and $\pm 16.0\%$ in urban, peri-urban, and rural dairy farming systems, respectively.

Table 5. 4 The weighted mean annual metabolizable-energy requirements across the different farming systems

Farming systems	Urban farm (Pure exotic)				Peri-urban farm (High grade/ Exotic blood)						Rural farm (Indigenous zebu breed)					
	MER _M	MER _G	MER _L	MER _T	MER _M	MER _G	MER _L	MER _W	MER _P	MER _T	MER _M	MER _G	MER _L	MER _W	MER _P	MER _T
Adult female	37.29	NA	51.33	88.62	37.24	NA	44.61	2.76	NA	84.62	27.81	NA	11.56	1.60	0.0	40.97
Adult male	36.75	NA	NA	36.75	36.83	NA	NA	2.80	13.12	52.74	36.35	NA	NA	1.93	5.54	43.82
Growing female	27.79	13.90	NA	41.69	27.33	14.36	NA	1.74	NA	43.43	22.39	13.32	NA	1.10	NA	36.81
Growing male	29.07	15.18	NA	44.25	28.44	15.16	NA	1.83	NA	45.43	25.38	13.55	NA	1.3	NA	40.24
Calf (≤12m)	17.58	16.98	NA	34.58	17.15	16.84	NA	0.88	NA	34.87	15.59	15.42	NA	0.64	NA	31.65
Calf (≤6m)	11.13	19.54	NA	30.67	10.96	17.26	NA	NA	NA	28.23	7.95	16.95	NA	NA	NA	24.88
Fattening male	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	36.03	NA	NA	2.29	6.55	44.87

There were either no breeding bull and fattening male animals or few in urban and peri-urban SHF; NA = not applicable

Table 5. 5. Daily methane production (DMP) (kg methane (CH₄)/head/day) for different categories of animal across farming systems

Farming system	Adult female	Adult male	Growing female	Growing male	Calf ≤1r	Fattening
Urban	199.21	82.60	93.72	99.47	77.70	NA
Peri-urban	190.21	118.56	97.62	102.12	78.39	NA
Rural	92.09	98.51	82.76	90.45	71.15	100.86

Note: NA = Not applicable

Table 5. 6. Emission factors (mean \pm sd. kg CH₄ /head/year) for different categories of cattle across farming systems

Farming systems	Emission factors (kg CH ₄ /head/year)					
	Adult female	Adult male	Growing female	Growing male	Calf (\leq 1)	Fattening male
Urban	72.71 \pm 6.24 ^a	30.15 \pm 2.43 ^a	34.21 \pm 2.71 ^a	36.31 \pm 2.78 ^a	26.67 \pm 2.3 ^a	NA
Peri-urban	69.43 \pm 5.59 ^b	43.28 \pm 3.29 ^b	35.63 \pm 3.14 ^b	37.27 \pm 3.12 ^a	25.89 \pm 2.25 ^a	NA
Rural	33.68 \pm 2.86 ^c	35.92 \pm 2.84 ^a	30.2 \pm 2.61 ^c	33.01 \pm 2.46 ^b	23.2 \pm 2.1 ^b	36.82 \pm 3.23
Mean	64.01 \pm 5.23	37.84 \pm 2.8	36.39 \pm 3.18	38.01 \pm 3.16	26.5 \pm 2.2	

Different superscript letters in the same column indicate significant differences between farming systems ($P < 0.05$)

Table 5. 7 Daily methane production (g/day), Emission factors (mean \pm sd., kg CH₄ kg/head/year), and emission intensity (CO₂-eq kg⁻¹ MY) for milking dairy cows across the farming systems.

Farming system	Urban	Peri-urban	Rural
MY(kg FPCM)	10.40 \pm 0.84 ^a	8.95 \pm 1.11 ^b	1.77 \pm 0.18 ^c
DMP (g/day)	199.2 \pm 26.2 ^a	190.21 \pm 25.99 ^b	92.9 \pm 12.03 ^c
EF (CH ₄ kg/head/year)	72.71 \pm 8.31 ^a	69.43 \pm 7.51 ^b	33.61 \pm 3.17 ^c
EI (CO ₂ -eq kg ⁻¹ MY)	0.6432 \pm 0.086 ^a	0.71 \pm 0.099 ^b	1.78 \pm 0.23 ^c

Note: Different superscript letters in the same row indicate significant differences between farming systems ($P < 0.05$)

Table 5. 8 Uncertainties in enteric methane emission factors for various cattle categories across farming systems

Farming system	Cattle categories					
	Adult female	Adult male	Growing female	Growing male	Calf (≤ 1) male	Fattening
Urban	20.1%	17.1%	31.7%	22.6%	34.5%	
Peri-urban	19.4%	19.4%	29.4%	21.7%	37.5%	
Rural	16.7%	15.5%	31.3%	14.6%	27.9%	24.1%
Mean	19.6%	16.9%	30.95%	16.3%	31.9%	24.1%

5. 5 Discussions

5.5.1 Seasonal feed digestibility

The variation in seasonal feed baskets and DMD of the feed in rural smallholder farmers could be due to a year-round reliance on natural pasture and crop residues. Feyissa et al. (2014) reported that the mean CP contents of natural pasture were reduced by 30.2%, while both IVOMD and ME contents were reduced by 17.8% each with the delay in harvesting time from mid-October (full heading stage of the pasture) to late-November (one and a half months past the full heading stage). Similar trends in digestible energy against season have been reported in Kenya by Goopy et al. (2018) and in Senegal by Ndao et al. (2020). Modest seasonal DMD variation was reported in the urban and peri-urban farms, owing to the high digestibility of concentrate-based diet supplementation in the daily dry matter intake. The weighted mean DMD of the feed basket estimated in the present study is similar to the studies of Wassie et al. (2022) and Goopy et al. (2018) in Ethiopia and Kenya, respectively, but is greater than the IPCC default estimate for Africa (IPCC, 2007a).

5.5.2 Emission factors and uncertainties

MER_L was the most important constituent of the metabolizable energy requirement, followed by MER_M in an intensive (urban and peri-urban) smallholder farming system, whereas MER_M was the largest constituent in the extensive (rural) farming system. The considerable variation in

MER_L across the farming system is attributed to significant differences in milk yield and feed intake between the farming systems. This might be because production influences the energy demand of milking dairy cows and the high feed intake, thereby increasing enteric CH₄ production. Since cattle productivity on a rural farm is low, a large proportion of gross energy intake is used for maintenance and is affected by live metabolic weight (Kouazounde et al., 2015). Previous studies in Sub-Saharan Africa have found similar results (Goopy et al., 2018; Ndao et al., 2020; Ndung'u et al., 2019). The significantly lower ($P < 0.05$) estimated DMP and EF in rural smallholder dairy farms than in urban and peri-urban farms could be due to the variation in production performances (milk yield, live weight, weight gain), and thus differences in energy requirements for maintenance and production across farming systems. For example, mature females in urban and peri-urban farms were heavier and had more milk yield, which led to higher EF than in rural farms. Similarly, the observed variation could also be attributed to low feed intake due to body weight differences, feed characteristics, and breed differences. Consistent with the current observations, Jo et al. (2015) and Shibata and Terada (2010) indicated that variation in livestock production systems (feed quantity and quality, body weight, feeding level, and livestock activity and health) has a wide range of impacts on enteric CH₄ emissions. Parta (2017) has also established a significant link between intake and methane production.

The variation between our results and some of the previous work cited earlier may in part be due to the approach they used and the value of input parameters (e.g., DMD, milk yield, body weight) used in predicting emission values (Table 5. 9). For instance, our current estimate of average weighted EF for milking cows is broadly consistent with the value in Sub-Saharan Africa, which provides an estimate in the range of 30-80 kg CH₄/year (Goopy et al., 2018a; Ndung'u et al., 2019; Ndao et al., 2020). Though they used a similar approach to estimate EF, the milk yield and the feed digestible energy are considerably lower than the assumed value in this study. Compared with IPCC's (2019) default value for high-producing dairy cows and low-productive multipurpose dairy cows in Africa, which are assumed to have lower body weight, milk yield, and feed digestibility than in the present study, our EF estimate for lactating dairy cows in urban, peri-urban, and rural farms was lower. The present estimate of EFs is also much lower than that reported by du Toit (2013) for intensive farming systems in South Africa, which

might be explained by the larger live weights of cattle in South Africa. Du Toit (2013) also used a different approach to estimate CH₄ emissions. Similarly, the average EF calculated for lactating cows (multipurpose/other cows) in rural smallholder farms (34 kg CH₄ per head/year) is lower than the value estimated by IPCC (2019) for the low productivity system of smallholder farmers in Africa. Furthermore, our EF estimate is lower than the IPCC (2019) value for low productivity systems in Sub-Saharan Africa and 38.5% lower compared with the 57.87 kg CH₄/head suggested by Wassie et al. (2022) for other cattle in Ethiopia. Similarly, our estimated value of EF is 35% lower compared with the 60 kg CH₄/head suggested by Tadesse et al. (2022) for crossbred dairy cattle and 39% higher than the value reported by Defar et al. (2018) for intensive production systems and extensive mixed crop-livestock production systems in Ethiopia. This is mainly because either the approach they use or the input data they generate to represent the complexity of the system might be the source of the variation. Herrero et al. (2013) suggest that lower estimates of CH₄ emissions from enteric fermentation are likely due to the use of more aggregated methods used to calculate CH₄ emissions. In addition, our findings show that the EFs of replacement males and females in urban and rural farming systems were much lower than those reported by IPCC for intensive and extensive farms in sub-Saharan Africa.

