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Modelling the Dynamic Interaction between Production Growth and Carbon Footprint of Livestock Sector in Ethiopia

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Master of Science in Economics (Applied Economic Modelling)

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Approval Sheet

This is to certify that the thesis prepared by Petros Terefe Tolcha, titled "Modelling the Dynamic Interaction between Production Growth and Carbon Footprint of Livestock Sector in Ethiopia" and submitted to the Department of Economics, Addis Ababa University in partial fulfillment of the requirements for the Masters of Science in Economics (Applied Economic Modelling) complies with the regulations of the university and meets the accepted standards for originality and quality.

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Abstract

Livestock is the largest agricultural subsector, supporting the livelihood of many populations and the economy in Ethiopia. The sector is, however, a significant contributor to the carbon footprint in the country. Only direct emissions from the sector accounted for more than 36% of total emissions. Thus, the purpose of this study is to model and evaluate the livestock production system and its contribution to the carbon footprint. A system dynamics model that represents the livestock production system and its interaction with the environment in Ethiopia has been built. The simulated results have demonstrated that increasing meat productivity through improvement in feed quality and supply, increasing slaughter, managing land use change, and implementing price policy have a sound effect on lowering greenhouse gas emissions (GHG) while also improving the supply and value of meat. The policy scenario has achieved 15% and 11% growth in meat and livestock value, respectively, while reducing greenhouse gas emissions by 40% compared to the base case in 2040.

***Keywords**: livestock, carbon footprint, system dynamics, Ethiopia*

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List of abbreviations

ASF	Animal Sourced Foods
CLD	Causal Loop Diagram
CO_2-eq	Carbon Dioxide Equivalent
CRGE	Climate Resilient Green Economy
CSA	Central Statistics Agency
DM	Dry Matter
EEA	Ethiopian Economics Association
EFCCC	Environment, Forest and Climate Change Commission
ETB	Ethiopian Birr
FAO	Food And Agriculture Organization
FDRE	Federal Democratic Republic Of Ethiopia
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GTP	Growth and Transformation Plan
LMP	Livestock Master Plan
NAP-ETH	National Adaptation Plan-Ethiopia
NBE	National Bank Of Ethiopia
NDC	Nationally Determined Contribution
SDG	Sustainable Development Goals
SFD	Stock and Flow Diagram
TLU	Tropical Livestock Unit
UN	United Nation
UNDESA	United Nations Department of Economic and Social Affairs
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
WB	World Bank

Chapter One

1. Introduction

1.1. Background

Environmental sustainability has gained prominence as consumption and production lead to the unsustainable use of resources (UNDESA, 2016). Drought, land degradation, wildfires, and other climate-related changes are occurring more frequently than ever. The use of fossil fuels, direct and indirect agricultural practices, industrialization, and other human-related activities have exacerbated the changes (Anthony J McMichael et al., 2004). These environmental changes are highly significant and challenging nearly all the inhabitants of the planet and nature (Kahn et al., 2019; Wolff et al., 2014). In the long term, the changes also lead to the slowdown of the economy and influence human society through agriculture and food security, water availability, biodiversity, and health (Auffhammer, 2019; Kahn et al., 2019; UNFCCC, 2007; Wade & Marcus, 2016).

Emerging economies, primarily those in sub-Saharan Africa, made only a light contribution to environmental changes. However, the change poses a serious threat to the socio-economic developments in the regions (FAO, 2009a; Mertz, Halsnæs, Olesen, & Rasmussen, 2009; D. Tadesse, 2010).

Occupying 40% of the total land area and providing livelihoods for 40% of the world's population, agriculture is a major activity for human society. However, this sector is experiencing significant problems as a result of environment-related problems such as climate change, land degradation, and biodiversity loss (McIntyre, Herren, Wakhungu, & Watson, 2009). On the other hand, the sector is also among the largest contributor to environmental changes (FAO, 2009a). For instance, about 30% of global emissions are attributed to the main agricultural activities such as farming, forestry, livestock, and fishing (McIntyre et al., 2009).

Livestock is the world's largest agricultural subsector, accounting for approximately 26% of unpopulated land used for grazing and 33% of cropland used for livestock feed production (Food and Agriculture Organization [FAO], 2012). The sector also contributes about 40% of the global GDP and provides major employment opportunities for households (Cheng, McCarl, & Fei, 2022). With 17% of world calories and 33% of protein consumption, the industry makes a significant contribution to global food security (McIntyre et al., 2009).

The livestock production sector is highly vulnerable and affected by environmental changes (Prasad, Dean, & Alungo, 2022; Rojas-Downing, Nejadhashemi, Harrigan, & Woznicki, 2017). The sector also substantially contributes to the changes. The production of livestock results in 14.5% of total greenhouse gas (GHG) emissions from both which composes of 44% methane (CH_4), 53% nitrogen oxide (N_2O), and 5% carbon dioxide (CO_2) (Gerber et al., 2013; Houzer &

Scoones, 2021). Every year, around 13 billion hectares of forest area are lost owing to land use changes for animal food and feed production. In addition, livestock intensification has degraded one-fifth of the world's grasslands (FAO, 2012). In Africa, overgrazing, deforestation, and agricultural practices, of which livestock production is significant have resulted in the degradation of more than 90% of the continent's land (D. Tadesse, 2010). Overgrazing has also led to the degradation of rangelands by about 48% in sub-Saharan Africa (Balehegn et al., 2021). Furthermore, the increase in livestock population in Africa is expected to increase livestock emissions (Rojas-Downing et al., 2017).

The livestock industry is dynamic and strongly relates to food and nutrition, economic growth, and the environment. Changes to one of these factors also affect the others and resulting in trade-offs (Smith & Nouala, 2015). If the industry is not managed in a way that takes advantage of the opportunities it offers and reduces the cost to the environment as a whole, the influence would be significant (Kimball, 2011; Steinfeld et al., 2006).

Given the rapid economic growth and unsustainable resource use in the recent few years, sustainability has risen to the forefront of growth goals, with Africa, in particular, needing to take the path of sustainable development (Hepburn & Stern, 2019; Ocolișanu, Dobrotă, & Dobrotă, 2022; D. Tadesse, 2010; Younis & Chaudhary, 2020). This is because they will be the most exposed areas unless they adapt to and mitigate the changes early (Mukim & Roberts, 2022).

The interest in research into the interactions of environment, human and economic activities are currently receiving a lot of attention (Mertz et al., 2009). The Sustainable Development Goals (SDG) have recently evolved as a global development agenda to take into account and capture the challenges and opportunities related to the environment, economy, and social factors (Hepburn & Stern, 2019). Agriculture plays a major part in fostering sustainable development (McIntyre et al., 2009). The livestock industry, in particular, is frequently where economic activity and environmental sustainability are compromised (Philip K. Thornton, 2010). However, the sector is one of the least researched in emerging economies (Akram, 2013). As a result, it is more important than ever to conduct research in the sector and address the associated environmental issues (Gerber et al., 2013). This is because creating a sustainable environment would guarantee sustained social and economic progress (Mishra, 2020; United Nations Environment Programme [UNEP], 2015).

1.2. Research problem

In Ethiopia, livestock forms the majority of agriculture, which supports the livelihood of the majority of the population as well as the country's economic development (Boka, 2020). The sector contributed 26% to the agricultural gross domestic product (GDP) in 2021 (National Bank of Ethiopia [NBE], 2021), and about 20% contributed to the GDP and foreign exchange earnings

(World Bank, 2017). Besides, households rely on the sector as a key supply of food and nutrition, a source of income, plough farmland and protection against crop failure (Fantu, Bart, Fanaye, & Taffesse, 2018; Prasad et al., 2022; Raney, Skoet, & Steinfeld, 2009b; Wieland, 2019).

The country has the largest livestock population in Africa with around 70 million cattle, over 52 million goats, 42 million sheep, 56 million chickens, and 1.6 million camels in 2020 (FAO, 2020d). The estimated value of tropical livestock units (TLU) is 51 million units in the same year (FAO, 2020g). The production system is distributed over the highland regions, where livestock production is subordinate to crop production, and the pastoral and agro-pastoral lowland regions, where livestock production dominates the other agricultural activities (Food and Agriculture Organization [FAO], 2020; Nell, 2006). However, these huge resources have been underutilized due to market inefficiencies, livestock feed shortages, disease, and low productivity (Food and Agriculture Organization [FAO], 2017).

Livestock is also increasing in value over time. The estimated value was 3.95 billion US dollars in 2010 and hit 5 billion US dollars by 2020 (FAO, 2020e). However, this growth is solely due to the increase in the livestock population and not because of productivity improvement (Philip K. Thornton, 2010). Even though productivity is still a major problem in the country, there is a potential for the country to increase production (Fantu et al., 2018; Shapiro et al., 2015; Tegegne & Feye, 2020). Productivity is hampered by factors such as, but not limited to, a lack of access to and adoption of better technology, seasonal and poor feed quality, market problems, animal disease, and farmer education and awareness (Fantu et al., 2018; Mamo, Mengistu, & Asebe, 2017; Mekuriaw & Harris-Coble, 2021).

The expansion of livestock production imposes a significant environmental burden on the country (Kimball, 2011). Livestock is a major source of greenhouse gas emissions and environmental change in the country. In 2018, about two-thirds of the emissions from agriculture, as well as more than 36% of the emissions from the entire country were produced directly by the livestock industry through enteric fermentation and manure production. The sector, through emission from enteric fermentation and manure production, contributed about 63.9 million tons of CO_2-eq emissions in 2010; the emission level has been steadily rising and attained 86.76 million tons of CO_2-eq emissions in 2020 (FAO, 2020b). This places the industry among the top emitters in the nation. The amount tends to increase along with the population of livestock in the nation unless some steps have taken to maintain the effect on the environment. Inadequate production systems, poor health and low productivity further exacerbate the emission level (Philip K Thornton et al., 2019).

Furthermore, the sector indirectly contributes to environmental changes through land use change which results in soil erosion, habitat and land degradation, and greenhouse gas emissions (Admassie & Abebaw, 2021; Alkemade, Reid, van den Berg, de Leeuw, & Jeuken, 2013; EFCCC, 2017; Kimball, 2011). Land use change and forestry accounted for 15.85% of total emissions in the country in 2018, with livestock contributing significantly due to larger livestock populations and the sector's reliance on land (N. Alemayehu, 2013; Climate Watch, 2022).

Livestock feed consumption is primarily dependent on natural resources, with natural pasture accounting for 55% of total feed consumption, followed by crop residue (31%), hay, and other by-products (CSA, 2021). The area used for grazing also increased from 1.37 million hectares in 2004 to 1.77 million hectares in 2015 (Fantu et al., 2018). This indicates that the sector is heavily reliant on the environment, paving the way for overgrazing and, eventually, environmental changes. The livestock population density is rising, and in 2010 there were 1.01 tropical livestock units per hectare of agricultural land. This value increased by more than 30% and stands at 1.32 tropical livestock units per hectare in 2020 as a result of the rising livestock population. This value is high compared to the developing countries and the world average which is 0.41 and 0.43, respectively (FAO, 2020g). This increase in livestock puts pressure on grazing land and reduces its accessibility (Fantu et al., 2018; Tilahun & Schmidt, 2012). Urbanization and corresponding growth in cropping further reduce the amount of grazing land, which influences the supply of animal feed (Mekuriaw & Harris-Coble, 2021).

Ethiopia's overall economic growth rate was 5.6% in 2021. Furthermore, population, per capita income, and urbanization have increased at rates of 2.6%, 2.9%, and 4.8% in 2021, respectively (World Bank, 2021). Thus, in these faces of rapid population growth, urbanization, and improved living standards, there is a high demand for animal-sourced foods (ASF), which leads to an increase in livestock production (Bachewe, Minten, & Yimer, 2017; Cheng et al., 2022; Minten, Dereje, Bachewe, & Tamru, 2018; Shapiro et al., 2015). This increment in output is achieved, however, through extensive land use change and feed production. This causes a shift in land use, which affects forests, water resources, emission levels and ultimately, the environment (Wellesley, Happer, & Froggatt, 2015). After all, the production of livestock in Ethiopia results in both direct and indirect environmental changes, such as emissions, deforestation and land degradation. These changes further exacerbate the effect of those environmental consequences. This trend has put social and economic development at risk. As a result, it is more important than ever to take action to address rising demand and enhance the economy, food security, and environmental sustainability (Kimball, 2011; Raney et al., 2009b).

Recently, countries have attempted to sustain production and consumption by launching development policies. In this regard, the Sustainable Development Goals (SDG) agenda, which was initiated by all United Nations (UN) countries in 2015, emphasizes the importance of environmental sustainability. Africa has also established Agenda 2063 to strengthen and accomplish the Sustainable Development Goals (SDGs) in light of the continent's vulnerabilities (African Union, 2022).

In Ethiopia, the climate resilient green economy (CRGE) initiatives, which were launched in 2011, seek to produce sustainable growth with no net increase in greenhouse gas (GHG) emissions from the base year, 2010 (Federal Democratic Republic of Ethiopia [FDRE], 2011). To further increase the economy's capacity to adapt to and withstand the effects of climate change, the government launched a national adaptation plan (NAP-ETH) in 2017 (Federal Democratic Republic of Ethiopia [FDRE], 2020). The other ten-year plan was released in 2020 as part of a home-grown policy change, and developing sustainable production is among the key pillars (Federal Democratic Republic of Ethiopia [FDRE], 2021a). Furthermore, the country has made a nationally determined contribution (NDC) to reduce total emissions. The first nationally determined contribution (NDC) was announced in 2017, and the newly updated NDC was introduced in 2021, to reduce greenhouse gas (GHG) emissions by 68.8% by 2030 (Federal Democratic Republic of Ethiopia [FDRE], 2021b). A long-term low-emission development strategy (LT-LEDS) was also introduced in 2023 to achieve net zero emissions by 2050 (UNFCCC, 2023). As the industry with the highest emissions, livestock is one of the plan's focus areas. This study will also contribute to the country's ongoing development program as a policy input.

In Ethiopia, prior studies on livestock have sought to comprehend the livestock production system, associations and contributions of the sector to the national economy and households, opportunities and challenges of the production and feeding practices, as well as the sector's relationship with the environment. For instance, see Altaye, Kassa, Agza, Alemu, and Muleta (2014); Asmare and Mekuriaw (2017); Fantu et al. (2018); Kochare, Tamir, and Kechero (2018); Mamo et al. (2017); Yisehak and Janssens (2014). Although a few studies have made an effort to investigate the relationship between the livestock industry and the environment using different analytical techniques, the interaction and sector's contribution to the carbon footprint have not been fully assessed. This study used a system dynamics approach to evaluate the greenhouse gas (GHG) contributions in production practices while examining the sector's dynamic interaction with the environment.

Overall, livestock contributes significantly to the social and economic development of the nation. However, the rapid increase in demand and subsequent increase in livestock production, which puts pressure on the environment, has raised concerns of sustainability. Thus, a production system that promotes social and economic well-being without escalating environmental effects is necessary. Accordingly, the goal of this study is to model the interaction of the livestock production system with the environment and to test alternative policy options for the reduction of carbon emission levels in the sector. The study employed system dynamics modelling, which is based on a simulation approach, to analyse the behaviour over time and develop policies that lead to reduced emissions and a sustainable environment in the livestock production system.

1.3. Research question

The study used a system dynamics modelling approach to assess the interaction between the livestock sector and the environment, specifically the sector's contribution to the carbon footprint. The study has driven by the following research questions;

- What are the main factors influencing the livestock production system in Ethiopia?
- How does the livestock production system interact with the environmental factors?
- Which livestock production system attains a sustainable production system that enhances the growth of production and value while also reducing greenhouse gas (GHG) emissions?

1.4. Objective

The general objective of this study is to develop and test a system dynamics model for evaluating the interaction between the livestock sector and its carbon footprint in Ethiopia. In addition to the main goal, the study also intended;

- To explore the factors influencing the livestock production system in Ethiopia.
- To investigate the causal relationship between livestock production systems and environmental factors.
- To identify the livestock production system that enhances the production and economic value of the sector while reducing greenhouse gas (GHG) emissions.

1.5. Significance of the study

First, the study would contribute to the ongoing national policy on the environment, agriculture, and livestock sector on the prospects of achieving an efficient livestock production system and reducing greenhouse gas (GHG) emissions. The study also supports farmers, agricultural practitioners and other stakeholders regarding the environmental effects and prospects of the sector. Furthermore, it informs the mitigation and options for better management practices to create a production system that promotes output and socioeconomic growth while minimizing greenhouse gas (GHG) emissions.

1.6. Scope of the study

The study's geographical scope is limited to Ethiopia. The study focused primarily on the major ruminants (cattle, goats, and sheep). Conceptually, the study has mainly looked into the interactions between livestock production and the environment with a focus on the sectors' contribution to greenhouse gas emissions. A system dynamics model was used in the study's methodology to evaluate the complexity and dynamics of the interaction between the livestock production system and its contribution to the carbon footprint.

1.7. Outline of the study

The study is structured into six chapters. The first chapter introduces the topic, research problem, and study objectives, while the second chapter provides a brief overview of livestock, its production system, and environmental implications in the country. The third chapter reviewed related literature with an emphasis on the model and empirical studies. The fourth chapter focused on the model's data and methodological aspects. In chapter five, the findings of various policy scenarios have been discussed and analysed for future policy implications. Finally, in chapter six, the study provides conclusions, policy implications, and limitations for future research.

Chapter Two

2. Overview of livestock sector in Ethiopia

2.1. Livestock production system in Ethiopia

In Ethiopia, the livestock production system comprises a variety of species. The livestock production system is largely extensive, consisting of indigenous breeds and a low-productivity production system. In the country, mixed farming and pastoral/agro-pastoral livestock production systems are widely practised (Shapiro et al., 2015; Philip K Thornton et al., 2019). A large portion of the arid and semi-arid lowlands employ the pastoral production system, which has enormous production potential. Furthermore, there is a growing production system in small-scale urban and peri-urban areas, and medium to big commercial farms which are unusual but essential (Ethiopian Economics Association [EEA], 2018).

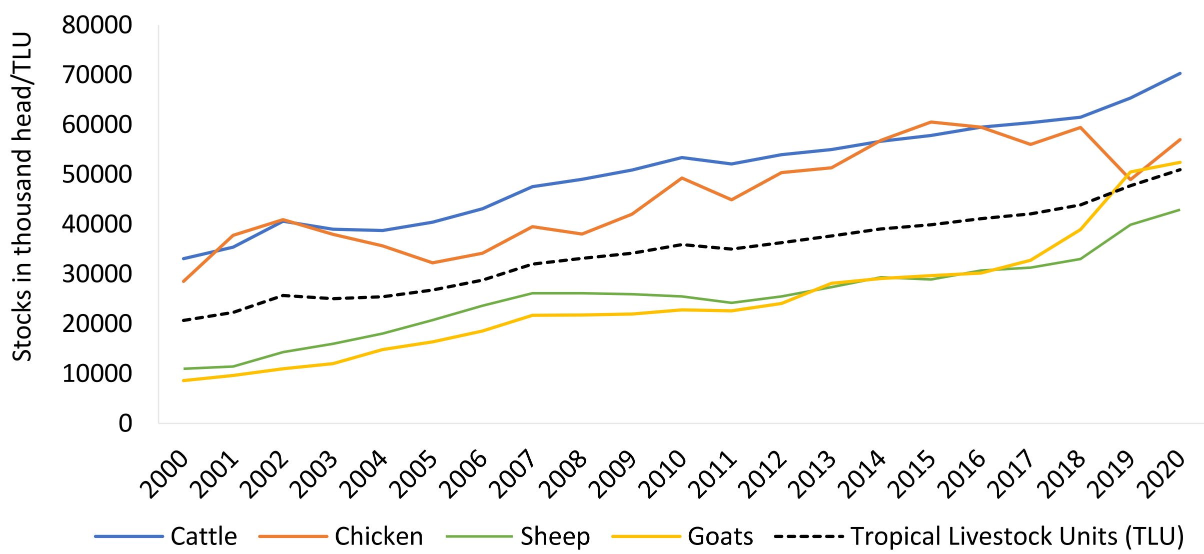


Figure 1: Major livestock population by type and tropical livestock units (TLU)

Source: FAO (2020g)

The above figure indicated that there is an ongoing upward trend in the population of major livestock measured in both type and units. The largest livestock species are cattle, which has raised from 33 million head in 2000 to 70 million heads in 2020. The majority of households in the nation also raise chickens. The number of chickens is increasing over time despite some fluctuations. In 2000, there were 28.5 million in the country; by 2018, that number had increased slightly to 59 million. In 2019, this number significantly decreased and fell to 49 million. In 2020, this stock increased to 56 million heads.

Both the trend for sheep and goats saw growth over time. With an increase in sheep numbers from 11 million in 2000 to 43 million in 2020. The goat population has increased from 8.5 million head in 2000 to 52 million head in 2020, with a record of rapid growth since 2017. In terms of livestock units, the number exhibits a gradual and consistent upward trend over time. The number of livestock units increased from 20.6 million in 2000 to 51 million in 2020. These figures place Ethiopia's livestock stock as the largest in Africa.

2.2. Contributions of livestock sector in Ethiopia

The livestock sector provides a variety of services to the country's social and economic development. In 2021, the industry has contributed 26% value added to the agricultural GDP (NBE, 2021). The sector's output also provides around one-fifth of both GDP and foreign exchange earnings (World Bank, 2017). The industry is estimated to contribute to more than 60% of Ethiopia's population in various ways (Kimball, 2011). Livestock also plays a significant role in increasing household income and well-being (Adane, 2020). The livelihood of about two-thirds of rural poor people depends on their livestock (Yisehak & Janssens, 2014). Additionally, the sector offers a range of services to households. Livestock is used as collateral for loans, a means of transportation, a source of food and income, employment, as well as for the production of raw materials and manure (S. Alemayehu et al., 2021; Duguma, Tegegne, & Hegde, 2012; Kimball, 2011). The nation has enormous potential to grow the industry and contribute even more to the farmers, society and economy (Shapiro et al., 2015). The figure below depicts the estimated potential value of the country's livestock over the period under consideration.

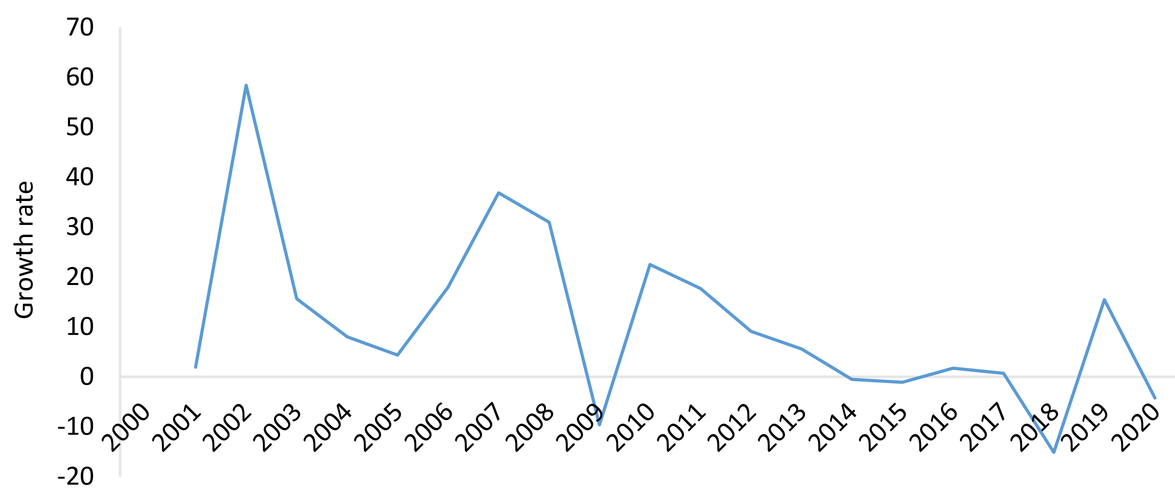


Figure 2: Growth rate of gross production value

Source: FAO (2020e)

As shown in the graph above, the growth of the production value of major livestock fluctuated between 2000 and 2020, reaching a high of 5.4 billion US dollars in 2017. The growth rate was booming during the years 2002 and 2007 which is primarily due to the increase in the livestock population during the same period. The estimated production value exhibits a slight increase up until 2008 and then experiences a 10% decline to reach 3.2 billion US dollars in 2009. The biggest decline occurred in 2018, with a more than 15% decrease in production value, which came to 4.6 billion US dollars. Following a period of up and down, the value reach 5 billion US dollars in 2020. Overall, the continued fluctuations in the prices of livestock products and livestock population are the cause of the production value's observed persistent fluctuation. First, between the years 2000 and 2020, there was a consistent occurrence of severe drought and disease in various parts of the nation, which affected the livestock and, consequently, the outputs and prices of commodities (Mera, 2018; Shitarek, 2012; Tegegne & Feye, 2020). Moreover, unstable livestock prices are observed for the period due to the seasonality of demand, climate change, and a lack of market information (Bachewe et al., 2017; Kassie et al., 2019).

2.3. Livestock production system and environmental changes

2.3.1. Greenhouse gas (GHG) emission

In the livestock production system, large amounts of emissions are caused due to enteric fermentation. Besides, livestock manure production has also contributed to the greenhouse gas emission. In Ethiopia, a sizable portion of the population depends on the livestock industry. The livestock industry's output tends to rise as a result of the need to feed and sustain the growing demand. The growth in the livestock population intensifies the pressure on the environment, which also increases greenhouse gas emissions (Berhe, Bariagabre, & Balehegn, 2020; Kimball, 2011). The figure below depicts the direct emissions caused by livestock through enteric fermentation and manure production.

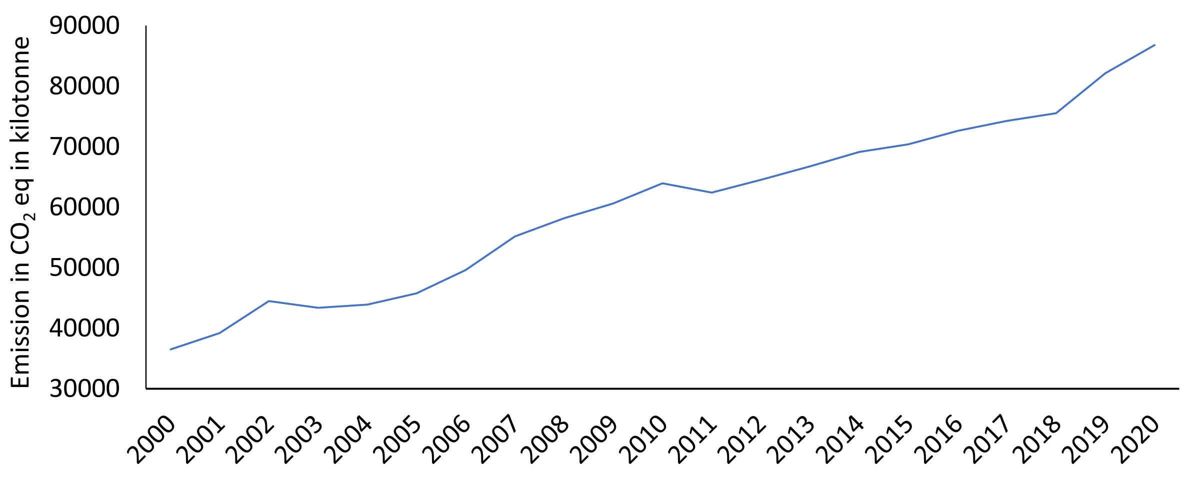


Figure 3: Direct greenhouse gas (GHG) emission from the livestock sector

Source: (FAO, 2020c)

The trends in direct emission levels show a consistent upward trend, with only a slight downward trend in 2003 and 2011 at nearly the same rate of 2.5%. In other cases, the level of emissions rises steadily along with the expansion of the livestock population. Since 2012, the level of greenhouse gas emissions has been rising steadily at an average rate of 3.7%. This is consistent with the growth of livestock units, which increase by an average of 4.27% over the same year. In 2012 and 2020, the emission level was 64.5 and 86.7 million tons CO_2-eq, respectively. The greatest contribution to the level of emissions comes from cattle (FDRE, 2011).

2.3.2. Land use change and degradation

The livestock industry is the largest contributor to land use change (FAO, 2012). In Ethiopia, particularly during the rainy season, green pasture serves as the primary source of feed for the livestock production system (Shapiro et al., 2015). This reliance and pressure on grazing land have resulted in significant land degradation and vegetation loss (Alkemade et al., 2013; Asmare & Mekuriaw, 2017). The availability of land is being further encroached upon by both the expanding population and extensive farming, which reduces the ability to produce feed (Shapiro et al., 2015).

A growing number of livestock populations are placing more strain on available agricultural land. Livestock units on agricultural land were 0.67 units per hectare in 2000, and they increased at an average rate of 4.3% to reach 1.01 units per hectare in 2010. Since then, the density has been increasing at a rate of 2.8%, reaching 1.32 livestock units per hectare in 2020 (FAO, 2020f). According to FAO (2020g), during the years 2000 to 2020, land covered by meadows and natural pastures is invading at a rate of 0.4%. Grassland cover is also decreasing at a rate of 0.12% between 2015 and 2019.

The increasing livestock population has resulted in land use changes in various parts of the country due to overgrazing and feed production. For example, grazing land cover in southern Ethiopia decreased by 3.18% between 1986 and 2018 (Kuma, Feyessa, & Demissie, 2022), while grassland cover in the country's central highlands decreased by 74.8% between 1973 and 2007 (Gessesse & Bewket, 2014). Furthermore, from 1986 to 2019, about 194 hectares of grassland were lost each year in the Ethiopian great rift valley region (Hassen, Bantider, Legesse, Maimbo, & Likissa, 2021), and grassland cover was reduced by 22.5% in the country's south-eastern rangeland (Habte, Eshetu, Legesse, Maryo, & Andualem, 2020). These changes in land cover would worsen and contribute to other environmental problems such as soil erosion, emission, and land degradation (Kimball, 2011).

2.4. Constraints of livestock production system in Ethiopia

The livestock sector in the country has been challenged by many problems in the production system. The issues are resource, technical, institutional, and policy-oriented, which have hampered the sector's growth (Tegegne & Feye, 2020). Animal health, shortage of feed and water, and market issues are the fundamental difficulties that face the livestock industry (Duressa et al., 2014; Mengistu et al., 2021).

One of the problems with the country's production system is the animal health and prevalence of parasites, which causes high mortality of animals in the country's agro-ecological zones (Tegegne & Feye, 2020). According to CSA (2021) a total of 59 million animals, of which nearly 39 million poultry, 8.7 million goats, 6.5 million sheep, 3.4 million cattle and other major livestock species were lost to death, mostly as a result of disease and other factors.

The country's livestock production system is primarily dependent on natural resources. The growth of the sector is being impeded in most areas by the low quality and availability of feed resources (Kidanemariam & Fesseha, 2020). The problem is that grazing land is diminishing as a result of increased population density, fixed land area, and larger animal sizes (Tilahun & Schmidt, 2012). For instance, the density of livestock units has increased on average at a 3.55% annual growth rate since 2000 (FAO, 2020g).

The infrastructure and market accessibility issues are also the main challenges for the farmers and industry. The distance of the market has hindered production by imposing indirect costs on farmers and livestock, posing both environmental and social risks (Tilahun & Schmidt, 2012). Other marketing issues affecting the sector include limited access to markets, difficult market spaces, a lack of and asymmetry in market information, and uncompetitive export markets (Kassie et al., 2019).

The sluggish increase in productivity is one of the major issues that still plague the nation's livestock production systems. In comparison to major livestock-producing nations, the productivity of livestock in Ethiopia is very low. This is demonstrated by the fact that the country's rising value of production could only be attributed to an increase in livestock populations rather than productivity growth (Fantu et al., 2018). The productivity is being constrained by several factors, including decreased reproduction, lack of feed, inadequate health services, and limited access to new inputs and services (CSA, 2021; Duguma et al., 2012; Mamo et al., 2017; Shapiro et al., 2015). Furthermore, the availability of feed and the number of animals in a given area have a significant influence on livestock productivity (Yisehak & Janssens, 2014).