The average uncertainty of emission factors for adult dairy cows found in this study is comparable with the default uncertainty range for Tier 2 emission factors (IPCC, 2006) and the report of Wassie et al. (2022) in Ethiopia but less than Wilkes et al. (2020) in Kenya. Feed digestibility, live weight, and work hours had considerable influences on enteric CH₄ emission factors for adult female and adult male cattle, respectively (Table 5. 8). Due to a lack of precision in seasonal body weight estimation using a heart girth meter, seasonal weight gain and loss for adult cattle were not considered. Hence, we assumed live weight lost during the dry season is expected to be compensated for in the wet season with no weight loss or gain for adult animals (FAO, 2018b), which may contribute to the uncertainty of the EF estimates used. The digestibility of the main diet composition used in this study comes from secondary sources, which adds uncertainty to the estimates of the emission factor.

5.5.3 Emission intensity

The significantly higher enteric methane emission intensity per kg of FPCM and for milking cows, in rural than in urban and peri-urban SHF could be attributed to the lower average feed digestibility and crude protein content reported in rural SHF than in peri-urban and urban SHF. As previously stated, seasonal feed baskets have shown significant variation in quality and quantity among rural smallholder farmers, which may be due to a reliance on natural pasture and crop residue throughout the year (Table 5. 3). In rural SHFs, DMD and crude protein content were below the 12-18% crude protein requirements of productive dairy cows (Moran, 2005). Low digestible feed is linked to high enteric CH₄ emission and, as a result, high EI per kg of milk yield (Gerber et al., 2011; C. Opio et al., 2013). Garg et al., (2018). Garg et al. (2018) indicated that feeding balanced rations improved the milk yield of dairy cows, which then helped reduce the EI of milk. According to Gerber et al. (2011), Zehetmeier et al. (2014), and Garg et al. (2018), increasing milk yield from 1300 to 5000 kg of FPCM/cow/year results in a large reduction in EI. Similarly, Zehetmeier et al. (2014) and Garg et al. (2018) stated that emissions per kilogram of milk yield decreased with increasing production intensity, with the highest values for low-input systems and the lowest values for intensive farming systems.

The variation in enteric methane EI across production systems in our findings indicates that smallholder dairy production systems, where dairy animal productivity is low to medium, offer a good opportunity to reduce EI while improving productivity by feeding a nutritionally balanced ration. Consistent with this, Garg et al. (2018) and Rotz et al. (2010) also indicated that dietary manipulation has a considerable potential for improving milk production and lowering GHG emissions from dairy animals. Because diet composition directly affects CH₄ emissions, diet manipulation is the most direct, and arguably the most effective, method of lowering the GHG intensity of milk for intensive dairy operations (Vellinga et al., 2011). Hence, increased animal productivity through improved feed offers important mitigation potential for smallholder dairy farming systems across intensification gradients in the study area.

Table 5. 9. A Comparison of key input variables and emission factors (EFs, kg CH₄/head. year) with IPCC default value

Farming system									
Cattle category	IPCC (2019) Tier I			Wassie et al. (2022)			Current findings (Urban SHFS)		
	LW (kg)	MY (L)	EF	LW (kg)	MY (L)	EF	LW (kg)	MY (kg)	EF
Adult cows	400	5.9	104	429	6.4	78	429.19	10.4	72.71
Adult male	450	-	87	419		47	435.27		30.15
Growing female	212	-	86	261		39	271.37.51		34.21
Growing male	237	-	83	261		41	288.13		36.31
Rural SHF (Extensive system)									
Adult cows	247	2.4	88	286	1.25	58	294	1.77	33.61
Adult male	382		104	343		57	351		35.95
Growing female	135		76	181		41	198		30.21
Growing male	202		87	227		54	234		33.01
Fattened male	225		64	281		52	375		36.82

Adult cows = ≥ 3years; Adult male = ≥ 3years; Growing female = 1-3 years; Growing male = 1-3 years; Calve ≤ 1

5. 5. Conclusions

In the present study, we use a more detailed analytical approach of the IPCC tier II by using information such as estimation of energy intake, diet quality, milk yield, and body weight, avoiding relying on the assumption of *ad libitum* intake to estimate daily methane production, thereby EF and EI across the three smallholder farming systems. Based on this approach, which could better represent the complexity of the smallholder dairy farming system, we estimated EFs of 73 and 34 kg CH₄ for intensive and extensive farms, respectively. Our estimates are up to 22.1% and 59.6 lower than the IPCC (2019) Tier I estimates for dairy cows and other cows, respectively. This suggests that IPCC Tier I and other studies partly rely on Tier I default values and coefficients, which tend to overestimate emissions from smallholder farming systems. Methane emission intensity has shown significant variation across the intensification gradients. Rural dairy farming showed significantly higher emission intensity per kg of milk yield than urban and peri-urban dairy farming. This study suggests that increased animal productivity through improved feed offers important mitigation potential for smallholder dairy farming systems across intensification gradients in the study area. Using country-specific (Study area) activity data to accurately characterize emissions will aid in explaining the spatial variation in emissions across countries and regions. The level of uncertainty can be reduced by improving data quality by measuring these key parameters more accurately as well as collecting data that represent different systems of interest.

Chapter Six

6. Synthesis, Implication and Future research

6.1 Synthesis

The dairy farming system is a major contributor to food security, contributing vital sources of income as well as providing nutritional benefits to many urban and rural people in Ethiopia. Similarly, the dairy value chain contributes to global climate change through the production of methane (CH₄) from enteric fermentation and manure management and nitrous oxide (N₂O) emissions from manure management (FEM, 2015; FAO-NZAGRC, 2017). Contrary, the sub-sector is the most vulnerable to climate change-related impacts. On the other hand, the demand for dairy products is expected to double in 2050 because of population growth, urbanization, and diet upgrades (FAO-NZAGRC, 2017). The Ethiopian dairy value chain is at the crossroads of increasing productivity, reducing GHG emissions/sinks, and enhancing resilience to climate change impacts under increasing global warming.

A number of improved dairy farming practices have been adapted and applied to increase animal productivity and farmers' income in Ethiopia in general and in the central highlands in particular. These improved practices (feed production and utilization, breed and health services, and manure treatment and management interventions) were done at the community level by smallholder farmers across the country. For these best practices to be up scaled and replicated in other areas with similar agro-ecology and farming systems, the improved practices have to be tested and characterized. Climate-smart dairy farming practices are an approach that provides a conceptual basis for assessing the effectiveness of agricultural practices to increase animal productivity and incomes in a sustainable manner, reduce or remove GHG emissions, and build resilience to climate change where possible (FAO, 2013). Various studies examined how the improved practices enhanced animal productivity and benefited GHG emissions mitigation in a wider range of ecological settings and farming systems (Opio et al., 2013; Gerg et al., 2013; van Dijk et al., 2015; Amole and Ayantude, 2016).

Accordingly, the present study tried to examine the environmental and economic benefits of the existing improved dairy farming practices, and factors influences on adoption decisions to draw a

lesson for stakeholders, researchers, academicians, and policymakers. Understanding farmers' Knowledge, attitude, and practices (KAP) about climate smart dairy farming can help support their efforts and develop interventions more suited to the local context. The result of the present study showed that smallholder farmers have substantial knowledge and a modest perception of CSD farming practices, and the majority of them believe that the improved practices have economic and environmental importance. Socio-economic factors and characteristics of the technology influenced farmers' KAP, and adoption decisions of the improved practices. A similar perspective is explored in Chapter 3 about factors influencing adoption choices and the impact of adopting a few or many improved dairy farming practices (IDFs) on household food security. Despite various factors influencing adoption decisions, smallholder farmers engaged in improved practices such as improved breeding, improved feed production and utilization, health services, and manure management practices.

Adopting either individual IDFs or a combination of them provides a significant food security effect compared to non-adopters. Moreover, compared to the other SHFs, those who implemented the entire technology ($B_1F_1S_1$) had a greater overall impact on HFCS. Implementing the entire package, for example, increases the average probability of food security by 40% for non-adopters. Hence, this study would contribute to ongoing efforts in Ethiopia to improve livestock production and increase the widespread adoption of dairy technology. Apart from food security benefits, the improved practices in the study area have largely helped in GHG emissions mitigation. There was a significant variation in the GHG emissions from milk production across smallholder farming systems. A significant and inverse relation was observed between milk yield, feed digestibility, and carbon footprints. Given the variation in carbon footprint across farming systems and the association between CF and feed digestibility observed, the specific intervention that may be called for by policymakers, stakeholders, and farmers should include improving feed use efficiency by improving feeding.

Managing animal waste is another potential mitigation measure. By shifting the manure into fertilizer, the amount of organic manure on farmland will increase, which will reduce the need for synthetic N-fertilizers. Improve the genetic potential of indigenous breeds by cross-breeding with exotic blood; improving feeding conditions will increase herd productivity and reduce GHG

emissions. This analysis was used as the basis for studies in subsequent chapters to develop improved, country-specific enteric methane emissions factors and emissions intensity and assess how to improve and mitigate each of those processes.

The estimation of enteric methane emissions shows that the EF estimates for lactating dairy cows in this study were lower than the IPCC's (2019) default value for both stall-fed high-productivity and dual-purpose low-productivity cows. Similarly, the estimated average EF and emission intensities (EI) vary significantly across farming systems. The significantly higher enteric methane emission intensity per kg of FPCM and for milking cows in rural SHF than in urban and peri-urban SHF could be attributed to the low average feed digestibility and crude protein content reported in rural SHF compared to peri-urban and urban SHF. The variation in enteric EI across production systems, where animal productivity is very low to medium, offers a good opportunity to reduce EI while improving productivity. Farmers, decision-makers, and industry partners can use these findings to prioritize enteric fermentation, which is the major carbon footprint hotspot that needs to be targeted.

In general, smallholder farmers can benefit by adopting improved dairy farming practices, which have a win-win impact on increasing animal productivity, enhance farmers food security and reducing GHG emissions. Hence, this study would contribute to ongoing efforts in Ethiopia to improve livestock production and to increase the widespread adoption of dairy technology. Furthermore, the present study contributes to an improved national GHG inventory and serves as a baseline for better quantifying mitigation targets and the effects of policies and measures.

6.2 Implications

6.2.1 Implication and Recommendation

The journey towards climate-resilient, sustainable dairy development requires the engagement of every stakeholder. As highlighted in the previous chapters, livestock development efforts in Ethiopia have been hampered by institutional and policy interventions and technological attributes. This indicates that technology adoption in dairy sectors necessitates the improvement of institutions and policy interventions throughout the dairy value chain in the study area. Therefore, policies geared towards improving institutional arrangements for the distribution of

technological inputs and output services could improve technology adoption and productivity in dairy. A public-private partnership (PPP) intervention may provide a win-win solution to the widespread coordination issue (Kebeb et al., 2017), allowing smallholder farmers access to inputs (AI, heifers, feed, and health services) while benefiting PPPs as well. The problem of collecting milk from dispersed smallholder farmers could be solved by establishing milk collection centers and dairy hubs that connect farmers to processors and assist urban milk processors in accessing milk produced by farmers (Jaleta et al., 2013). Market access constraints could be alleviated as a long-term strategy through infrastructure improvements and targeted institutional arrangements. Ensuring effective and reliable access to agricultural technology information and improving farmers' awareness of the potential benefits of adoption could solve technology-related barriers.

The effectiveness of GHG emissions mitigation strategies in smallholder dairy farming systems is dependent on the accuracy with which GHG emissions are estimated and accurate emission inventories and mitigation measures are provided. Developing Tier II model methodology could reflect area-specific EF and enable more accurate reporting of enteric CH₄ emissions from cattle systems. Most of the GHG emissions mitigation measures positively affect animal productivity, thereby improving farmers' income and food security (Opio et al., 2011; Gerber et al., 2013).

The degree of intensification was the main source of carbon footprint variability in milk production. The CF of milk production was higher in rural-extensive dairy farming systems than in urban-intensive dairy farming systems. Reduced enteric CH₄ emissions, increased animal productivity, and a consequent drop in milk CF might all be achieved through improved feeding, which includes raising the proportion of concentrate, enhancing fodder crops, chemically treating crop residue, and treating pasture hay. Feeding conditions such as stall feeding could help reduce the energy required for walking and grazing, which would enhance animal productivity and reduce emission intensity. Stall feeding also reduces pasture land degradation and could reduce nutrient loss through leaching and trampling of dung and urine patches.

Manure management practices such as composting, improved manure handling and storage, and anaerobic digesters for biogas and fertilizer reduce CH₄ and N₂O emissions and nutrient loss and contribute to adaptation. Although it was widely assumed that manure was primarily used for

fertilizer, the majority of it was used as cooking fuel. As a result, there was a substantial loss of nutrients through a dun cake, which has a considerable effect on soil carbon and soil fertility in the study area. When organic manure is used as fertilizer instead of fuel, more organic manure will be produced on the farm, increasing the efficiency with which nutrients are used and lowering the need for synthetic fertilizer.

This study suggests that increased animal productivity through improved feed has significant mitigation potential for smallholder dairy farming systems across the study area's intensification gradients. Using country-specific activity data to characterize emissions will help explain the spatial variation in emissions across countries and regions. The study suggests assisting SHF in implementing plans that will contribute to the development of climate-resilient dairy products, which calls for interventions at various points along the dairy value chain.

6.3 Limitations

Under this, limitations specific to general and specific objectives and those associated with different methodological approaches. From the very beginning, the study is spatially delimited to highland agro-ecology and a homogeneous smallholder farming system; hence, the output does not represent different agro-ecologies. Similar to this, the unit of study and a modeling framework is designed to catch up with the broad pillars of smallholder climate smart (CSD) dairy practices and GHG emission reduction, which specifically represent the conditions of Ethiopia's central highlands. Since climate-smart dairy practices are not a single specific technology or practice that can be universally applied, this study may not sufficiently reflect the peculiarities of CSD farming practices in different farming system contexts. It requires site-specific assessments to identify suitable agricultural production technologies and practices.

Chapter 4 quantifies the carbon footprints of milk production, variability across farming systems, and subsequently ways to mitigate or reduce emissions. Quantifying the extent to which these strategies might mitigate the carbon footprint of each farming system and its economic implications was beyond the scope of this thesis.

Our study relies on animal characteristics and activity data (animal measurements, breed, etc.), which should not be automatically extrapolated outside of a similar geographic range for generalization. It does, however, highlight the need for additional measures and the importance of employing a robust methodology that could reduce the uncertainty associated with activity data. The findings of this study may also need some adjustment to fit prevailing conditions in other areas or settings. Since CSD farming is relatively new, and few scientific studies have been conducted in the area, the theoretical framework, variables, and indicators differ from place to place. The present study, therefore, adopted an emerging framework, developed new variables, and employed the latest techniques to reflect existing farming practices and draw important policy recommendations.

Despite these drawbacks, this study has a lot to contribute to our understanding of the economic and environmental advantages of CSD farming, factors that influence technology adoption decisions, and thus contribute to the development of a climate-resilient green economy.

6.3.3 Future research

In light of the limitations discussed above, which could influence the generalizability of this study, we believe that additional research is needed for robust generalization and recommendations.

- Future research should focus on quantifying evidence-based low-carbon alternatives and their mitigation potential and economic implications.
- There is a need for a high degree of accuracy for live weight measurements to estimate seasonal live weight fluxes to help eliminate/minimize inaccuracies, particularly for rural smallholder farmers.
- To accurately estimate enteric methane emission factors on free-grazing cattle, GPS tracking should be used to estimate the distance covered and walking during grazing.
- The need for further research which should focus on quantifying enteric methane emissions across the agro-ecological variations.
- Furthermore, nitrogen emissions and CH₄ emissions from manure, and emissions from small ruminants must be investigated to provide a comprehensive picture of the contribution of SHF systems to greenhouse gas emissions.