2.5. Policies on agriculture, livestock and environment in Ethiopia

Several plans and initiatives for the socioeconomic growth of the nation have been laid out. There have been policies on the growth and transformation of the agricultural sector, but when it comes to the livestock sub-sector and the environment, it remained scant. For instance, there is a clear program on agriculture to transform and maintain the agriculture sector as the primary source of economic growth in both growth and transformation plans I and II (GTP-I and GTP-II) (Federal Democratic Republic of Ethiopia [FDRE], 2016). However, until the Growth and

Transformation Plan II (GTP-II), there was no clear program in the livestock subsector (Shapiro et al., 2015).

The livestock master plan (LMP) is a five-year development roadmap to contribute to the growth and transformation plan II (GTP-II) (2015-2020) sets out to increase the livestock output and productivity. The roadmap seeks to accomplish the same goals as GTP II in terms of reducing poverty, promoting food security, economic expansion, foreign exchange earnings, and reducing and adapting to climate change (Shapiro et al., 2015).

The Climate Resilient Green Economy (CRGE) strategy was introduced in 2011 to become a middle-income nation by 2025, with an economy that is climate change resilient and no net increase in greenhouse gas (GHG) emissions from 2010. In addition, the nation also has a green economy (GE) strategy that aims to promote low-carbon development. As it makes up an economy and the means of subsistence for many populations, agriculture, and in particular the livestock sector, is one of the areas of focus. Developing improved livestock production practices that will support household livelihoods and the country without raising emission levels is among the main pillars of the strategy (FDRE, 2011).

The national adaptation plan (NAP-ETH), which was also launched in 2017, had the same objective of boosting adaptability and resilience to the effects of climate change. Agriculture, particularly livestock, has been identified as a key priority area of the adaptation plan due to its vulnerability to the changes (FDRE, 2020).

The ten-year development plan (2021-2030) was introduced in 2020 as part of home-grown policy reform, with agricultural development as one of its main emphases. The main goal was to develop an agriculture that would be resilient to climate change and support livelihoods and economic transformation. Moreover, the environment and climate change are other areas of focus that aim to promote sustainable development by guaranteeing sustainable utilization and harmonious interactions with ecosystems. One of the goals of the strategy is to increase the ability to reduce greenhouse gas (GHG) emissions (FDRE, 2021a).

Apart from national and sectorial policies, the country has also made efforts to reduce country-wide emission levels. The country committed to making the first nationally determined contribution (NDC) that aims to reduce its overall greenhouse gas (GHG) emissions. The newly revised nationally determined contribution (NDC) was introduced in 2021 to support the efforts to further reduce the level of greenhouse gas emissions across the nation by 68.8% by 2030 (FDRE, 2021b). Furthermore, in 2023, the country launched a long-term low-emission development strategy (LT-LEDS) with the goal of reaching net zero emissions by 2050 (UNFCCC, 2023).

The goal of this study is to develop a livestock production system that leads to a sustainable environment, which is the cornerstone of almost all policy initiatives. As a result, the study would also be used as a policy input for an ongoing policy program.

Chapter Three

3. Review of related literature

3.1. System dynamics modelling and environment

Broadly, system thinking is a methodical approach to examining the behaviour of the entire system of the dynamic problem, whereas system dynamics is a methodology to comprehend and simulate the dynamic problem over time (Bala, Arshad, Noh, & Simulation, 2017). Barbrook-Johnson and Penn (2022) also define system dynamics as a computer model with stocks, auxiliaries, and flows that use defined equations to generate comprehensive results for analysis. The process of feedback interaction, non-linearity, delays, and the structure to recognize and represent the dynamics of complex systems are all concerns in system dynamics (Dangerfield, 2020; Pruyt, 2013; Sterman, 2000). System dynamics has been widely used to investigate a variety of issues, most notably socioeconomic, business, and environmental issues (Schwaninger, 2020; Sterman, 2000).

System dynamics models are often used because problems are complex and dynamic and cannot be understood without integrated and simulation-based modelling (Tedeschi, Nicholson, & Rich, 2011). System dynamics is advantageous in that it integrates social, economic, and environmental factors within the same system of analysis (Bassi, Costantini, & Sforna, 2020).

System dynamics modelling is a scientific-based approach to modelling that employs a defined methodology. The first step in system dynamics is selecting and defining the dynamic problem. Next, mapping and conceptualizing the model for the dynamic problem, followed by the formulation of the quantified model, simulation of the built model, validation of the model, and analysis and interpretation of the results (Bala, Arshad, Noh, et al., 2017; Barbrook-Johnson & Penn, 2022; Probst & Bassi, 2017; Van Niekerk, Brent, Musango, & De Kock, 2017).

System dynamics has been widely used to analyze environmental sustainability issues (Barbrook-Johnson & Penn, 2022; Dangerfield, 2020; Ford, 2009). Environmental issues are dynamic, with multiple interconnected components that interact with one another (Pruyt, 2013; Van Niekerk et al., 2017; Walters et al., 2016). Additionally, nonlinearities, spatial lags, and temporal lags are common in environmental problems (Costanza & Ruth, 1998).

Strong interactions between various sectors, state changes over time, delayed system responses, feedback interactions, multiplicity and nonlinearity of the interactions, and behaviours that spontaneously emerged from the problem's patterns and structure are all factors contributing to the dynamic complexity in the system (Currie, Smith, & Jagals, 2018). In particular, the relationship between the human population and the environment is complex and dynamic (Sterman, 2000). In a situation where problems have dynamic complexity, the system dynamics method would be used to understand the dynamic behaviour and draw decent and useful insights for policy analysis (Bassi et al., 2020; Currie et al., 2018; Sterman, 2000).

3.2. Review of empirical studies

Many studies show that the livestock industry is inextricably linked to the environment and natural resources. Despite its variety of socioeconomic advantages, the sector contributed both directly and indirectly to many of the depletion of natural resources and environmental changes (Baltenweck, Enahoro, Frija, & Tarawali, 2020; Cheng et al., 2022). For instance, the works of Abbasi and Abbasi (2016); Broom, Galindo, and Murgueitio (2013); Delgado, Rosegrant, Steinfeld, Ehui, and Courbois (2001); M. Herrero et al. (2013) and Philip K. Thornton (2010) concluded that increasing livestock production, which is driven by urbanization, income growth, and population growth, would increase food availability, alleviate poverty, and economic growth, but also degrade natural resources like land and water, and contribute to climate change.

Anthony J. McMichael, Powles, Butler, and Uauy (2007); Stehfest, van den Berg, Woltjer, Msangi, and Westhoek (2013) and Mario Herrero, Thornton, Gerber, and Reid (2009) have revealed that livestock production is responsible for a significant amount of land use change and biodiversity loss, as well as more for than one-fifth of global greenhouse gas (GHG) emissions. Besides, Rojas-Downing et al. (2017) and Orheruata and Omoyakhi (2007) strengthen that livestock is a major contributor to greenhouse gas (GHG) emissions. According to Bailey, Froggatt, and Wellesley (2014), livestock is a major source of greenhouse gases (GHG) and climate change, and its impact is expected to grow as demand for the products grows. Nonetheless, changes in emission levels pose a risk to the sector by affecting feed production, water availability, and health.

Post et al. (2020), in their study of the effects of livestock production systems, discovered that the production systems are responsible for a variety of adverse effects, including environmental and health issues. The production system has also been responsible for the massive degradation of the land and a decline in environmental quality (Warsame, Mohamed, & Mohamed, 2023). The studies highlighted the need for creating a more sustainable livestock production system to address the issues facing the industry.

Nicholson, Blake, Reid, and Schelhas (2001) found that the livestock sector has a significant impact on biodiversity loss, environmental degradation, soil erosion, and greenhouse gas emissions in developing countries. The study argued that these issues are primarily the result of ineffective production practices and management in least-developed nations. The quality and availability of feed are other major factors that limit the production of livestock in developing nations, particularly in sub-Saharan Africa (Fraval, Duncan, Notenbaert, Mutua, & Thornton, 2021).

In their review of livestock and environment interactions in Asia and Sub-Saharan Africa, Otte, Pica-Ciamarra, and Morzaria (2019) claimed that increased livestock production causes greenhouse gas (GHG) emissions, water stress, land degradation, and loss of biodiversity. The study proposed that effective policies that take into account the trade-offs that exist in the sector and environment should be developed.

In Ethiopia, the system of raising livestock is highly interrelated with and reliant on the environment and natural resources. The potential of the nation and the expansion of its resources in this area would have a significant impact on natural resources and ultimately on the environment. Kimball (2011), who used Geographic Information Systems (GIS) mapping and a review of the literature, has discussed several environmental effects of the livestock sector albeit its paramount services to the population and the nation. The study showed that an increase in livestock population is causing a variety of environmental changes, such as soil erosion, land degradation, greenhouse gas (GHG) emissions, water pollution, and deforestation in Ethiopia. These growing changes in the environment and climate in the region are further affecting the sector due to its reliance on natural resources (Gashaw, Asresie, & Haylom, 2014).

In their study of smallholder cattle farming in the Metekel zone, northwest Ethiopia, Altaye et al. (2014) found that the main sources of feed are natural pasture, crop residue, preserved hay, and stubble grazing. Mamo et al. (2017) also strengthen that pasture is the most important supply of feed for livestock in the Gambela region of Ethiopia. Concurrently, Free grazing is the most common feed system in the Gilgel Gibe catchment in Southwest Ethiopia (Duguma et al., 2012). The studies also noted that low productivity, poor health, and climate change have all constrained the production system.

According to Kochare et al. (2018) Crop residue, unmanaged pasture, and trees and shrubs make up the feed system in the Wolayta zone of southern Ethiopia. The nation's feed system has also been made up of agricultural and industrial byproducts. The main problem of production in Ethiopia is found to be low quality and scarcity of forage, drought, and land degradation, among other things (Birhan & Adugna, 2014).

Growing livestock populations have also been identified as the primary drivers of land use change in Ethiopia's highlands. This further affected the environment by reducing feed production, crop-livestock productivity, and vegetation loss (Mekuria et al., 2018).

Communal grazing land is the most common feed source for livestock production in Ethiopia's rural highlands. Overstocking is common, which is primarily caused by an increase in cropland and livestock population, resulting in environmental changes in the study area (Tschopp, Aseffa, Schelling, & Zinsstag, 2010).

These works of literature demonstrate that Ethiopia's livestock system is highly interconnected and affects the environment. As a result, the sustainability of the natural resource and the growing contribution to the greenhouse gas (GHG) footprint would be critical considerations in the expansion and production of the livestock sector in the country. This is because the industry's rapid growth eventually leads to unsustainable use of resources and environmental changes. Despite the massive environmental challenges that livestock poses, the research on its mitigation and adaptation is scant (Graham et al., 2022). Although the reviewed studies have attempted to investigate the prospects and interrelationships of livestock production and natural resources, the interaction of the industry with environmental factors and the way to minimize greenhouse gas (GHG) emissions were not fully covered in the literature.

There is a huge opportunity to sustain the livestock production system that supports food production and livelihood while reducing the negative environmental consequences, mainly in developing countries (Paul, Butterbach-Bahl, Notenbaert, Nderi, & Ericksen, 2020). Thus, the purpose of this study is to develop a system dynamics model for evaluating the interaction between the livestock sector and the environment, as well as its contribution to carbon emissions in Ethiopia.

3.3. Conceptual framework

The livestock production system consists of the interactions between livestock, population, and the environment. The human population implies the demand for food production, whereas the livestock represents the livestock units and their respective production intensities. The environment indicates the land, water and temperature that are used to produce feed, and water and maintain animal health (Oladunni et al., 2022). The livestock industry is one area where there is a trade-off exists between the need for increased food production and environmental changes. Population growth, urbanization, and improved living standards all imply a greater need for more livestock production, whereas environmental factors imply increased pressure on land, water, and greenhouse gas emissions (GHG) (Ominski et al., 2021).

The study developed the conceptual framework below based on the reviewed literature and the livestock production system in the country. First, the study identifies the main issue with the interaction between the livestock sector and the environment and then goes on to identify the key factors interacting in the subsectors. Designing the causal loop diagram (CLD) that represents the problem under consideration, as well as the stock-flow diagram that quantifies the issue, followed. After the model has been validated, base and alternative scenario simulations would be run and the results were examined for any potential policy implications.

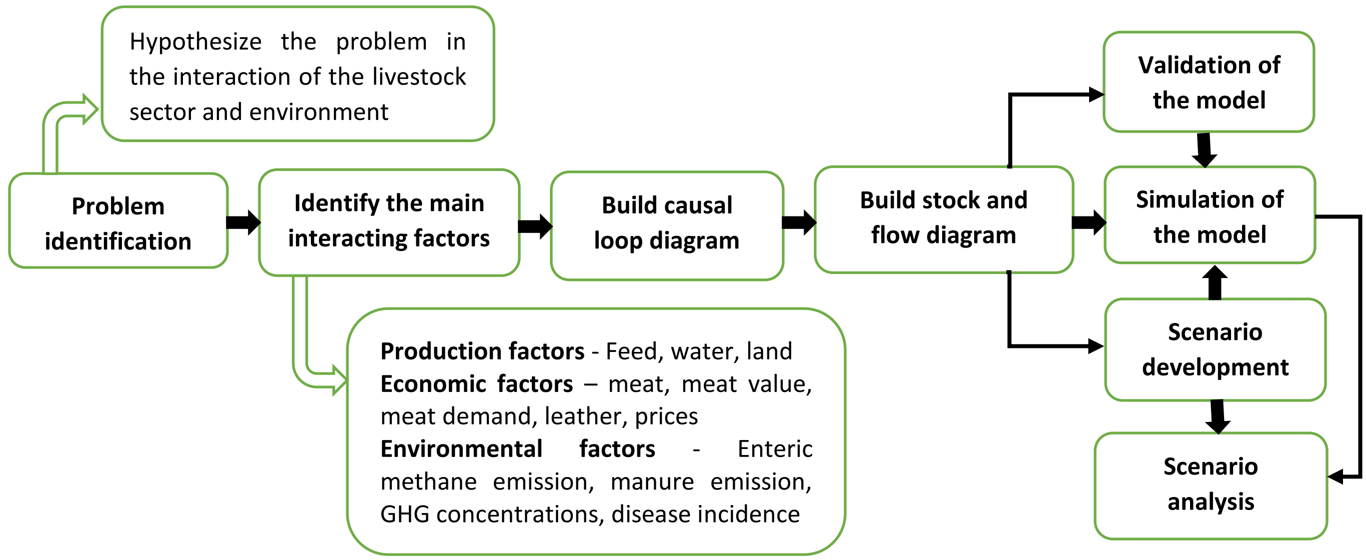


Figure 4: Framework of the study

Source: Own conception based on Bala, Arshad, and Noh (2017) and Probst and Bassi (2017)

Chapter Four

4. Methodology and model development

4.1. Choice of method and data source

The livestock production sector is broad and complex which necessitates an assessment of livestock production practices, and their socioeconomic and environmental implications. The sector is also dynamic with multiple interrelations with the human population, environment and socioeconomic factors. This is due to the livestock industry's reliance on the environment for feed biomass and water, as well as the production process, directly and indirectly, contributing to environmental changes by releasing greenhouse gas (GHG) emissions.

On the other hand, the sector is also used to supply food and has an economic value in the country. Thus, an integrated model that accommodates the sector's relationship with the human population and environment is required. Furthermore, it is necessary to choose the best course of action in policymaking that can sustain the rising need for livestock production while maintaining environmental effects. As a result, a dynamic simulation model based on the system dynamics model is employed to capture a comprehensive understanding of the complexity and dynamicity of the sector.

The development of the system dynamics model for the issue is based on the analysis and comprehension of the driving forces behind the system of livestock production and their implications on the environment. A system dynamics model is very useful for exploring and simulating the dynamicity, feedback interaction, and prospects of current activities as well as for evaluating an alternative policy case. The model also takes into account the causal relationship between the structure, non-linearity, and delays of the dynamic behaviours of the problem (Bala, Arshad, & Noh, 2017).

The livestock production sector was modelled by taking into account the major ruminants (cattle, goats and sheep) that are all converted to the tropical livestock units (TLU[1]) in Ethiopia. Existing related literature has been reviewed to develop the model that reproduces the causal and feedback interaction of the livestock production system and environment in Ethiopia. To quantify and parameterize the model's variables, ranges of data are gathered from various surveys and reports from both national and international organizations. The model was simulated for a period of forty years, from 2000 to 2040, with the first twenty years serving as reference mode and the remaining twenty years based on the predicted future behaviour of the model. This period has been chosen to assess and stimulate the country's current policy frameworks. To simulate the model for the intended time, Vensim simulation software was used.

[1] The conversion rate of the major ruminants to the tropical livestock units (TLU) [1 TLU = 250 kg live weight]: cattle = 0.7, goats and sheep = 0.1 (Rothman-Ostrow, Gilbert, & Rushton, 2020)

4.2. Dynamic hypothesis

The demand for livestock products is increasing over time. This is primarily due to an increase in population and an improvement in the population's living conditions. This ultimately fuels an increase in livestock production. The number of livestock units and their corresponding productivity are the main factors that affect livestock production. In Ethiopia, the livestock output growth is attributed to the growing number because productivity is very low. The availability of feed, feed quality, temperature and the prevalence of disease are the main factors that influence productivity.

Conversely, an increasing number of livestock units put a greater strain on the environment. This is because the industry is mostly dependent on the environment, and the increasing number which is driven by the rising demand places a burden on the ecology. The sector affects the sustainability of the environment largely by causing pressure on the land or availability of feed and water, as well as by directly releasing greenhouse gas (GHG) emissions in the form of methane (CH_4) through enteric fermentation and manure production. Furthermore, the sector indirectly contributes to greenhouse gas (GHG) emissions through changes in land cover and loss of habitat.

The rising livestock population and the industry's low productivity are the main contributors to the rise in enteric methane emissions produced during production. This increase in the total emission level, which causes the rise in the temperature, further affects the livestock industry by lowering the amount of feed intake and its availability, raising the needed water level for the livestock and causing death directly and through increased disease prevalence.

4.3. Model structure

4.3.1. Causal loop diagram (CLD)

A causal loop diagram is a framework that illustrates a certain subject by describing the underlying dynamic and systemic causes of the behaviour. It demonstrates the structure of the feedback system that encapsulates the dynamics and the root causes of the behaviour. The causal relationship between model variables and their interaction with feedback are both included in a causal loop diagram. There are also feedback loops that balance and reinforce each other in the causal loop diagram. The reinforcing loop demonstrates how the system achieves growth, while the balancing loop shows how the system creates goal-seeking or self-regulating behaviours (Bala, Arshad, & Noh, 2017; Walters et al., 2016).

A causal loop diagram depicting how the livestock production system interacts with the environment was created to investigate environmental sustainability, specifically the contribution of the sector to the carbon footprint in Ethiopia. The causal loop has been created based on the dynamic hypothesis to explore and reproduce the behaviour of the problems. The causal loop diagram shown below makes an effort to grasp the system structure of the livestock inventory, its interactions with the environmental factors and the industry's output and economic value.

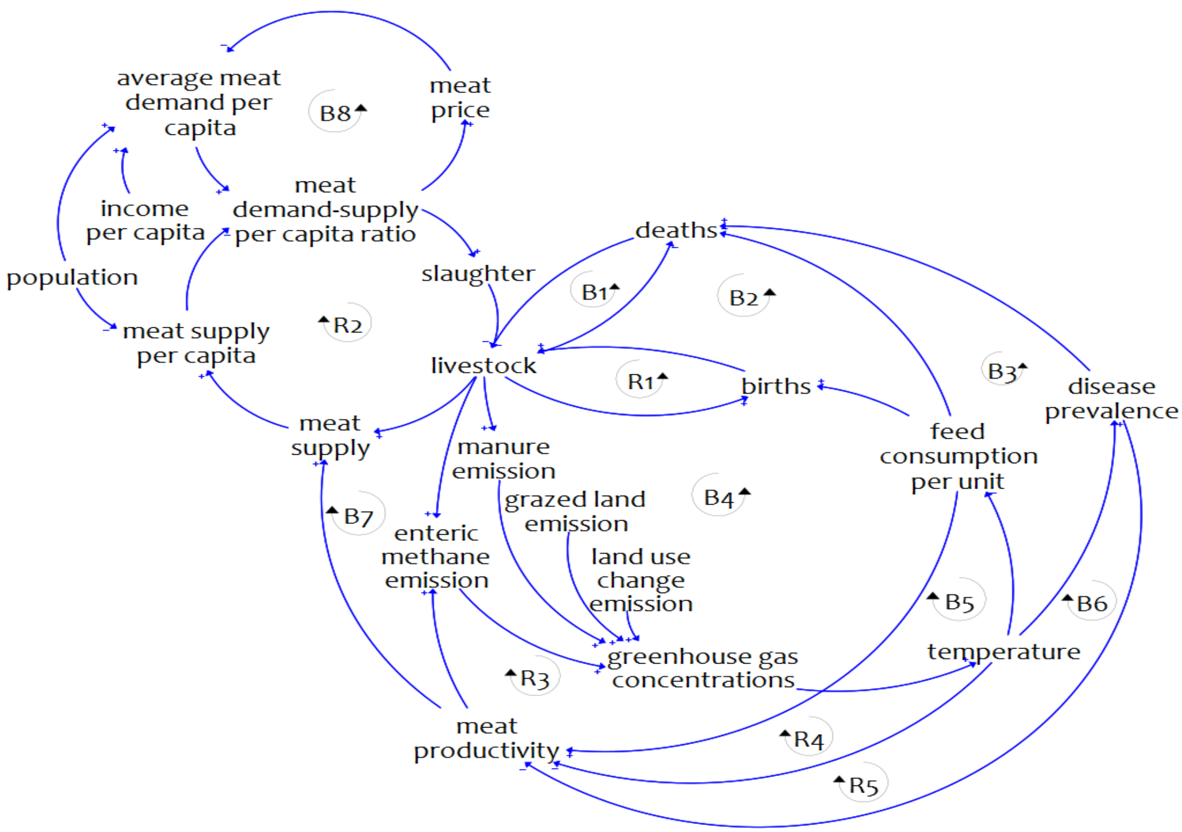


Figure 5: A causal loop diagram (CLD) representing the model

The causal loop diagram (CLD) displays several reinforcing and balancing feedback loops that examine the feedback interaction of the inventory of the sector and the environment. The important feedback loops are discussed as follows.

The first reinforcing loop R1 indicates that an increase in livestock population leads to more births and hence more livestock. More livestock, on the other hand, leads to more deaths and, eventually, less livestock. This is indicated by balancing loop B1.

According to balancing loop B2, as livestock unit increase, more emissions are produced through enteric fermentation and manure, resulting in higher greenhouse gas (GHG) concentrations and temperatures. This higher temperature reduces livestock feed consumption, resulting in more livestock deaths.

Feedback loop R2 indicates more livestock units result in higher levels of meat output and lower demand due to increased meat availability. This reduces the number of slaughtered animals and preserves the livestock population.

More livestock, according to balancing loop B3, results in higher levels of enteric methane and manure emission, as well as greenhouse gas (GHG) concentrations, which raise the temperature. As a result, disease prevalence has increased, as have deaths, resulting in fewer livestock units. According to feedback loop B4, the greater the number of livestock, the greater the enteric methane and manure emissions, greenhouse gas (GHG) concentrations, and temperature. This higher temperature reduces livestock feed consumption, which reduces livestock births and population.

In feedback loop B7, the more livestock units, the more enteric methane and manure emissions, as well as greenhouse gas (GHG) concentrations and temperature, which reduce meat productivity and supplies. Given the growing demand due to population and income per capita growth, lower meat supply leads to an increased gap between meat demand and supply and raises slaughters, which reduces the livestock population. Furthermore, the larger livestock units emit more enteric methane and manure, resulting in higher concentrations of greenhouse gases (GHG) that raise the temperature. Higher temperatures reduce livestock feed intake, meat productivity, and meat supplies. This widens the gap between supply and demand eventually leading to more slaughter and a reduction in livestock numbers. This is indicated by balancing loop B5.

As shown by balancing loop B6, an increase in livestock units causes an increase in enteric methane and manure emissions, as well as greenhouse gas (GHG) concentrations, which raises the temperature. A higher temperature increases disease prevalence, reducing meat productivity and supply. This, in turn, increases the meat supply and demand gap and slaughter, eventually reducing livestock numbers. Reinforcing loop R3 demonstrates that higher greenhouse gas (GHG) concentrations from enteric fermentation, manure and land use change and degradation emission raise temperatures and reduce livestock productivity, increasing the amount of enteric methane emissions produced. This is because low-productive livestock typically has high emission intensities. After all, enteric fermentation, in particular, is directly correlated with the major factors that lower livestock productivity (FAO, 2019). This contributes to an increase in the level of emissions in the atmosphere.

Higher levels of greenhouse gas (GHG) emissions in the atmosphere, caused directly by enteric fermentation and manure emissions and indirectly by land use change and land degradation, are reinforced by the effect on livestock feed consumption. The more greenhouse gases produced, the higher the temperature, which reduces feed consumption per unit and meat productivity. Heat stress causes livestock to consume less feed, resulting in lower meat productivity (P. Thornton, Nelson, Mayberry, & Herrero, 2022). As a result, enteric methane emissions and greenhouse gas (GHG) concentrations rise. This is denoted by reinforcing loop R4.

A reinforcing loop, R5, demonstrates how rising greenhouse gas (GHG) concentrations lead to higher temperatures, which in turn raise disease prevalence. Higher disease prevalence causes less meat productivity, which increases enteric methane emissions and greenhouse gas emissions. Balancing loop B8 demonstrated that price rise in response to higher demand relative to the supply of meat, which in turn lowers average per capita demand for the meat as well as demand relative to supply.

4.3.2. Stock and flow diagram (SFD)

The stock and flow diagrams (SFD) converted the causal loop diagram (CLD) to a quantified and mathematical model. It is the crucial stage in which mental models are transformed into complete and communicable results. Stock-flow diagram used a set of the system of differential equations to replicate the reference behaviour of the dynamic hypothesis. The stock and flow diagram is a system of feedback structures that depicts integral finite difference equations with a collection of feedback loop structure variables and simulates the dynamics of the behaviour over time (Bala, Arshad, & Noh, 2017; Sterman, 2000). The livestock production system's stock and flow diagram is shown in the figure below, where the stock and flows are connected to form a structure that defines the behaviour of the system.

Five important stock variables are used to create the model. Population is the first stock, and it is changing as a result of the change in the rate of natural increase. This changing population increases the demand for livestock outputs, resulting in livestock production growth. The livestock inventory makes up the other stock and grows as a result of births. The slaughters, and deaths, in contrast, result in a decrease in the livestock unit. These changes in the livestock inventory are directly contributing to greenhouse gas (GHG) through enteric fermentation and manure production in the production process. And indirectly through land cover change and overgrazing of the vegetation.

The population of the livestock and the intensity of their enteric methane emissions, as well as the emission from manure production, are the main factor that contributes to the other stock model variable, the greenhouse gas (GHG) concentrations. A greenhouse gas (GHG) concentration rises due to the increased livestock population and manure production, and high enteric methane emission intensity, which are primarily influenced by the productivity of the livestock. Changes in land use and vegetation loss as a result of livestock expansion are other factors that contribute to greenhouse gas (GHG) concentrations.

The available feed produced from feed production on grazing land, crop residue, and other supplements is also the other noteworthy stock variable. When feed production is high, the amount of feed available raises and it falls when the production is low and temperatures are high. Another stock considered in the model is the availability of water for livestock. It denotes the total amount of water available for livestock in the country. Temperature changes are assumed to have the greatest impact on livestock water consumption. They require more water at higher temperatures and vice versa.

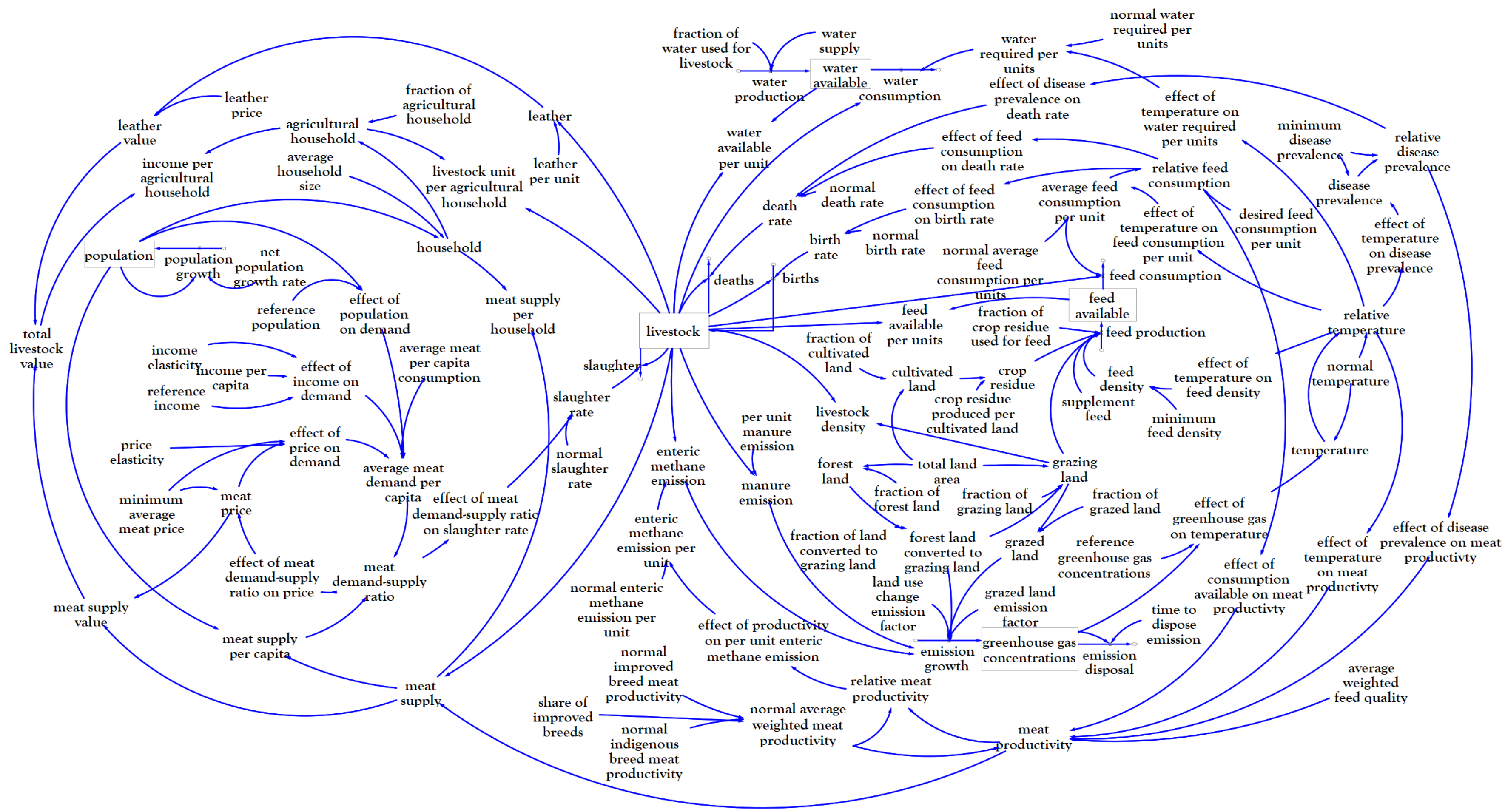


Figure 6: Stock and flow diagram (SFD) of the model

The stock-flow model requires the specification of equations and parameterization of the variables before running the simulation. The table below provides a summary of the values of variables and parameters of the model along with information on the unit of measurement and source of the values.