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Appendices

Appendix I 1. Household survey questionnaires

Study Site Identification

1. Woreda: _____
 2. Kebele: _____
 3. Date of interview: _____
- Enumerator's Name: _____

Part I: Demographic and socio-economic characteristics

General information

Zone, Wareda _____ PA _____ village _____ date _____

Part I: Household Information

1. Name of the household head: _____
2. Name of respondents (*if not HH head*): _____
3. Sex of the respondent: Male Female
4. Age of the respondent: _____ years
5. Position in the household
 - A. Household head
 - B. Son
 - C. Relative
 - E. Daughter
 - F. Others (specify) _____
6. Educational status
 - A. Illiterate
 - B. Primary
 - C. Read and Write
 - D. Secondary and Above
7. Marital status
 - A. Single
 - B. Divorced
 - C. Married
 - D. Widowed
 - E. Others _____
8. Family size and background

No	Age category	Sex	Education	Remark
1	≤15			
2	16-64			
3	>64			
	Total			

Part II: Farm Characteristics

1. What is your major farming activity?
 - A. Livestock production only
 - B. Crop production only
 - C. Crop livestock production
2. What are your major sources of income and the amount earned last year? (Multiple responses are possible). (Tick) rank the most three to five of them. 1, the most; 2 the 2nd most; 3 the 3rd most 4

No	Sources of income	Total income	Rank
2	Annual/perennial crops		
2	Forage and crop residue		
3	Animal and animal products		
4	Cow dung/dung cake selling		

5	Non-farm income (Petty trade, wage, salary etc...)		
	Others source (Specify) _____		
	Total income in the reference year		

3. Do you have your own agricultural land? A. Yes B. No

If yes how big (ha or local unit)

Agricultural land	Total land size (ha)	Crop land	Grass land/forage land	Other (ha)

4. For how long have you been engaged in farming? _____

5. What are the common annual/perennial crops you have been growing in the last growing season? (Give an example, Multiple response possible)

Crop	Rainy season		Amount produced	Crop residue produced
	Long	Short		
Cereals				
Pulses				
Oil crops				
Root and tuber				
Vegetable				
Fruits				
Others				

6. How do you see the trend of your production for the last 5 years?

A. Increasing C. Constant

B. Decreasing D. No idea

E. Others specify _____

7. If your response for question number 5 is decreasing in production, what were/are possible Causes for decreasing in production? (Multiple responses are possible).

A. Drought C. Absence of high yielding variety seeds

B. Soil fertility problem D. Absence of chemical/organic fertilizer

E. Pests out break

F. Others specify _____

8. What type of land preparation and treading do you use?

A. Animal B. Machine C. Both

9. If you used animal power in the past crop year, fill the following table?

Reference year (2011)	Land size (ha)	Number of animal used	Number of days	Estimated hours animal work/day	Cost of rent draught animal

10. Do you USE synthetic fertilizer in your farm?

A. Yes B. No

11. If your answer is yes (mention type and amount)

Fertilizer used	Artificial Fertilizer (kg/ha)	Pesticide for crop land (ha)	Lime (ha)
Amount/year			

12. Have you sold livestock in the last year? A. Yes B. No

If yes, income earned from the livestock _____?

13. Do you have agricultural extension services in your area? A. Yes B. No

If yes, what kind

A. Technical advices C. Training

1. 2. 3. 4. 5.
11. On a scale of 1 to 5, with 5 being the most important, how important do you think climate change issues are to your area/community?
1. 2. 3. 4. 5.
12. How interested are you to learn more about climate change and ways you can help?
A. Very Interested C. Not Interested at all
B. Somewhat interested D. Don't Know / not sure
13. Who do you think should be responsible for tackling climate change issues? Please tick all that you think apply
A. The local government D. Me and my family
B. Regional and international organizations E. Private sector
C. Developed countries F. Volunteer organizations
14. Do you think that you and the public in general can do anything to adapt to and mitigate /deal with climate change?
A. Yes B. No
15. Do you know about CSD production?
A. Yes B. No
16. If yes, explain what you understand by CSLSF practices in your area.
-

17. Please rate the following questions regard to your understanding about the economic, social and environmental value of CSDF practices.

	Agree	Disagree	Strongly dis agree
1 Exotic breeds are more productive than local breed	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
2 Improved forage increase animal productivity	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
3 Concentrate feed have high nutritive value	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
4 CSLF practices reduce GHGs emission of animal-agriculture	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
5 CSLF practices resilient to climate change impacts	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
6 CSLF practices enhances animal productivities	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
7 CSLF practices improve farmers' income	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

18. How important do you think the following in helping reduce climate change?

	Very important	Moderately important	Not important	Don't know
Reduce deforestation	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Improved LS husbandry	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Use improved forage	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Use improved feed	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Use dung cake as fuel	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Use dung cake as fertilizer	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Use of improved breed	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Grazing land management	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Part IV: Adaptation strategy

1. Do you remember a specific event where your farm has been affected by climate?
D. Yes B. No
If yes mention any types of adverse/extreme events you faced _____
2. What are the impacts/consequences of climate change/variability for the last 5 years?
A. Poor crop yields D. water shortage

- B. Loss of livestock productivity E. infestation of disease and parasite
 C. Decline in quantity and quality of pastureland

3. In your opinion, which segments of the community has most affected by climate change and variability impact? (Multiple response Possible). Rank according to degree of harm to climate change.

Segments of community	The most affected	Rank according to degree of harm
Children	<input type="checkbox"/>	<input type="checkbox"/>
Disabled people	<input type="checkbox"/>	<input type="checkbox"/>
Women	<input type="checkbox"/>	<input type="checkbox"/>
Elders	<input type="checkbox"/>	<input type="checkbox"/>
Others	<input type="checkbox"/>	<input type="checkbox"/>

4. When negatively affected by adverse climate condition, which of the following adaptation strategy you have been practicing in order to reduce the impact?

Of the strategy pursued, rank according to level of effectiveness in reducing the impact. (1= most effectively applicable, 2= effective, 3= moderate, 4= least, 5= none).

Adaptation/coping strategy	Tick which is appropriate	Rank according to level of effectiveness
Using different or new crop variety	<input type="checkbox"/>	
Use fertilizer application	<input type="checkbox"/>	
Soil and water conservation	<input type="checkbox"/>	
Shifting planting date	<input type="checkbox"/>	
Crop diversification	<input type="checkbox"/>	
Planting drought tolerant crops	<input type="checkbox"/>	
Off-farm activities	<input type="checkbox"/>	
Making enclosure (kallo) for calves and lactating cows around village	<input type="checkbox"/>	
Hay making	<input type="checkbox"/>	
Purchasing feed for a few animals	<input type="checkbox"/>	
Selling of dung cake	<input type="checkbox"/>	
Others specify....		

5. Which of the following adaptation strategy do you suggest being strong in the future? Which do you think environmentally sound, applicable to practice and viable to cope with current climatic condition?

Adaptation Strategy	Tick the appropriate	Rank	Remark
Invest in social capital (joining community group)			
Work on asset based (physical capital) adopt CSLF practices	<input type="checkbox"/>		
Improving market access and market information	<input type="checkbox"/>		
Improve knowledge and information access	<input type="checkbox"/>		
Improve institution and entitlements	<input type="checkbox"/>		
Encourage innovation (Adopting and using agricultural technologies)	<input type="checkbox"/>		

Of the strategy pursued, rank according to level of effectiveness in adapting climate change (1= most effective, 2= moderately effective, 3= less effective)

6. What are the other non-climatic factors that contributed to climate change impacts and variability? (Multiple response possible)

- A. Population pressure E. Deforestation
 B. Soil degradation F. Improper settlement pattern

- C. In appropriate development interventions
- D. Others specify _____

7. What are the barriers that negatively affecting adaptation strategy of farmers? Please rank these barriers according to their economic and social importance on your livelihoods.