Table 1: Initial value and values of the parameters of the model

Parameters	Initial value/Value	Unit	Source
Population	67,031,867	Person	World Bank (2020b)
Water available	690,000,000,000	Liter	FAO (2020a)
Livestock	20,684,572	TLU	FAO (2020g)
Feed available	51,283,692,000	Kg	Bediye, Nemi, and Makkar (2018); FAO (2016)
GHG concentrations	36,633,150,000	Kg CO_2	FAO (2020b)
Fraction of agricultural household	61.4	Dmnl[2]	FAO (2022)
Average household size	5	Person	
Normal birth rate	22	Dmnl /Year	CSA (2021)
Normal death rate	6.7	Dmnl/Year	
Normal slaughter rate	1.9	Dmnl/Year	
Normal disease prevalence	11.9	Dmnl	Mekuriaw and Harris-Coble (2021)
Normal average meat consumption	5.3	Kg/Person/Year	Tafere and Hassen (2012)
Desired feed per unit	2280	Kg/TLU/Year	Jahnke and Jahnke (1982); Kochare et al. (2018)
Average feed consumption per unit	1596	Kg/TLU/Year	Abera, Tolera, and Assefa (2014); Tesfay, Gebrelibanos, Woldemariam, and Tilahun (2016)
Total land area	110, 430,000	Hectare	FAO (2016)
Fraction of forest land	12.2	Dmnl	
Fraction of grazing land	18	Dmnl	
Fraction of grazed land	23	Dmnl/Year	Gebreselassie, Kirui, and Mirzabaev (2016)
Fraction of land converted to grazing land	0.089	Dmnl/Year	EFCCC (2017)
Leather per unit	17	Kg/TLU	Adem (2019)
Leather price	10	ETB/Kg	Shapiro et al. (2015)
Minimum feed density	1,580	Kg/Hectare	Ayele, Tolemariam, Beyene, Tadese, and Tamiru (2022)
Normal per unit enteric	1288	Kg CO_2/TLU/Year	Gibbs and Johnson (1993)

[2] Dmnl: indicates that the unit is dimensionless

methane emission			
Per unit manure emission	53.2	Kg CO_2/TLU/Year	M. Tadesse and Getahun (2021); Woodbury and Hashimoto (1993)
Share of improved breeds	2.2	Dmnl	Mekuriaw and Harris-Coble (2021)
Normal water required per unit	9125	Liter/TLU/Year	Sileshi, Tegegne, and Tsadik (2003)
Grazed land emission factor	15,310	Kg CO_2/Hectare	Atsbha, Desta, and Zewdu (2019)
Land use change emission factor	38,300	Kg CO_2/Hectare	Meragiaw, Woldu, Martinsen, and Singh (2021)
Average weighted feed quality	90.79	DM	Bayissa, Dugumaa, and Desalegn (2022)
Normal indigenous breed productivity	108	Kg/TLU	Negassa, Rashid, and Gebremedhin (2011); Tefera et al. (2019)
Normal improved breed productivity	156	Kg/TLU	Teye and Sunkwa (2010)
Supplement feed	61,416,000	Kg/Year	Bediye et al. (2018)
Water supply	1,850,000,000,000	Liter/Year	Water Footprint Network (2016)
Fraction of water used for livestock	34.5	Dmnl	
Normal water required per unit	9,125	Liter/TLU/Year	Sileshi et al. (2003)
Minimum average meat price	320	ETB/Kg	Feed the Future (2017)
Fraction of cultivated land	15	Dmnl	FAO (2016)
Fraction of crop residue used for feed	60	Dmnl	Teshager (2019)
Crop residue produced per cultivated land	2,000	Kg/Hectare	McIntire, Reed, Teḍla, Jutzi, and Kebede (1988)
Time to dispose emission	15	Year	Defar (2016)
Income per capita	5,743	ETB/Person/Year	World Bank (2020a)
Net population growth rate	0.03	Dmnl/Year	World Bank (2020b)
Price elasticity	0.733	Dmnl	Tafere, Taffesse, Tamiru, Tefera, and Paulos (2010); Worku and Tafere (2012)
Income elasticity	0.933	Dmnl	
Normal temperature	25	˚C	-

4.3.2.1. Definitions of the main variables of the model

1) *Livestock:* is the total number of major ruminants including cattle, sheep and goats which all converted to the same unit. Livestock is measured in terms of the tropical livestock units (TLU). Livestock is increased through births and reduced through deaths and slaughters. This could be expressed as;

   Livestock = INTEG (births – deaths - slaughter, 20,684,600)

2) *Meat supply:* refers to the total meat/carcass output produced from the major ruminant measured in tropical livestock units (TLU). It is measured in Kilogram (Kg). Meat supply is influenced by meat productivity and the number of livestock. The equation is;

   Meat supply = livestock*meat productivity

3) *Total livestock value:* it is the estimated amount of money generated from the meat output and leather produced from the tropical livestock unit (TLU). Measured in Ethiopian birr (ETB). It is assumed to be the sum of the value of meat and leather products of the livestock. This is described as;

   Total livestock value = leather value + meat supply value

4) *Greenhouse gas (GHG) concentrations:* estimated greenhouse gas in the atmosphere that are attributed by the major ruminants directly through enteric methane and manure production, as well as indirectly through land use change and degradation of the habitat. Accounted in terms of the kilogram of CO_2-eq emission level. This is mainly affected by the emission growth due to the emission contributed directly through enteric fermentation and manure production, as well as the emission due to changes in land use and loss of vegetation. Besides, this emission level is disposed from the atmosphere after some time.

   Greenhouse gas (GHG) concentrations = INTEG (emission growth-emission disposal, 36,633,100,000)

5) *Meat productivity:* refers to the average meat yield or average carcass weight produced by the tropical livestock unit. Measured in Kg/TLU. Feed quality and availability, breed, disease prevalence and temperature are the main factors affecting meat productivity. This is expressed as follows;

   Meat productivity = normal average weighted meat productivity*effect of disease prevalence on meat productivity*effect of temperature on meat productivity*effect of feed consumption on meat productivity*average weighted feed quality

6) *Feed consumption per unit*: it is the actual feed consumed by the livestock unit annually. It is measured in the Kg/TLU/Year.
7) *Average weighted feed quality*: this is indicated by the average share of the dry matter content of the feed consumed per tropical livestock unit. The unit is the percentage share of dry matter (DM) content.
8) *Disease prevalence*: refers to the prevalence of livestock-level disease. Foot and mouth livestock disease which is the most prevalent disease has been used to indicate the incidence of livestock disease. Measured in the percentage of prevalence of disease per tropical livestock unit.
9) *Leather:* it is the average amount of skins and hides produced per major ruminant that is measured in the tropical livestock unit (TLU). Measured in terms of Kg/TLU.

   Leather = livestock*leather per unit

10) *Meat and leather price:* it is the average market price of meat and leather. It is measured in ETB/Kg.

The values and model equations for the other supplementary variables are shown in the appendix [Appendix A].

Chapter Five

5. Results and Discussion

5.1. Model validation

Model validation would be conducted to build confidence in the outcomes of the model. In system dynamics, the model should be tested based on its reflections on the reality, understanding and relevance of the system. Model validation determines whether the simulated model accurately reproduces the model behaviour. To build confidence in the system dynamics model under consideration, the model would perform some basic tests. The most common tests are divided into structural and behavioural model tests. The model structure is tested through its reflections of the working of the real system, while the behaviours have been tested through its reproduction of the real behaviour of the system (Bala, Arshad, & Noh, 2017).

5.1.1. Model structure test

Model structure testing is a pre-simulation test that includes determining the relevance of the model equation and unit, the accuracy of parameter values, and the adequacy of the model boundary (Bala, Arshad, & Noh, 2017; Sterman, 2000).

5.1.1.1. Structure verification test

The structure of the model has to be matching the existing knowledge of the system. The model is primarily created through a thorough analysis of the existing reports, books, and other technical documents on the industry. Data, terminology definitions, and reports from the Central Statistics Agency (CSA) and the Food and Agricultural Organization (FAO) serve as the cornerstones for developing the sector's production system and how it interacts with the environment, particularly concerning the sector's contribution to greenhouse gas emissions. The causal loop diagram and stock and flow diagram were created and are thought to replicate the actual behaviour of the problem. The primary elements of the country's production system have been incorporated, as shown in the sectoral overview of the livestock in the nation. Additionally, sectors' contributions to the emission of greenhouse gases include all pertinent links from the sector. The key parameters that are thought to define the issue are included in the model's boundary.

5.1.1.2. Extreme condition test

The changes to the values are tested to check and validate the true relationship. Zero values are considered in the equations to check the variables are not taking unrealistic values. The model, for instance, starts the feed consumption per livestock at zero and looks for the values that the key variables are taking. The supply of meat and its value are both expected to be zero if there is no feed for livestock to eat, which will result in low productivity and eventual livestock death.

The graph below confirms that changes in meat productivity and meat supply are proportional to changes in feed consumption per livestock in extreme conditions, with a value of zero.

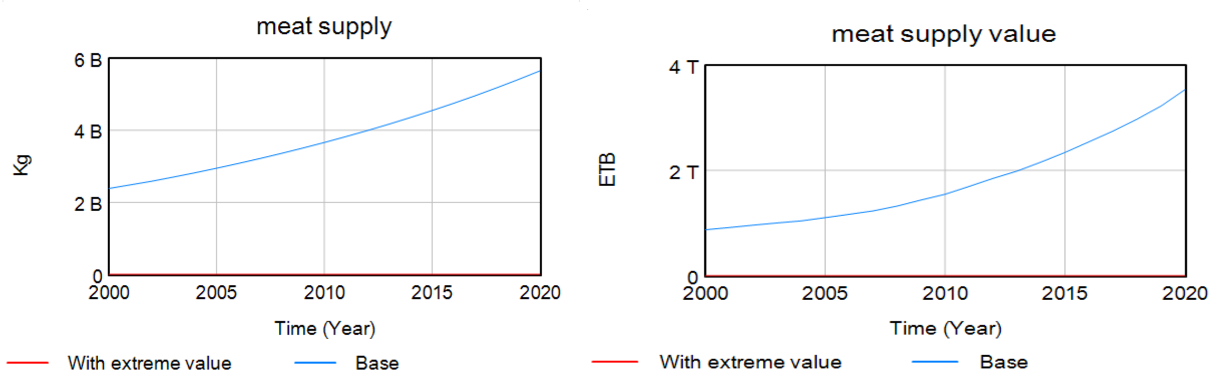


Figure 7: Extreme condition test

As shown in the figure, when the feed consumption of livestock is set to zero, meat supply and its value would not take on a value. Thus, it is justified that the model's behaviour produces the desired behaviour.

5.1.1.3. Parameter verification test

The parameters of the model have been collected from the literature and it considered the real values of the system. The initial values and parameters of the model are based on the relevant real knowledge of the sector. The parameters used to initialize the model, along with their corresponding units and sources, are listed above in the table [Table **1**].

5.1.1.4. Dimensional consistency test

The units of each variable inserted in the model for the simulations are meaningful and correct. The units are consistent with the specifications of the equations and the relationship between variables. The units of some of the variables are presented in the below table.

Table 2: Units of some selected variables of the model

Type of variable	Name of variable	Unit
Stock	Population	Person
	Livestock	TLU
	Greenhouse gas (GHG) concentrations	Kg CO_2
Flow	Births	TLU/Year
	Slaughters	TLU/Year
	Deaths	TLU/Year
Auxiliary	Productivity	Kg/TLU
	Meat supply	Kg
	Leather	Kg
	Total livestock value	ETB

Feed consumption per unit	Kg/TLU/Year
Feed quality	DM
Manure emission	Kg CO_2/Year
Enteric methane emission	Kg CO_2/Year
Share of improved breeds	Dmnl
Grazed land	Hectare
Water available per unit	Liter/TLU

The type and units of other supplementary variables are indicated in the appendix [Appendix A].

5.1.1.5. Boundary adequacy test

This test concerns whether the model's boundary changes could bring policy changes to the outcomes (Bala, Arshad, & Noh, 2017). The model has attempted to consider the relevant and sensible boundary for the livestock and its interaction with the environment particularly with greenhouse gas emissions. The trade-off that exists between the growth in the meat supply and greenhouse gas emission has connected through a specification that considers the real knowledge of structure. The meat supply is primarily determined by the number of livestock and meat productivity, which are both influenced by other variables in the model. On the other hand, greenhouse gas emissions that are contributed directly and indirectly by livestock are included in the model.

5.1.2. Model behaviour test

Following that, a model behaviour test is used to determine how accurately the model produces the reference data (Bala, Arshad, & Noh, 2017; Sterman, 2000). The four main variables in the study—livestock, meat supply, enteric methane, and manure emission—were chosen to test the model's behaviour accuracy over a given time series of data sets. The historical data is simulated for the years 2000 to 2020. The reference data for livestock and meat supply is based on an estimate from the FAO’s livestock and crop production (FAO, 2020d). On the other hand, the reference data for enteric methane and manure emission is retrieved from the Food and Agriculture Organization (FAO) climate change estimation (FAO, 2020c).

The graph below depicts the simulated value of livestock and meat supply in the country over twenty years in comparison to the historical data. As shown in the graph, the difference between historical data and simulated model value is close to zero.

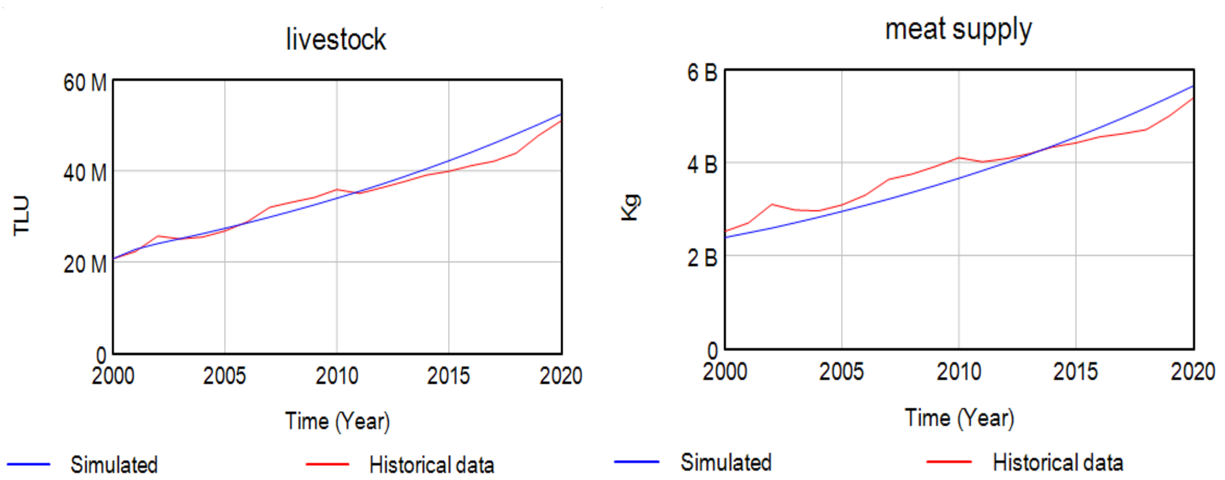


Figure 8: Simulated and historical behaviour of the livestock and meat supply

Furthermore, the simulated value of direct emission from enteric fermentation and manure production has been shown to fit the historical data under consideration. There is no statistically significant difference between the values of simulated and historical data, indicating that the model is a good fit for the real structure.

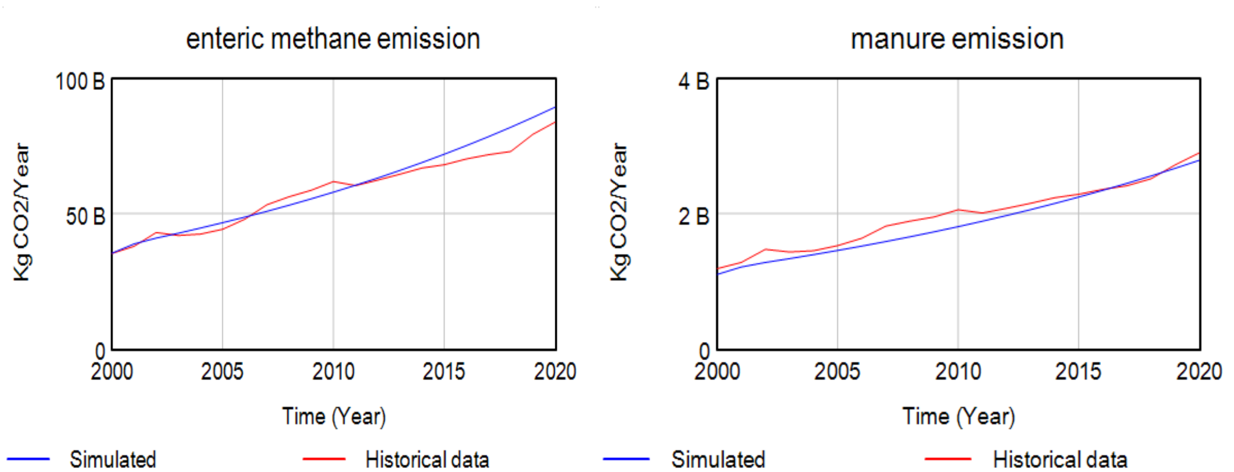


Figure 9: Simulated and historical behaviour of emission from enteric fermentation and manure production

Overall, the differences between the simulated results and the reference data are very small in the validation of the main variables. This provides confidence in simulating and analyzing alternative future policy scenarios.

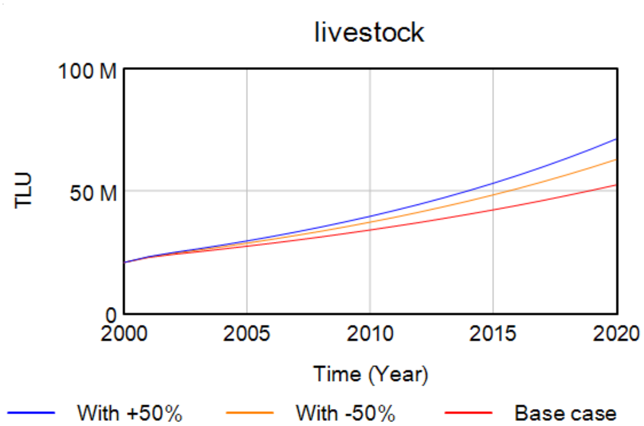
5.1.3. Sensitivity analysis

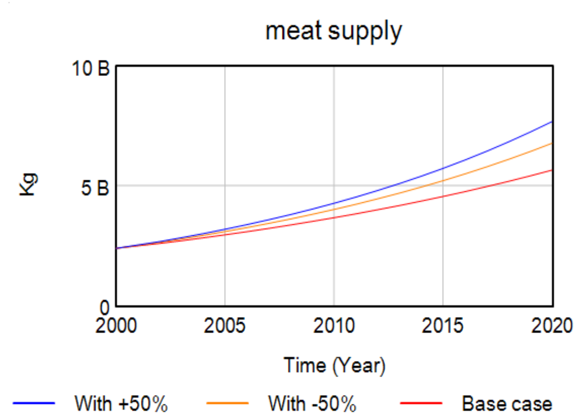
Sensitivity analysis is employed to identify the sensitivity of the results to the changes in the parameters. It is also used to identify the leverage points in the analysis of the relationship between the parameter and results (Bala, Arshad, & Noh, 2017). A sensitivity test is carried out to identify the most important and relevant variables that might change the results of the main variables.

The parameters that would be anticipated to change the variables have been chosen based on the literature to test the sensitivity of the livestock, meat supply, total livestock value, and greenhouse gas emission in the model. Meat supply has been primarily influenced by livestock numbers and meat productivity. Livestock productivity in Ethiopia is primarily influenced by feed availability and quality, livestock health, breed type, and temperature (Duressa et al., 2014; Kidanemariam & Fesseha, 2020; Mengistu et al., 2021). Total livestock value, on the other hand, is determined by changes in the prices of livestock products such as leather and meat. Increasing meat and leather production, as well as their prices, would change the estimated value of the livestock.

The other key variable in the model, greenhouse gas emissions, depends on both direct and indirect changes in livestock production. Greenhouse gas emissions are directly proportional to livestock population because of emissions from manure and enteric fermentation, as well as emissions from land use change and degradation that are caused due to livestock expansion. Thus, increasing the rate of off-take and slaughter could be considered to balance the increase in livestock numbers and reduce the proportional direct and indirect environmental effects.

The study has determined the key parameters that could change and lead to different outcomes of the main variables. Given the factors that affect Ethiopia's livestock production system, it has been determined that changes in meat supply, livestock value, and greenhouse gas emissions depend on the parameters such as feed quality and supply, disease prevalence, breed type, slaughter, prices of the products and land use changes. The model considers sensitivity analysis with 50% of the parameter below or above the base case value depicted in the simulated behaviour of chosen variables shown below.





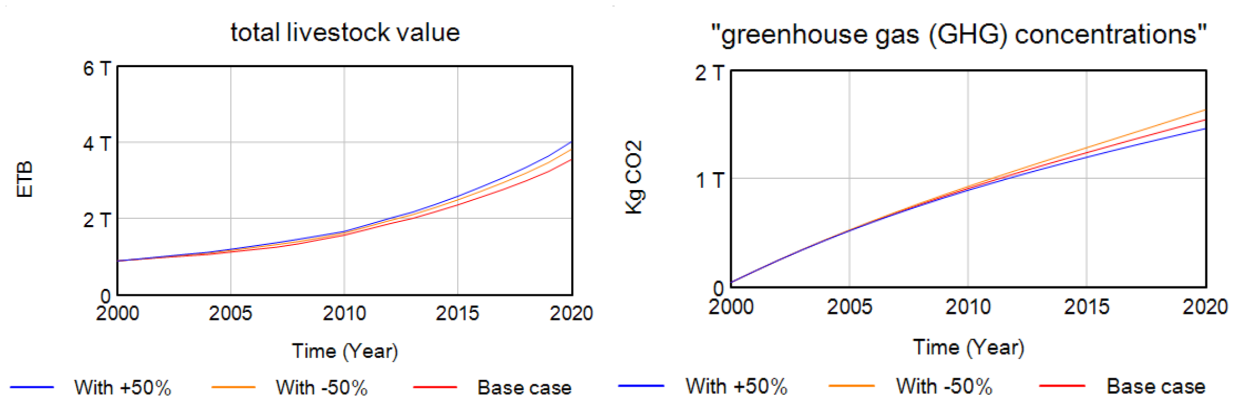


Figure 10: Sensitivity analysis of livestock, meat supply, total livestock value and greenhouse gas (GHG) concentration to the slaughter rate

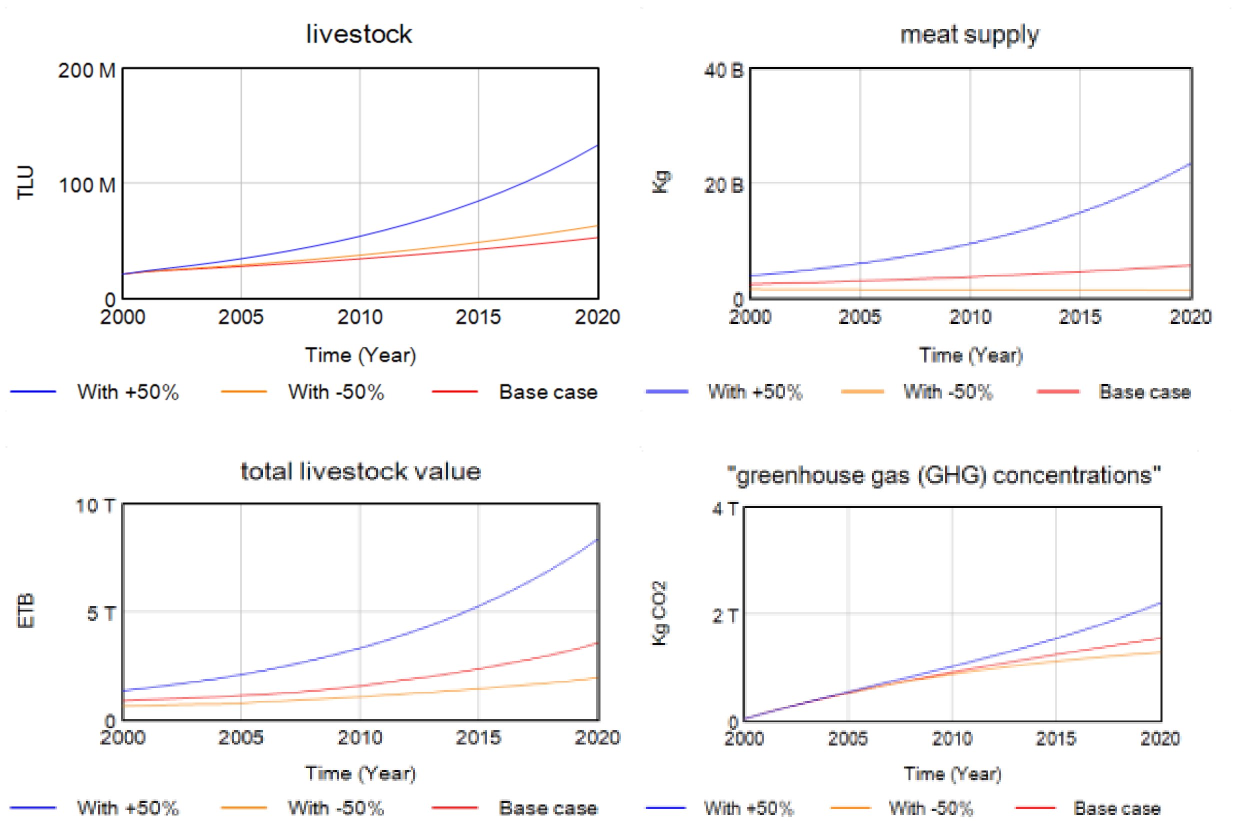


Figure 11: Sensitivity analysis of livestock, meat supply, total livestock value and greenhouse gas (GHG) concentration to feed consumption per unit

In addition to the parameters of feed consumption per unit and slaughter rate, the main variables are found to be sensitive to feed quality. Total livestock value and greenhouse gas (GHG) emissions, in particular, are found to be sensitive to meat prices and a fraction of grazed land, respectively. These sensitive parameters could be taken into account for further policy scenario analysis. However, the main variables are less sensitive to breed type, disease prevalence, forest land conversion, and leather price.

Although livestock genetics and breed are among the major constraints of the livestock production system, unless massive investments are made to replace local breeds, it does not result in significant changes to the main variables. This is because the share of improved breed livestock, which includes exotic and hybrid livestock, is as low as 2.2% in Ethiopia (Mekuriaw & Harris-Coble, 2021).

Less sensitivity of the breed type may also indicate that widespread adoption of improved breed types is necessary to significantly change the main variables. In comparison to other parameters, this would be expensive and unfeasible. The main difficulty in implementing significant investment in the adoption of improved breeds could include a lack of resources, innovation, the breeding policy, knowledge dissemination, and a lack of knowledge about the potential livestock resources (Bassa, 2021; Kebebe, 2019; Shapiro et al., 2015). Furthermore, extensive adoption of improved livestock breeds necessitates a long-term and large-scale investment (Haile et al., 2019).

The results of the sensitivity analysis of all parameters have indicated in the appendix [Appendix B].

5.2. Scenario design

Policy scenario planning is a common task in system dynamics modelling for simulating alternative practices and investigating future outcomes. The purpose of this study is to model the interaction of the sector with the environment. In addition, the study also aims to identify the possible policy case that improves the production system while reducing the carbon footprint of the sector. As a result, the model has identified six scenarios, including the baseline and the other five. Growth in meat productivity, land use management, meat productivity growth with slaughter and price policy, and a combination of all policy scenarios are the five scenarios. The simulation period covered the year between 2000 and 2040 and the policy scenarios are activated after 2020.

5.2.1. Base case

The first scenario case examined the prospects of current livestock production activities on the future outcomes of the selected variables. The graph below depicts the trends of the major variables in the current production system. The base case has been simulated for the years 2000 to 2040.

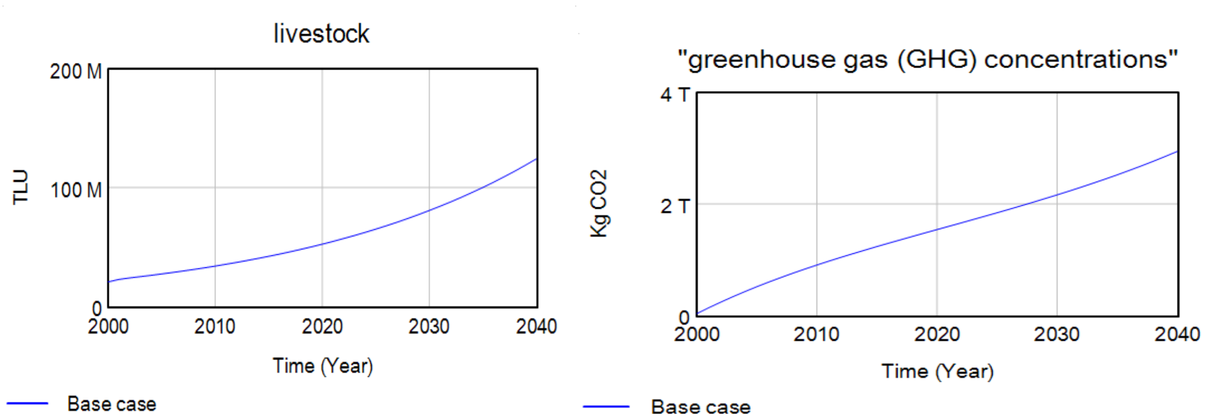


Figure 12: Simulated values of livestock and greenhouse gas concentrations (GHG) under base case

The number of livestock is increasing over time, as shown in the graph above. The number has risen over time and is expected to reach 124 million livestock units by 2040. This expansion could be attributed to the reinforcing loop (loop R1) dominance. On the other hand, the concentration of greenhouse gases (GHG) has increased, and the sector's emissions are expected to reach 2.9 gigatons of CO_2-eq by 2040. The reason for this includes, among other things, an increase in livestock, land conversion and degradation, as well as low livestock productivity (Cardoso, 2012; Kimball, 2011).

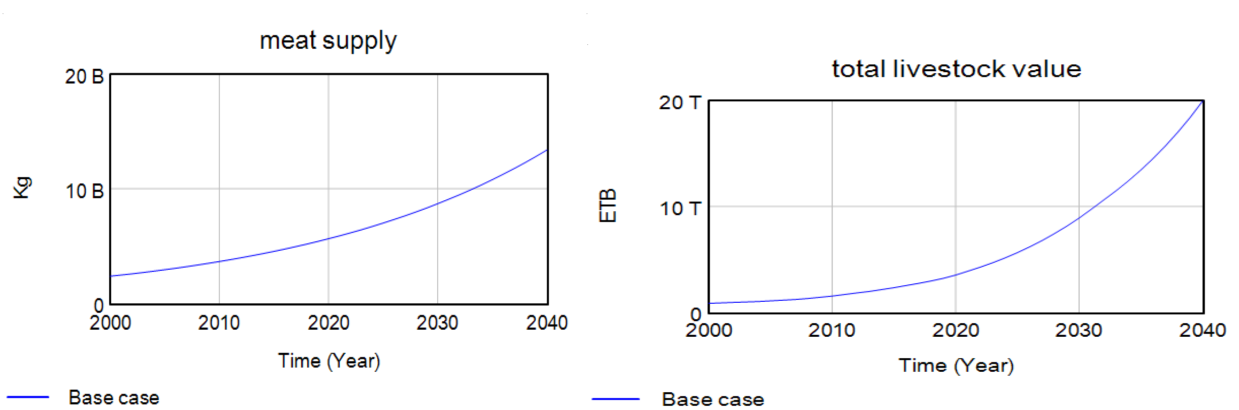


Figure 13: Values of meat supply and total livestock under base case

For the simulated period, the supply of meat output and livestock values have both increased. In 2020, the estimated amount of meat was 5.65 million tons, and this figure is expected to rise to 13.39 million tons by 2040. Despite an increase in livestock numbers, the meat supply is increasing gradually because productivity is the main constraint in the production system. The livestock value, which includes the value of meat and leather, has steadily increased in line with the number of livestock. In 2040, the value is expected to reach 19.96 trillion birr.

The value of all the selected main indicator variables has shown a tendency to grow over the simulated period. The following table compares the growth of the selected valuables over the period under the base case.