Barriers	Rank	How they affect	Remark
Population growth			
Soil degradation and fragmentation of agricultural land			
Urban expansion and in appropriate settlement pattern			
Expansion large farm land			
Lack of improved forage, crop varieties			
Shortage artificial fertilizers			
Inflation, rise prices of agricultural inputs, commodities			
Lack of market linkage for LS products			
Lack of animal health center			
Others specify			

Part V: Climate Smart dairy farming

Adoption of exotic cattle breeds

- Have you ever used any improved agricultural farming or practice? A. Yes B. No
- If yes list down the improved farming you have used for the last five years (be it in crop, livestock and natural resource management)
 - Crop production _____
 - Natural resource _____
 - Livestock production _____
- Do you keep exotic cattle breed in addition to local breed? A. yes B. No
- If yes, mention the breed? _____
- When did you introduce? _____ why _____
- Reason for shifting to exotic breed (Holstein) _____
- Livestock (cattle) population category and sub-category

Sub-category	Age	Pure breed (Exotic)		Cross breed		Indigenous	
		Number	BW (HG)	Number	BW	Number	BW
Mature dairy cow	>3						
Growing heifer	2-3 years						
Young female	1-2 years						
Mature male (BB)	>3years						
Growing male	2-3 years						
Young males (steer)	1-2 years						
Dry cow/Pregnant							
Adult reproductive females							
Adult reproductive male							

6. Milk Production performances

Milk production	No cow	Average milk produced/cow		Consumption/L /day	Sold (L)	Current price Birr
		Wet season	Dry Season			
Indigenous						
Cross breed						
Exotic breed						

Herd structure

Herd parameter	Pure breed	Cross breed	Local/indigenous
Age at first calving			
Fertility of adult females (%)			
Death rate, prenatal (%)			
Mortality of young females (%)			
Mortality of young males (%)			
Mortality of adult animals (%)			
Death rate, older (%)			
Adult female replacement (%)			
Weight of adult females			
Weight of adult male			
Weight of fattening females			
Weight of fattening males			

Feeding system

1. What are the main sources of feed for your dairy cattle? (Rank)

Sources		List	Rank
Pasture	<input type="checkbox"/>		
Dairy Ration (Concentrate)	<input type="checkbox"/>		
Crop residue	<input type="checkbox"/>		
Industrial by-product	<input type="checkbox"/>		
Others			

2. Livestock Feeds utilized during the reference period

3. How do you feed your cattle?

1	
2	
3	
4	

1= Stall at home stead 2= Grazing on paddocks

3= Grazing communal land

4. Specify the type and amount of concentrate feed purchased and offered for your cattle?

Type of concentrate feed	Amount given per day					
	Milking cow	Dry cow	Heifer	Calf	Bull	Ox

5. Specify the type and amount of crop residue produced/purchased and offered for your cattle?

Type of crop residue	Amount produced (kg)		Amount given per day					
	Wet	Dry	Milking cow	Dry cow	Heifer	Calf	Bull	Ox
Teff straw								
Wheat straw								
....								

6. Specify the type and amount of By-product purchased and offered for your cattle?

By-products	Amount produced (kg)		Amount given per day					
	Wet	Dry	Milking cow	Dry cow	Heifer	Calf	Bull	Ox
Brewery								
Nug cake								
...								

7. How often do you offer feeds for your animals?
- A. Once a day C. Three times
 B. Twice D. Four times
8. Specify type and amount feed offered per day (kg) (please provide the detail amount, proportion and feed type for different classes of animals in your herd)?

Feed type	Feed (kg)												Remark
	Milking cow		Dry cow		Bull		Ox		Heifer		Calf		
Season	Wet	Dry	W	D	W	D	W	D	W	D	W	D	
Ration/concentrate													
Green fodder/grazing													
Hay													
Crop residue													
By-product													
Other													
													100

9. Specify the type and amount of improved forage produced and offered for cattle?

Improved forage	Growing 1=yes, 2-No	Where Cultivated*	Cultivated area (acr)	Established mm&yr	Productio n level**	Kg/ha
Napier grass						
Oats						
Vetch						
Rhodes grass						
Alfalfa (Lucern)						
Desmodium spp						
Sesbania						
Tree Lucern						
Others						

*1 = Farm land 2 = Farm boundary 3 = Terrace bank 4 = Bush land

**1 = Poor 2 = Moderate 3 = High

10. By what criteria do you choose the type of fodder to plant? (Rank from 1= most important to 3=least important)

	Criteria	Rank
1		
2		

1 = High yielding; 2=Fast growth; 3= Animal produce more milk; 4=Disease/pest tolerant; 5= Easy to harvest and feed to animal; 6=Availability/cost of seed/planting material; 7=Advice from extension workers; 8= climate tolerant; 9=other (specify) _____

11. What factors determine total area of improved fodder production? (Rank from 1- most important to 3-least important)

	Determining factors	Rank
1		
2		

1= Farm size; 2= Number of LS; 3= Labour availability; 4= Amount of seed/plant material available; other (specify) _____

12. If you have not planted fodder what are the reason? (Rank from 1- most important to 3-least important)

	Reasons	Rank
1		

1= Small land size; 2= Lack of seeds/planting materials; 3= lack of labour; 4= Cheap to buy; lack of information; 6= lack of money to establishment; 7= other

13. Do you use fertilizer for forage production? A. Yes B. No

14. If yes, specify type and amount for the past cropping season?

15. Do you regularly experience feed shortage?

16. If yes, specify season/month severe feed shortage?

17. How do you solve the problem of feed shortage? _____

18. How do you conserve feed for your livestock? (note multiple response)

- A. No conservation C. Make silage
 B. Bale hay D. other (specify)_____

19. Trends in pastureland productivity for the last decades

- A. Increasing D. No change
 B. Decreasing

If your answer is decreasing, justify the reasons.

20. Do you use communal grazing? A. Yes B. No

21. Grazing land condition indicators

Indicators variables	Increase	Decrease	No change	Remark
Cover of grass layer				
Availability of palatable grass species				
Availability important browse species				
Proportion of herbaceous biomass to woody cover				
Grazing land degradation or erosion				

22. Trend in communal grazing

- A. Increasing C. No change
 B. decreasing

23. Do you use supplementary feed for your animals? A. Yes B. No

If yes mention types of supplementary feeds and its sources.

24. Have you participated in Dairy cattle Extension Program during the reference period?

- A. Yes B. No

25. How far is the nearest farmer milk collection center from your residence? _____ hrs

26. What are the main barriers to implement CSLF practices

- A. Lack of knowledge
 - B. Lack of initial capital
 - C. Lack of enough space
 - D. Lack of market linkage
 - E. Rise prices of inputs (Breed, varieties)
27. Do you participate in any social institution? A. Yes B. No
28. If yes, in which institution you have been participating?
- A. Dairy cooperative
 - B. Agricultural cooperative
 - C. Other Social network
29. What are the benefits from engaging in dairy cooperative?
- A. Market access
 - B. Least cost for dairy inputs (AI, Heifers, Feed)
 - C. Access to credit
30. Have you ever got access to credit? A. Yes B. No
31. If yes, for what purpose?
- A. To buy cross breed cow
 - B. To buy improved forage
 - C. Other, Specify

Adoption of Manure Management Practices

1. How do you manage manure from your farm?
- A. Manure storage
 - B. Manure treatment
 - C. Manure application (spread on pasture)
2. How do you store manure and how often do you remove?
- A. Daily clean and store in pile
 - B. Store in open backyard/main gate
 - C. Store cover with straw
 - D. Liquid/Slurry storage
 - E. Litter stacking Composting
 - F. Anaerobic digester
 - G. Composting
3. How do you treat manure
- A. An aerobic digestion (biogas)
 - B. Solid separation
 - C. Aeration
4. What do you do with livestock manure? (*Rank from 1= most important to 3=least important*)

Use as	Rank	Season
Fertilizer		
Dry dung cake for fuel		
Biogas generation		
Construction materials		
Sale to other		

5. Do you prepare compost from manure? A. Yes B. No
6. If you do NOT, why not? [*select one*]
- A. Lack of labor to collect manures
 - B. Limited knowledge
 - C. time consuming
 - D. Small manure quantities
- Other (specify) _____
7. Do you have a biogas digester?
- A. Yes in planning
 - B. Yes under construction
 - C. Yes functioning
 - D. No
8. If you use manure for biogas production, how has it benefitted your household? (*multiple*)
- A. Less cooking time
 - B. Reduced firewood use
 - C. Save money
 - D. Reduced smoke pollution
 - E. Env'tal significant
 - F. Other (specify) _____
9. Do you use biogas slurry for farm (Crop and fodder production)? A. Yes B. No
10. If you do NOT use manure for biogas production, what are the constraints?