Table 3: Summary of the values of main variables under the base case

	Variables			
Years	Livestock (in mill)	Meat supply (in bill)	Total livestock value (in trill)	Greenhouse gas (GHG) concentrations (in trill)
2020	52.43	5.65	3.54	1.54
2030	80.79	8.71	8.92	2.17
2040	124.28	13.39	19.95	2.94
2030-2040	54.09%	54.15%	151.98%	40.9%
2020-2040	137.03%	137%	463.56%	90.9%

Livestock numbers and meat supply have shown an average growth of 137% between 2020 and 2040 under the base case. This shows most of the growth in the meat supply is only due to the changes in the number of livestock not due to growth in meat productivity. This result is in line with the findings of Fantu et al. (2018), who claim that production growth is solely attributable to livestock growth. Furthermore, total livestock value and greenhouse gas (GHG) concentrations have grown by 463.56% and 90.9%, respectively, for the same period. Although the growth in greenhouse gas (GHG) emissions has shown a tendency to grow slowly, it grows with the livestock population.

5.2.2. Scenario 1: Meat productivity growth

The meat productivity of the livestock production system in Ethiopia is very low. The main causes of low productivity include poor quality and availability of feed for consumption, livestock disease, and temperature changes (Fantu et al., 2018; Ma'alin, Abdimahad, Hassen, Mahamed, & Hassen, 2021; Mekuriaw & Harris-Coble, 2021; Shapiro et al., 2015). Conversely, this low productivity with the larger number of livestock is contributing to the growing greenhouse gas (GHG) emission level both directly and indirectly. This policy aims to strengthen the existing sectoral policy and to test the potential of reducing the emission level through productivity growth. Since productivity is low, increasing the productivity level would have multiple effects. The first is raising the meat supply and the other is achieving the potential reduction of the emission contributed through enteric fermentation (Enahoro et al., 2019; M. Herrero et al., 2013).

Enhancing breed genetics, feed quality and quantity, as well as the prevention of livestock disease, all contribute to an increase in meat productivity (Mengistu et al., 2021). In this policy scenario, full growth in feed consumption to the desired level (1596 to 2280 Kg/TLU/Year) and an improvement in feed quality (90.79 to 100% of dry matter content) are taken into account to see the full production and emission reduction potential of the livestock sector. Feed consumption per unit and feed quality are chosen because the two parameters are sensitive to changing meat productivity and thus the other main variables when compared to other parameters.

5.2.3. Scenario 2: Land use management

Land use change and habitat degradation caused due to livestock expansion and growth are one of the main factors contributing to the growing greenhouse gas (GHG) emission in the country (Kimball, 2011). Therefore, to maximize the relationship between the growth of production and environmental changes, sustainable land use management in the livestock production system is required (Idel, Fehlenberg, & Reichert, 2013).

This policy scenario is tested to reduce the emission that is caused by vegetation loss by managing and controlling the grazing system. This policy scenario took into account regulating and managing all the grazing land use (23% to 0%) caused by livestock to determine the maximum capacity that the country could reduce.

5.2.4. Scenario 3: Meat productivity growth with slaughter

Although there is a growing demand for livestock products, the production and supply of meat and other animal-sourced foods are not satisfying the growing demand (Shapiro et al., 2015). Despite accounting for the majority of agricultural value-added and export revenues, the sector's contribution to household nutrition is minimal in Ethiopia (Tafere & Hassen, 2012). The average off-take rate of major livestock in Ethiopia is estimated to be 22%, which is 8% lower than the potential off-take rate (Nell, 2006). Furthermore, livestock product consumption and utilization are very low. Increasing the off-take and slaughter rate has been critical in improving the country's and households' livelihoods and nutrition (Jemberu et al., 2022). In addition to lowering potential greenhouse gas emissions, balanced growth in livestock also helps to enhance production, protect natural resources, and lower management costs (Cardoso, 2012).

This policy scenario is considered to achieve a higher slaughter rate and production of meat to satisfy the growing need for meat at a lower price while reducing the ecological footprints. Furthermore, this scenario is considered to achieve less greenhouse gas (GHG) emissions by reducing the stock of livestock. The policy scenario took into account increasing the slaughter rate to 8% to produce more meat and achieve low emissions given the country's current low slaughter rate in comparison to the demand for meat.

5.2.5. Scenario 4: Meat productivity growth with price policy

In Ethiopia, the marketing and pricing of livestock products are inadequate and poorly managed (Addis, 2017; Shapiro et al., 2015). This scenario takes into account the effect of changes in meat prices. The value chain for livestock and meat products is extensive and complex, with numerous actors involved in its marketing (Dinku, Abebe, Lemma, & Shako, 2019; Solomon, Assegid, Jabbar, & Ahmed, 2003). The sector's poor and long value chain paved the way for the actors to absorb the entire profit of the products (Gadisa, 2022). As a result, farmers do not benefit from the pricing and marketing of livestock products. The main reason is the market's long value chain and a lack of marketing information (Kassie et al., 2019; Tilahun & Schmidt, 2012). Thus, increasing the price of the product would improve the farmer's and the economy's income and livelihoods. However, raising the price is not a sufficient condition for farmers to increase their income; rather, the policy must be delivered alongside well-controlled value chains.

This policy scenario considered a small price change to test see how the estimated value of the livestock would improve. Given the sensitivity of the parameter to the total livestock value, a 5% increase in the meat price from the base was considered.

5.2.6. Scenario 5: Combination of all policy scenarios

In this policy scenario, all of the policy cases are activated simultaneously to affect the key model variables. It has considered increasing the productivity of meat production, managing and controlling land use change and degradation, increasing the slaughter of livestock, and raising the price of meat.

The country's ongoing climate resilient green economy (CRGE) policy has also advocated increasing the production of livestock products while also increasing the productivity of livestock through the supplementation of feed, raising the off-take rate, improving the efficiency of value chains, and management of grazing and pasture land (FDRE, 2020).

5.3. Scenario analysis

The model's key parameters have been examined in various contexts. The results of the suggested policy scenarios are depicted in the following figure. The nation has the highest population of livestock in all of Africa (FAO, 2020d). Over the simulation period, the livestock population increased in all scenario cases. In comparison to the other scenarios, the meat productivity growth with slaughter and the combination of all policy cases that consider increasing meat productivity while also raising meat prices and slaughtering, as well as managing land use change, has the lowest number of livestock. The number increased from 52 million in 2020 to 82 million tropical livestock units in 2040.

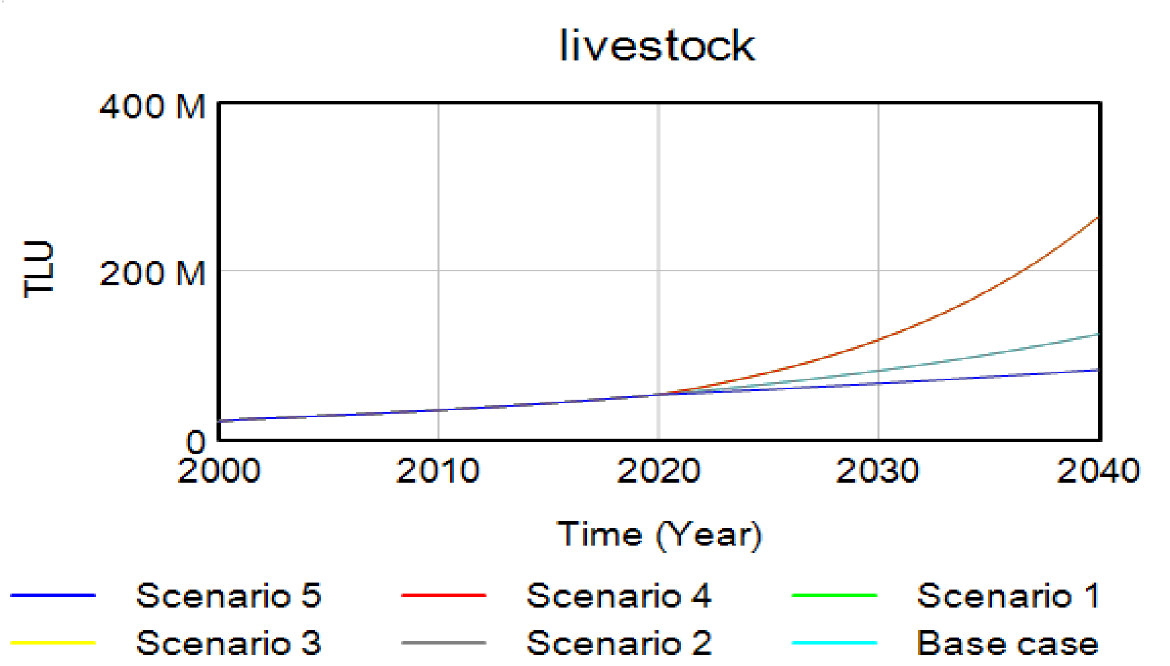


Figure 14: Livestock number under different policy scenarios

The first and fourth scenarios, which take into account increases in feed quality and supply for consumption, as well as price policy, have shown the greatest increase in livestock numbers. This is because of the fewer livestock deaths as a result of feed shortages and an increase in births. In Ethiopia, one of the main factors that limited the production of livestock and resulted in the death of many livestock was the lack of feed, especially improved quality feed (Catley, Admassu, Bekele, & Abebe, 2014). Thus, supplementing more and higher-quality feed would boost livestock growth in two ways: one by reducing deaths due to feed shortages and the other by increasing livestock fertility. In the two scenarios, the figure is expected to rise from 118 million in 2030 to 264 million in 2040.

The meat supply has also demonstrated a similar phase of growth over time. Compared to the other policy scenarios, the meat supply grows at the highest rates under scenarios with rising meat productivity and with the introduction of price policy. Under both scenarios, the amount is anticipated to reach 22 million tons in 2030 and 50 million tons in 2040, respectively. Ayele, Tolemariam, Beyene, Tadese, and Tamiru (2021); Duressa et al. (2014); Grima (2018); Hatew et al. (2023) have also found that improved feed quality and increased feed supply are more effective in increasing livestock productivity and output.

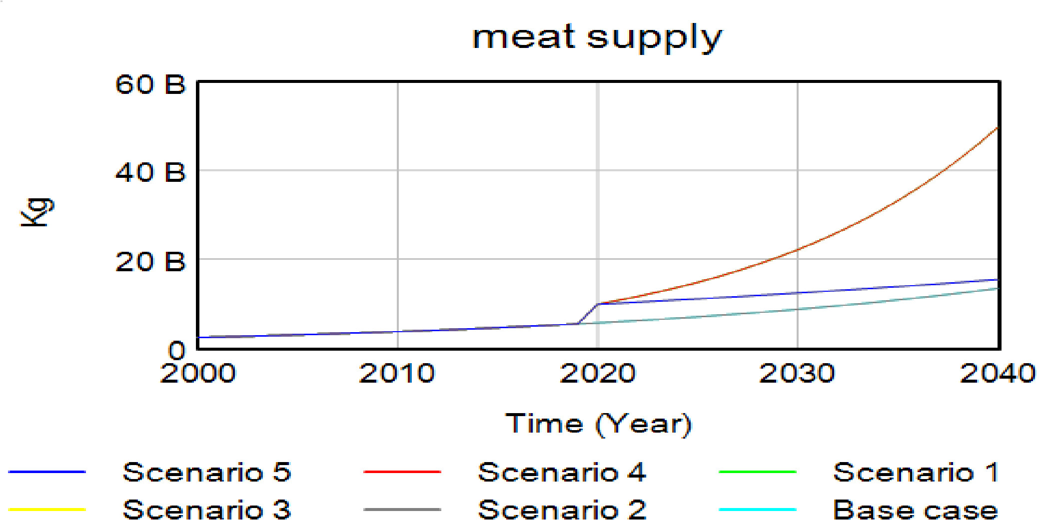


Figure 15: Meat supply under different policy scenarios

The figure above also indicated that less meat has been supplied under the base case and land use management scenario. This is due to the low meat productivity of the livestock sector existing in the current production activities of the livestock sector (FAO, 2020d).

The total livestock value increases rapidly almost under all policy scenarios. The estimated value has increased under meat productivity growth, meat productivity with price policy, whereas the value slightly growing under other scenarios.

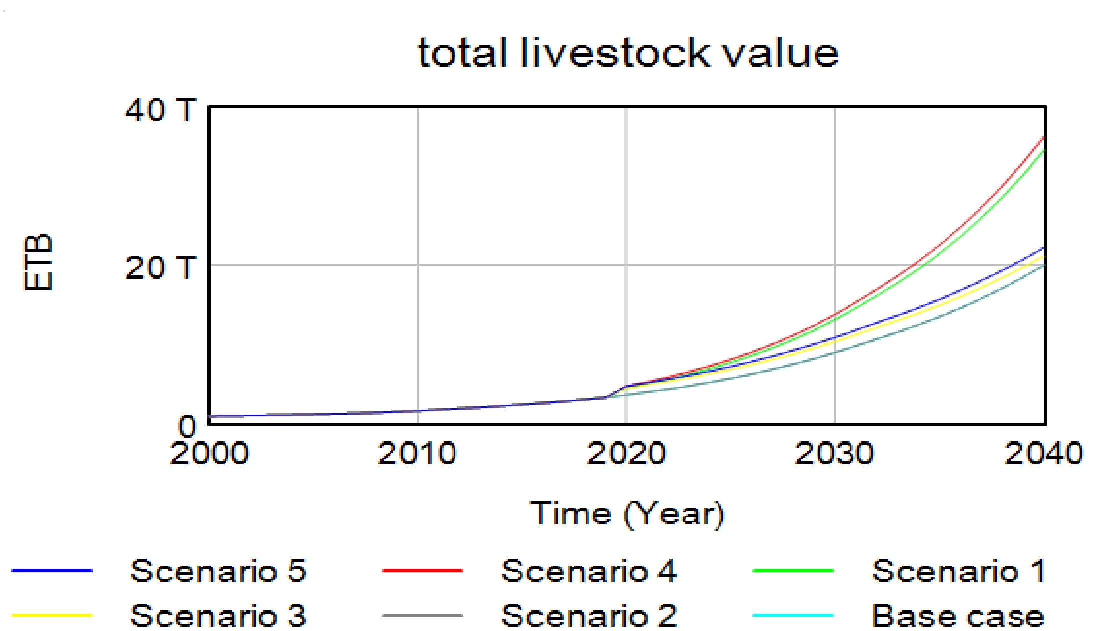


Figure 16: Total livestock value under different policy scenarios

The estimated livestock value has recorded the highest value under meat productivity growth with price policy. The value was estimated to be 14 and 36 trillion birrs in 2030 and 2040, respectively. The meat productivity growth scenario has also shown higher value with a slight difference from the meat productivity growth with the introduction of the price policy. The value has attained 13 and 34.5 trillion birrs in 2030 and 2040, respectively.

The level of emission increased with different phases under the scenarios considered. In comparison to the base case, the greenhouse gas (GHG) result shows a better result under land use management, meat productivity growth with slaughter, and the combination of all other policies.

Introducing the scenario of meat productivity growth, slaughtering, price policy and managing the land use change to the model is the most effective in reducing the greenhouse gas (GHG) emission as compared to the other policy scenarios. Under this policy scenario, the greenhouse gas emission has reached 1.6 and 1.8 gigatons of CO_2-eq in 2030 and 2040, respectively. This is because improving feed quality and supplementation, and thus meat productivity growth, has the potential to reduce direct emissions (Andeweg & Reisinger, 2014; Caro, Kebreab, & Mitloehner, 2016; Ericksen & Crane, 2018; FAO, 2019; FDRE, 2020). On the other hand, balancing the stock of livestock through slaughtering could also lessen potential emissions from livestock, and consequently, greenhouse gas emissions (Liu et al., 2022) and land use and degradation management, which eradicates indirect emissions, are also policy options for reducing greenhouse gas emissions (Alemu, 2015).