- A. Lack of knowledge D. Lack of labor for manure collection
 B. Limited manure quantity E. Lack of access to credit
 C. Lack of money F. If any (Specify)

11. How do you store manure and how often do you remove/use?

Manure management	Dry season (% for each use)	Wet season (% for each use)
Collected and spread on pasture/ crop every day	<input type="checkbox"/>	<input type="checkbox"/>
Dry lot (a paved/unpaved open confinement area without any significant vegetative cover where accumulating manure may be removed periodically)	<input type="checkbox"/>	<input type="checkbox"/>
Left where deposited on pasture	<input type="checkbox"/>	<input type="checkbox"/>
Store in open backyard/main gate	<input type="checkbox"/>	<input type="checkbox"/>
Composed	<input type="checkbox"/>	<input type="checkbox"/>
Stored as a liquid or slurry	<input type="checkbox"/>	<input type="checkbox"/>
Anaerobic digester	<input type="checkbox"/>	<input type="checkbox"/>
Dung cake (stored and used for fire/sale)	<input type="checkbox"/>	<input type="checkbox"/>

Part VI: Household Food Security and Adoption Benefits

- From where did you get food for your household?
 - Own produce
 - Purchase
 - Food aid
- Is the amount of food you produced enough for your household consumption?
 - Yes
 - No
- If your response is NO, why?
 - Low production
 - Large family size
- If you purchase from the market, did you get enough supply?
 - Yes
 - No
- Did you afford the price?
 - Yes
 - No
- How many days have you eaten the following food items in the last seven (7) days? Dietary diversity of the week
 Asking about 12 food groups they consumed during the day or night prior to the survey, whether consumed within the household or prepared within the household.
 •“Normal”, “usual” or **average** condition of the household
 • Put “0” if the household did not eat and put “1” if the household ate the food group in the **last 7 days for breakfast, lunch, and dinner.**

S/n	Food items	HHDS	D1	D2	D3	D4	D5	D6	D7
1	Cereals (maize, wheat, rice, pasta/spaghetti, bread, or other)		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
2	Roots and tubers (potatoes, carrots, or other)		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
3	Pulses /legumes/nuts (beans, peas, lentil, chick peas or other)		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
4	Vegetables and leaves (cabbage, Carrot, Spinach other)		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

5	Fruit (banana, orange, mango, Apple, Avocado ...)		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
6	Meat, poultry, offal (beef, goat, lamb, poultry), eggs		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
7	Milk and its products (milk, cheese or other)		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
8	Sugar , sugar products, honey		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
9	Oil/fats (oil, fat or butter)		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
10	Condiments (spices, tea, coffee) or other miscellaneous food		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

7. Do your households prefer the type of food consumed?
 A. Yes B. No
 If your response for is YES, how often did that happen in a month?
 A. Rarely C. Often
 B. Sometimes D. Other (specify) _____
8. How many times do you and your household member eat per day?
 A. Only once C. Three times
 B. Twice D. Not constant
 Others (specify) _____
9. In your view, to what extent has the implementation of the improved dairy cattle production practices increased your household food security?
 A. A little C. a lot
 B. Somewhat D. Not at all
10. In your view, to what extent has the implementation of the improved practices enhanced your household income?
 A. A little C. a lot
 B. Somewhat D. Not at all
11. In your opinion, which practices have been MOST BENEFICIAL and what do you consider as the three MOST IMPORTANT benefits from applying these improved practices?

Improved practices *	Important benefit**		
	1	2	3
1			
2			

Improved practices *: 1= Improved fodder production; 2= Exotic breed; 3= Improved LS mg't; 4= Manure composting; 5= other (specify).

*Benefits*** : 1= More income; 2= Increased crop prodn; 3= less affected by Climate shock; 4= Improve HH food security; 5= better for the env't; 6= other (specify).

Appendix I.2. Checklists for Key Informants Interviews and Group Discussion

1. What do you understand by the term climate change? What about climate change issues?
2. Have you observed any changes in the climatic conditions in your area over the last period? How do you perceive the changes? How did you know that the change has occurred? What happened to the trends of *climatic parameters* (Temperature, rainfall...), and *extreme events* (drought, flood...) over the last 30 years
3. What are the major impacts of climate related shocks in the area and how do you observe their impacts on farming communities and/or household's livelihoods? (See in relation to livelihood assets in general and food security in particular).

4. Which human activities contribute to climate change?
5. What do you think are some of the activities you engage in your farming that worsen the impact of climate change for you as a farmer?
6. Do you think that climate could affect your farm in the future? How
7. In what way do you think your industry may contribute to climate change issues? Either contributing to lessening the effects or towards increasing the effects?
8. What are the activities and improved practices promoted by the government project? How did you promote the improved agricultural practices in the project area? For government agent
9. What improved practices are popular among farmers?
10. What are the benefits of those practices in term of farm/milk productivity, income, livelihoods? What are the potential environmental benefits? (E.g. how has the improved practices helped to reduce the use of inorganic fertilizers and consume less wood fuel?) Kindly share with us the success stories.
11. Have you heard of the term climate smart agriculture? A. Yes B. No
If yes, where did you hear the term climate smart agriculture and what do you understand it to mean?
12. What barriers hinder their uptake within this farming system? What other reasons outside this farming system might have contributed to their unsuccessful adoption?
13. What institutional support would facilitate wider promotion of improved practices in this area? Which institutions/organizations are relevant to the promotions and implementation of improved agricultural practices? How are these institutions supporting the promotion of these practices in the project area?
14. What intervention must be used for better implementation of dairy technologies in the future to increase the level of adoption in the area?
15. What policy support could encourage successful application of improved agricultural practices in this area? Kindly share with us any information you have on any effort by the government (County and National levels) that would create a favorable environment for their uptake.

Appendix II

Appendix II Table 1. Contingency coefficient for discrete independent variables used in B&ONL models

	Gender	Education	Off-farm ac	Access -Ex	Access Cred	Access inf	Cop Memb
Gender	1	.022	.045	.045	.037	.017	0.022
Education	.022	1	.051	.109	.068	.068	0.158
Off-farm ac	0.045	0.051	1	0.165	0.137	0.201	0.58
Access 2 Ex	.059	.109	.0.165	1	.247	.167	0.261
Access 2 Crd	0.037	0.068	0.137	0.247	1	0.192	0.133
Access to inf	0.017	0.068	0.201	0.167	0.192	1	0.133
Member of agri. coop	0.022	0.158	0.058	0.261	0.133	0.133	1

Appendix II Table 2 Variance inflation factor for continuous explanatory variables used in B&OLM models

Variables	Colinearity Statistics	
	VIF	1/VIF
Age	1.051	0.96

Family size	1.042	0.96
Dependency ratio	1.268	0.788
Land holding	1.201	0.833
LS Holding (TLU)	1.202	0.832
Distance to market access	2.01	0.429
Distance to farmers training center	1.363	0.734
Initial Capital	1.30	0.760

Appendix II Table 3 Marginal effects estimates for the determinants of farmers' Knowledge

	(1)	(2)	(3)	(4)
GENDER	0.00342 (0.0145)	0.000952 (0.00402)	-0.0000184 (0.000316)	-0.00435 (0.0185)
HHAGE	-0.00939*** (0.000972)	-0.00261*** (0.000791)	0.0000505 (0.000855)	0.0119*** (0.000788)
EDUCAION	-0.136*** (0.0200)	-0.0379*** (0.0105)	0.000733 (0.0123)	0.173*** (0.0284)
FAMILSIZE	0.00175 (0.00389)	0.000488 (0.00108)	-0.00000943 (0.000163)	-0.00223 (0.00493)
DepRaio	-0.0569 (0.0730)	-0.0159 (0.0207)	0.000306 (0.00517)	0.0725 (0.0929)
AGRLAND	0.00598 (0.00551)	0.00167 (0.00160)	-0.0000322 (0.000542)	-0.00762 (0.00705)
TLU	-0.000463 (0.00198)	-0.000129 (0.000555)	0.00000249 (0.0000435)	0.000590 (0.00252)
OFFFARMACI	0.00252 (0.0141)	0.000703 (0.00397)	-0.0000136 (0.000246)	-0.00321 (0.0180)
ACCESS2EX	-0.0719*** (0.0179)	-0.0200** (0.00678)	0.000387 (0.00650)	0.0915*** (0.0235)
ACCESS2CRED	-0.0121 (0.0145)	-0.00338 (0.00411)	0.0000653 (0.00110)	0.0155 (0.0185)
ACCESS2INF	-0.0604* (0.0306)	-0.0168 (0.00973)	0.000325 (0.00549)	0.0769* (0.0389)
MEMBERCOP	-0.00974 (0.0141)	-0.00271 (0.00406)	0.0000524 (0.000893)	0.0124 (0.0180)
DISTAN2WOR~A	0.0045** (0.0045)	0.064** (0.0014)	0.0036* (0.015)	-0.012** (0.004)
DISTAN2MIL~L	0.000744 (0.000684)	0.000207 (0.000195)	-0.00000400 (0.0000680)	-0.000947 (0.000861)
BT	0.00747 (0.00843)	0.00208 (0.00243)	-0.0000402 (0.000683)	-0.00951 (0.0107)
ICT	-0.00703*** (0.00117)	-0.00196** (0.000663)	0.0000378 (0.000640)	0.00895*** (0.00137)
N	480	480	480	480

Standard errors in parentheses; * p<0.05, ** p<0.01, *** p<0.001

FTC = Farmers training Center, ICT = Initial capital for the technology, BT = Benefits of the technology

Number of observation = 480

Appendix II Table 4 Marginal effects estimates for the determinants of farmers' perception

	(1)	(2)	(3)	(4)
--	-----	-----	-----	-----

	GENDER	-0.0313	-0.0308	-0.0281	0.0901	
		(0.0229)	(0.0225)	(0.0204)	(0.0650)	
Age		-0.00939***	-0.00261***	0.0000505	0.0119***	
		(0.000972)	(0.000791)	(0.000855)	(0.000788)	
	EDUCAION	-0.0648***	-0.0638***	-0.0582***	0.187***	
		(0.0143)	(0.0145)	(0.0138)	(0.0374)	
	DepRaio	-0.00699*	-0.00688*	-0.00628*	0.0201*	
		(0.00295)	(0.00298)	(0.00268)	(0.00832)	
	AGRLAND	0.00326	0.00321	0.00293	-0.00940	
		(0.00404)	(0.00401)	(0.00364)	(0.0116)	
	TLU	0.00157	0.00155	0.00141	-0.00454	
		(0.00147)	(0.00144)	(0.00131)	(0.00419)	
	OFFARMACI	0.0232*	0.0228*	0.0208*	-0.0669*	
		(0.0106)	(0.0105)	(0.00989)	(0.0301)	
	ACCESS2EX	-0.0662***	-0.0652***	-0.0595***	0.191***	
		(0.0147)	(0.0137)	(0.0142)	(0.0370)	
	ACCESS2CRED	-0.0167	-0.0164	-0.0150	0.0482	
		(0.0108)	(0.0106)	(0.00999)	(0.0310)	
	ACCESS2INF	-0.0175	-0.0173	-0.0157	0.0505	
		(0.0109)	(0.0106)	(0.00994)	(0.0310)	
	MEMBERCOP	-0.00316	-0.00311	-0.00284	0.00911	
		(0.0107)	(0.0106)	(0.00961)	(0.0309)	
	DISTAN2WOR~A	0.00402**	0.00396**	0.00361*	-0.0116**	
		(0.00139)	(0.00140)	(0.00150)	(0.00410)	
	DISTAN2MIL~L	0.00159**	0.00157**	0.00143**	-0.00458**	
		(0.000538)	(0.000524)	(0.000454)	(0.00143)	
	HHDDS	-0.0124*	-0.0122*	-0.0112	0.0358*	
		(0.00633)	(0.00617)	(0.00573)	(0.0178)	
	HHFCS	-0.000211	-0.000208	-0.000190	0.000609	
		(0.000824)	(0.000811)	(0.000732)	(0.00237)	

	N	480	480	480	480	

Standard errors in parentheses
 * p<0.05, ** p<0.01, *** p<0.001

Treatment effects

ttest adopty1a = nonadopty1d61, unpaired

Two-sample t test with equal variances

Variable	Obs	Mean	Std. Err.	Std. Dev.	[95% Conf. Interval]	
adopt~61	100	75.59989	.5165855	4.620481	74.57166	76.62813
nonad~6b	100	60.8125	.3287925	2.940809	60.15806	61.46695
combined	200	68.2062	1.412772	17.8703	67.41598	69.99642
diff		14.79	.6123439		15.99683	13.57796

diff = mean(adoptyc61) - mean(nonadopty1d6b) t = 56.8102
 Ho: diff = 0 degrees of freedom = 158

Ha: diff < 0 Ha: diff != 0 Ha: diff > 0
 Pr(T < t) = 0.0000 Pr(|T| > |t|) = 0.0000 Pr(T > t) = 1.0000

ttest nonadopty1d6b = adoptyc61, unpaired

Two-sample t test with equal variances

Variable	Obs	Mean	Std. Err.	Std. Dev.	[95% Conf. Interval]	
adopty1a	100	71.71	.0913303	.9133032	71.52878	71.89122
nonad~61	100	59.79297	.271729	2.71729	59.2538	60.33214
combined	200	65.75149	.445929	6.306388	64.87213	66.63084
diff		11.91703	.2866668		11.35171	12.48234

diff = mean(adopty1a) - mean(nonadopty1d61) t = 41.5710
 Ho: diff = 0 degrees of freedom = 198

Ha: diff < 0 Ha: diff != 0 Ha: diff > 0
 Pr(T < t) = 1.0000 Pr(|T| > |t|) = 0.0000 Pr(T > t) = 0.0000

ttest adopty2a = nonadopty1d62, unpaired

Two-sample t test with equal variances

Variable	Obs	Mean	Std. Err.	Std. Dev.	[95% Conf. Interval]	
adopty2a	99	65.38104	.7948125	7.908285	64.80376	69.95832
nonad~62	99	50.40493	.3019694	3.004557	49.80568	51.00417
combined	198	59.39298	1.417743	19.94941	58.59708	62.18889
diff		17.97612	.8502426		16.29932	18.95292

diff = mean(adopty2a) - mean(nonadopty1d62) t = 34.6650
 Ho: diff = 0 degrees of freedom = 196

Ha: diff < 0 Ha: diff != 0 Ha: diff > 0
 Pr(T < t) = 1.0000 Pr(|T| > |t|) = 0.0000 Pr(T > t) = 0.0000

ttest nonadopty1d6b = adopty1d62, unpaired

Two-sample t test with equal variances

Variable	Obs	Mean	Std. Err.	Std. Dev.	[95% Conf. Interval]	
adop~d62	98	65.59989	.5165855	4.620481	64.57166	66.62813
nonad~6b	100	50.8125	.3287925	2.940809	50.15806	51.46695
combined	199	58.2062	1.412772	17.8703	55.41598	60.99642

```

diff |      14.78739  .6123439      15.99683  13.57796
-----
diff = mean(nonadopty1d6b) - mean(adopty1d62)      t = 46.8102
Ho: diff = 0      degrees of freedom = 197

```

```

Ha: diff < 0      Ha: diff != 0      Ha: diff > 0
Pr(T < t) = 0.0000  Pr(|T| > |t|) = 0.0000  Pr(T > t) = 1.0000

```

ttest adopty3a = nonadopty1d63, unpaired

Two-sample t test with equal variances

```

-----
Variable |  Obs   Mean   Std. Err.  Std. Dev.  [95% Conf. Interval]
-----+-----
adopty3a |  45  51.22857  .2560968  2.624212  51.72072  52.73642
nonad~63 |  45  49.20269  .325141  3.331704  48.55793  50.84746
-----+-----
combined |  90  50.24    .318853  4.620619  50.08705  51.34421
-----+-----
diff |      2.025877  .4138868      2.209926  3.841827
-----

```

```

diff = mean(adopty3a) - mean(nonadopty1d63)      t = 6.9754
Ho: diff = 0      degrees of freedom = 88

```

```

Ha: diff < 0      Ha: diff != 0      Ha: diff > 0
Pr(T < t) = 1.0000  Pr(|T| > |t|) = 0.0000  Pr(T > t) = 0.0000

```

. ttest nonadopty1d6b = adopty1d63, unpaired

Two-sample t test with equal variances

```

-----
Variable |  Obs   Mean   Std. Err.  Std. Dev.  [95% Conf. Interval]
-----+-----
adopt~63 |  43  52.37827  .5271208  4.714712  51.32906  53.42747
nonad~6b |  45  50.8125  .3287925  2.940809  50.15806  51.46695
-----+-----
combined |  89  51.59538  .3158134  3.994759  50.97165  52.21911
-----+-----
diff |      1.565765  .6212575      2.792806  .3387244
-----

```

```

diff = mean(adopty1d63) - mean(nonadopty1d6b)      t = 2.5203
Ho: diff = 0      degrees of freedom = 87

```

```

Ha: diff < 0      Ha: diff != 0      Ha: diff > 0
Pr(T < t) = 0.0064  Pr(|T| > |t|) = 0.0127  Pr(T > t) = 0.9936

```

ttest adopty4a = nonadopty1d64, unpaired

Two-sample t test with equal variances

Variable	Obs	Mean	Std. Err.	Std. Dev.	[95% Conf. Interval]	
adopty4a	53	57.52273	.6213581	4.121624	56.26964	58.77582
nonad~64	53	54.77281	.4869256	3.229899	53.79083	55.75479
combined	106	56.14777	.4192074	3.932514	55.31455	56.98099
diff		2.749915	.789419	1.180602	4.319229	

diff = mean(adopty4a) - mean(nonadopty1d64) t = 3.4835
Ho: diff = 0 degrees of freedom = 104

Ha: diff < 0 Ha: diff != 0 Ha: diff > 0
Pr(T < t) = 0.9996 Pr(|T| > |t|) = 0.0008 Pr(T > t) = 0.0004

. ttest nonadopty1d6b = adopty1d64, unpaired

Two-sample t test with equal variances

Variable	Obs	Mean	Std. Err.	Std. Dev.	[95% Conf. Interval]	
adopt~64	54	56.28333	.4271706	3.82073	55.43307	57.13359
nonad~6b	56	50.8125	.3287925	2.940809	50.15806	51.46695
combined	100	54.04791	.3715155	4.699341	53.31417	54.78166
diff		5.470827	.539054	5.535509	5.406146	

diff = mean(nonadopty1d6b) - mean(adopty1d64) t = 11.0040
Ho: diff = 0 degrees of freedom = 98

Ha: diff < 0 Ha: diff = 0 Ha: diff > 0
Pr(T < t) = 0.0000 Pr(|T| > |t|) = 0.0000 Pr(T > t) = 1.0000

ttest adopty5a = nonadopty1d65, unpaired

Two-sample t test with equal variances

Variable	Obs	Mean	Std. Err.	Std. Dev.	[95% Conf. Interval]	
adopty5a	81	49.43396	.1474078	1.073145	48.13817	50.72976
nonad~65	81	47.85168	.4650792	3.385827	46.91843	48.78493
combined	162	48.64282	.2699216	2.779013	47.10761	49.17802
diff		1.72	.4878808	1.852	2.450228	

diff = mean(adopty5a) - mean(nonadopty1d65) t = 3.2555
Ho: diff = 0 degrees of freedom = 160

Ha: diff < 0 Ha: diff != 0 Ha: diff > 0
Pr(T < t) = 0.0000 Pr(|T| > |t|) = 0.0000 Pr(T > t) = 1.0000

. ttest nonadopty1d6b = adopty1d65, unpaired

Two-sample t test with equal variances

Variable	Obs	Mean	Std. Err.	Std. Dev.	[95% Conf. Interval]	
adopt~65	80	52.49474	.1483494	1.326877	52.19945	52.79002
nonad~6b	80	50.8125	.3287925	2.940809	50.15806	51.46695
combined	160	51.65362	.1917628	2.425629	51.27489	52.03235
diff		1.682236	.3607104	2.394673	.9698001	

diff = mean(nonadopty1d6b) - mean(adopty1d65) t = 4.6637
Ho: diff = 0 degrees of freedom = 158

Ha: diff < 0 Ha: diff != 0 Ha: diff > 0
Pr(T < t) = 0.0000 Pr(|T| > |t|) = 0.0000 Pr(T > t) = 1.0000

Appendix II Table 5. Food groups and its weight: Food consumption score (FCS)

No	Food items	Food groups	Weight
1	Sorghum, Wheat, Maize , Rice, Millet and other	Cereal	2
2	Potatoes, Sweet potatoes, Cane, Carrot and others	Roots and tuber	
3	Beans. Peas, Lentils Check pea and others	Pulses	3
4	Cabbage, Onion, Tomato, Spinach and others	Vegetables	1
5	Banana, Orange, Mango, Apple, Avocado and others	Fruit	1
6	Meat, Poultry, Egg, and Fish	Meat and fish	4
7	Milk, Yogurt and other diary	Milk	4
8	Sugar/Honey	Sugar	0.5
9	Oils, Fats and Butter	Oil/fats	0.5
10	Spices, Tea, Coffee, Pepper and others	Condiments	0

Household FCS is calculated based on the food group intake of a household over the last 7 days. A households' FCS has a maximum value of 112, acceptable food consumption > 42, borderline food consumption 28.5–42 and poor food consumption 0–21. sources (WFP, 2009)

Appendix II Table 6. Food groups and its weight: Household diet diversity score (HDDS)

Food groups	Score
Cereal	1
Roots and tuber	1
Legumes, nuts, and seeds	1
Vegetables	1
Fruit	1

Meat	1
Egg	1
Fish	1
Milk and milk products	1
Oil/fats	1
Sugar/honey	1
Condiments	1

In order to HDDS, the number of food groups consumed over a 24-hour period by a household or individual is added together, with a maximum of 12 food groups consumed per day. (WFP, 2009)

Appendix II Table 7 Input parameters used to estimate emission factors for enteric methane emissions are present

Parameter	Symbol	Unit	Sources
Herd structure		%	The present study
Coefficient for estimating net energy	Cfi	MJ day/kg	
Coefficient for activity	Ca	MJ day/kg	The present study
Methane conversion rate	Ym		The present study
Dry Matter Digestibility	DMD	(g/100)gDM	Seconder source
Metabolizeable energy	M/D	MJ/DMkg	Estimated
Average live body weight for all category	LW	kg	The present study
Average daily weight gain	ADG	kg	(Haile et al., 2011; Dadi et al., 2021)
Average daily milk yield	MY	Kg/day	The present study
Energy Content of Milk	ECM	MJ/Kg	The present study
Number of hources of work	Hour	hrs	The present study

Appendix II Table 8 Estimated feed compositions and its proportion based on the three farming systems sourced from the study

Feed type Season	Feed proportion (%)			
	Urban SHF		Peri-urban SHF	
	Wet season	Dry season	Wet season	Dry season
Pasture grazing	NF	NF	10	3
Grass hay	37	33	23	24
Compound dairy ration Concentrate	4	4.5	3	3.5
Wheat bran	10.5	11	8	8
Wheat middling	7	7	6	7
Oats grain	2	2	2	3
Noug cake	8.5	9	6	5.5
Cotton seed cake	1.5	2.5	2	1.5
Linseed mill	1	1.5	1	1.5
Soybean	2	3	2	2.5
Desho grass	1.42	1	2.42	2.5
Napier grass	NF	NF	NF	NF
Vetch (<i>Vicia sativa</i>)	NF	NF	1.5	1
Alfalfa	NF	NF	1	NF
Oats straw	2	NF	2.52	2.5
Wheat straw	5.58	5	8	8.5
Barley straw	5	5.42	7.5	9
Teff straw	4	4.5	4	5
Grass pea hull	1	NF	1	2
Faba bean hull	1.5	1.5	1	1.5
Brewery residues	4.5	5.58	5	4.5
Molasess	1.5	2.5	2	2.5
Local beverage residue (Atela)	NF	1.00	1	1.5

DMD = dry matter digestibility; SD = standard deviations; NF: not fed

Appendix II Table 9 Margin of error and probability density function (PDF) used in uncertainty analysis

Parameter	Farming systems	Uncertainties	PDF, justification	References
Live Weight	Urban	±22.0% -24.3%	Norma, SE small compared with mean	Calculated from the study
	Peri-urban	±21.2% -29.0%	Norma, SE small compared with mean	Calculated from the study
	Rural	±19.61% -34.5	Norma, SE small compared with mean	Calculated from the study
Milk yield	Urban	±16.96%	Norma, SE small compared with mean	Calculated from the study
	Peri-urban	±23.96%	Norma, SE small compared with mean	Calculated from the study
	Rural	±21.78%	Norma, SE small compared with mean	Calculated from the study
ECM	Urban	±7.56%	Norma, SE small compared with mean	Calculated from the study
	Peri-urban	±7.56%	Norma, SE small compared with mean	Calculated from the study
	Rural	±6.49%	Norma, SE small compared with mean	Calculated from the study
DMD	Urban	±10.82%	Triangular distribution minimum	Calculated from the study
	Peri-urban	±10.56%	Triangular distribution minimum	Calculated from the study
	Rural	±13.45%	Triangular distribution minimum	Calculated from the study
Work hours	Urban	NA		
	Peri-urban		Norma, SE small compared with mean	Calculated from the study
	Rural	±19.25	Norma, SE small compared with mean	Calculated from the study
CH ₄ conversion factor	Urban	±20%	Norma, SE small compared with mean	IPCC, 2019
	Peri-urban	±.20%	Norma, SE small compared with mean	IPCC, 2019
	Rural	±20%	Norma, SE small compared with mean	IPCC, 2019

Appendix II Table 10 Conversion factor used to estimate tropical livestock unit

Livestock category	Conversion factors
Horse	1.1
Cow/Ox	1
Cow	1
Heifer	0.75
Calf	0.25
Weaned calf	0.34
Donkey (adult)	0.7
Donkey (young)	0.35
Sheep/Goat	0.13
Goat	0.13

Strock et al., (1991)

Appendix II Table Tests of the parallel regression assumption

	Chi2	df	P>Chi2
Wolfe Gould	91.38	32	0.352
Brant	95.17	32	0.34
Score	130.3	32	0.25
Likelihood ratio	92.02	32	0.347
Wald	86.83	32	0.37

Appendix III picture from the study area