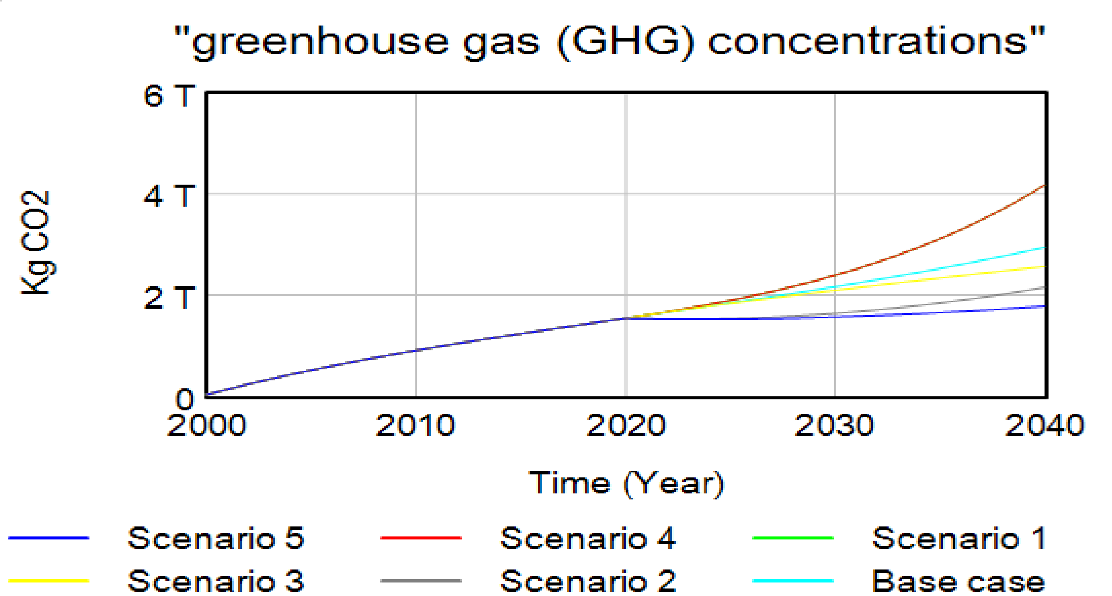


Figure 17: Greenhouse gas (GHG) concentrations under different policy scenarios

The indirect emission contributed through land use change has also a considerable contribution to greenhouse gas (GHG) concentrations. Thus, the effect of the land management policy scenario has also shown better results in reducing greenhouse gas (GHG) emissions. The emission level has attained 2.15 gigatons CO_2-eq in 2040 under this policy scenario. Ravi, Shaw, Boulenger, and Neto (2023) agree that sustainable grazing systems and land use practices should be taken into account to lessen the negative effects on the environment and lower greenhouse gas emissions in the livestock industry.

The rising demand for livestock products, particularly in sub-Saharan Africa, is implying that livestock expansion and output supply will continue to rise (Mario Herrero et al., 2009; Philip K. Thornton, 2010). This growth contributes to poverty reduction, improved livelihood, and nutrition (FAO, 2009b). However, the expansion of livestock and increased production has negative environmental consequences, particularly the increase in greenhouse gas emissions (Steinfeld et al., 2006). This has revealed that there is a compromise between production and greenhouse gas (GHG) emission levels. The direct relationship between production growth and negative environmental problems in the sector fuels concerns about sectoral management for a sustainable environment. Better and more efficient sector management is required for increased contributions to food and income growth while also reducing the influence on the environment (Enahoro et al., 2019; Otte et al., 2019; Qi, Xin, John, Groisman, & Chen, 2017; Raney, Skoet, & Steinfeld, 2009a). The comparison of the number of livestock, production growth, value of livestock, and greenhouse gas emissions under various scenarios relative to the base case is shown in the following figure.

Table 4: Summary of the growth/reduction in the values of the main variables for different scenarios from the base case

	Years	**Livestock (in mill)**	**Meat supply (in the bill)**	**Total livestock value (in trill)**	**Greenhouse gas (GHG) concentrations (in trill)**
Base case	2020	52.43	3.54	5.65	1.54
	2030	80.79	8.71	8.92	2.17
	2040	124.28	13.39	19.95	2.94
		Growth/reduction in relation to the base case (%)			
Scenario 1	2030	45.69	154.29	46.77	10.43
	2040	112.52	270.95	72.88	41.76
Scenario 2	2030	-	-	-	-24.34
	2040	-	-	-	-26.88
Scenario 3	2030	-18.62	42.06	15.77	-3.29
	2040	-34.17	14.91	5.94	-12.76
Scenario 4	2030	45.69	154.29	54.09	10.43
	2040	112.52	270.95	81.51	41.76
Scenario 5	2030	-18.62	42.06	21.55	-27.63

2040	-34.17	14.91	11.23	-39.64

As demonstrated in the table above the growth and reduction of the values of the main variables are compared to the base case growth in values. The greenhouse gas (GHG) concentrations have shown a reduction under land use management policy, meat productivity with slaughter and a combination of all the scenarios with the reduction of 26.88%, 12.76% and 39.64% in 2040 as compared to the base case during the same year.

On the other hand, the production growth in meat has also progressed under all the scenarios except with no change in the land use change management policy. The largest meat supply is attained under the meat productivity growth scenario and so under meat productivity growth with price policy. The result has shown a growth of 270.95% as compared to the base case in 2040. About 14.9% growth in the meat supply has been recorded under meat productivity growth with slaughter and combined policy scenarios as compared to the base case in 2040.

The production of livestock, as indicated by meat supply, has primarily increased under the two scenarios. Meat productivity growth through improved feed quality and supply, as well as the introduction of a price policy to productivity growth, which also increases the estimated livestock value, are two scenarios that have a substantial effect on meat supply. However, this increase in production is not environmentally sustainable because it is not accompanied by a reduction in greenhouse gas emissions.

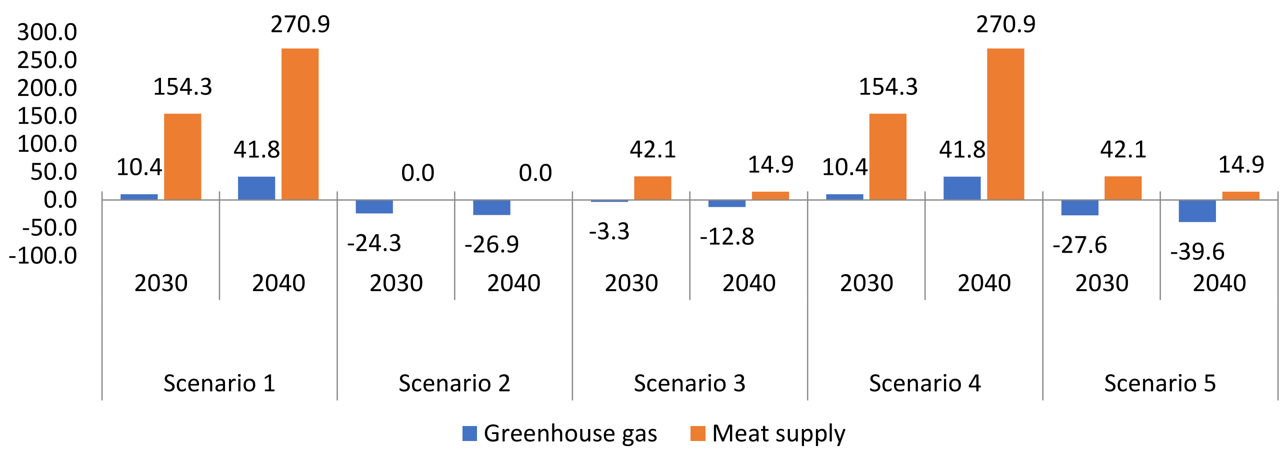


Figure 18: Production (meat supply) and greenhouse gas growth from the base case

Greenhouse gas reduction has been relatively achieved through land use management, meat productivity growth with slaughter, and the combination of all policy scenarios.

Livestock expansion is one of the leading causes of land degradation, which results in environmental changes and greenhouse gas emissions in Ethiopia (Kindu, Schneider, Teketay, & Knoke, 2015). As also suggested by Mekuria et al. (2018) and Kimball (2011) better resource management and land use could be better policy choices, to mitigate the negative environmental consequences of the livestock industry.

Under a scenario of managing the indirect emissions caused by land degradation has the potential to reduce greenhouse gas emissions by up to 27% from the baseline. However, this has been accomplished with no change in production and with a lower reduction in emissions than the sector's potential.

The scenario that incorporates meat productivity growth while also increasing slaughters to balance the potential stock that could produce emissions yields better outcomes in decreasing emissions while also increasing production. Activating this scenario would lead to the growth of meat by 42% and 15% than achieved in the base case in 2030 and 2040, respectively. Improved feed that matches livestock nutrient requirements could lead to more efficient and sustainable meat production (Rotz, 2020). Additionally, a synergy of increasing the quantity and quality of feed and preserving land use could increase output and productivity while also promoting an environmentally friendly production system (Mekasha, Gerard, Tesfaye, Nigatu, & Duncan, 2014). The potential emission reduction is also 3.3% and 13% than attained under the base case in 2030 and 2040, respectively.

The scenario that incorporates all of the policy cases from the tested scenarios can be regarded as an effective policy scenario because it achieves the greatest possible reduction in greenhouse gas emissions while also increasing the meat supply over the baseline. In comparison to the base case in 2040, this policy scenario results in about 40% greenhouse gas emissions and a 15% increase in the supply of meat. Amsalu and Addisu (2014); (Mekuria et al., 2018) and Tolera and Abebe (2007) has also support that increasing the quantity and quality of forage while lowering the mean number of livestock holding as well as sustainable land management could address the sector's environmental problems.

Chapter Six

6. Conclusion and policy implications

6.1. Conclusion

In Ethiopia, the livestock sector has significant social and economic advantages for households and the country (Boka, 2020; NBE, 2021; World Bank, 2017). However, the growing livestock production driven by rising demand has various negative environmental implications. The industry contributes directly to the increased carbon footprint through manure and enteric fermentation, as well as indirectly through land use change and degradation. Accounting only for direct emissions, the sector is responsible for more than 65% of agriculture and 36% of all national emissions (FAO, 2020b; Kimball, 2011).

The study's goal is to model the interactions between livestock and the environment, with a focus on how that interaction affects the carbon footprint. Furthermore, the study intends to test alternative policies for sector production growth and environmental sustainability. A system dynamics model was used to simulate and capture the dynamics and interactions of the livestock industry and the environment. A simulation model is also used to analyse and examine the prospects of various policy implementations. The simulated results revealed that the model's main variables were sensitive to changes in feed quality and supply, slaughtering, land use change, and product price.

In the current phase of production activities, livestock population and greenhouse gas emissions would reach 124 million tropical livestock units and 3 gigatons CO_2-eq by 2040, respectively. The estimated livestock value and meat supply would also be 13 million tons and 20 trillion birrs by 2040, respectively.

Furthermore, the model was tested against various scenarios to determine the best production system for increasing output while lowering greenhouse gas (GHG) emissions. Scenarios such as land use management, meat productivity growth, meat productivity growth with slaughter, and price policy, as well as their combinations, have all been considered. Higher meat production and value are recorded in the scenario of increased meat productivity through improved feed quality and consumption, as well as price policy implementation. Land use management, increased meat productivity, and, on the other hand, increased slaughter are all effective policies for lowering greenhouse gas emissions.

The combination of all the policies, including increased meat productivity due to better feed quality and quantity, improved land use management, increased slaughter, and price policy, has been identified as a leverage policy scenario. The policy is the better choice for increasing the supply and value of meat while reducing greenhouse gas emissions. According to this policy scenario, the amount of meat produced and its value both reach 15 million tons and 22 trillion birrs in 2040, respectively, representing increases of 15% and 11% from the base case for the same year. On the other hand, greenhouse gas emissions will reach 1.6 ad 1.8 gigatons CO_2-eq emission in 2030 and 2040. As compared to the base case, this value has shown a decrement of 28% and 40%, respectively, in the same year.

6.2. Policy implications

The study investigates the growth and expansion of livestock production, as well as the implications on the carbon footprint of the sector. Several policy simulations under different scenarios have been run to test and identify better production systems in the sector.

Some policy scenarios typically offer higher growth of meat and livestock value than the other scenarios. However, when all of the policy scenarios are combined, a more sustainable production system is achieved. Thus, the study suggests taking into account improving meat productivity levels through increasing feed quality and supplementation, increasing livestock slaughter, implementing the price policy under well-managed value chains, and improving the grazing land use management to increase the production growth of meat and its value on the one hand, and to decrease greenhouse gas emissions on the other.

6.3. Limitations and further research

The main limitation of the study was its aggregate analysis of the livestock industry at the country level, which might not explore and examine the peculiarities of the production system in different agricultural settings. As a result, the report will recommend more investigation on the country's lower-case studies. The analysis also fails to account for the outputs' value chains, distribution and marketing networks. Thus, further research into livestock output distribution and marketing has been proposed. The quality of the meat produced is presumed to be up to standard in the study, which likewise requires more evaluation. Further research is also necessary into the production, gathering, and marketing of the leather industry. The study was also limited in its inclusion of the dynamics of land use change and its interaction with livestock production. Further research is also required to gain more policy insights into its management.

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Appendices

Appendix A: Model equations, values and units

1. agricultural household = fraction of agricultural household*household
   Units: Household
2. average feed consumption per unit = normal average feed consumption per units*effect of temperature on feed consumption per unit
   Units: Kg/(Year*TLU)
3. average household size = 5
   Units: Person/Household
4. average meat demand per capita= SIMULTANEOUS (average meat per capita consumption*effect of income on demand*effect of price on demand*effect of population on demand, 5.3)
   Units: Kg/Person
5. average meat per capita consumption = 5.3
   Units: Kg/Person
6. average weighted feed quality = 0.9079
   Units: Dmnl
7. birth rate = normal birth rate*effect of feed consumption on birth rate
   Units: 1/Year
8. births = birth rate*livestock
   Units: TLU/Year
9. crop residue = cultivated land*crop residue produced per cultivated land
   Units: Kg/Year
10. crop residue produced per cultivated land = 2000
    Units: Kg/Hectare/Year
11. cultivated land = total land area*fraction of cultivated land
    Units: Hectare
12. death rate = normal death rate*effect of feed consumption on death rate*effect of disease prevalence on death rate
    Units: Dmnl/Year
13. deaths = death rate*livestock
    Units: TLU/Year
14. desired feed consumption per unit = 2280
    Units: Kg/(Year*TLU)
15. disease prevalence = minimum disease prevalence*effect of temperature on disease prevalence
    Units: Dmnl

16. effect of consumption available on meat productivity= WITH LOOKUP (relative feed consumption, ([(0,0)-(10,10)],(0,0),(0.483,1),(0.5,1.03525),(0.7,1.16414),(0.75,1.40985),(1,1.8798)))
Units: Dmnl
17. effect of disease prevalence on death rate = WITH LOOKUP (relative disease prevalence, ([(0,0)-(10,10)],(0,1),(1,1),(1.25,1.058),(1.5,1.1075),(1.67,1.233),(2.167,1.6)))
Units: Dmnl
18. effect of disease prevalence on meat productivity = WITH LOOKUP (relative disease prevalence, ([(0,0)-(10,10)],(0,1.0229),(0.504,1.01156),(1,1),(1.2605,0.987),(1.68,0.98),(2.1849,0.977)))
Units: Dmnl
19. effect of feed consumption on birth rate = WITH LOOKUP (relative feed consumption,([(0,0)-(10,10)],(0,0),(0.33,0.71945),(0.43,0.8846),(0.87,0.984),(1,1),(1.75,1.21),(2,1.333)))
Units: Dmnl
20. effect of feed consumption on death rate= WITH LOOKUP (relative feed consumption, ([(0,0)-(10,10)],(0,1.4194),(0.25,1.3821),(0.433428,1.36932),(0.764873,1.32955),(0.886686,1.30682),(1,1)))
Units: Dmnl
21. effect of greenhouse gas (GHG) on temperature= WITH LOOKUP (greenhouse gas (GHG) concentrations/reference greenhouse gas (GHG) concentrations, ([(0,0)-(10,10)],(1,0.926),(1.50942,0.9372),(2.27834,0.9484),(3.43898,0.9596),(5.19083,0.9708)))
Units: Dmnl
22. effect of income on demand = EXP(income elasticity*LN(income per capita/reference income))
Units: Dmnl
23. effect of meat demand-supply ratio on price= WITH LOOKUP (meat demand-supply ratio, ([(0,0)-(10,10)],(0.0066578,1),(0.0946,1.20455),(0.21875,2.9167),(0.375,5)))
Units: Dmnl
24. effect of meat demand-supply ratio on slaughter rate= WITH LOOKUP (meat demand-supply ratio, ([(0,0)-(10,10)],(0.0946,1),(0.3321,1.02273),(0.634373,1.07386),(1.14448,1.30114),(2,1.45)))
Units: Dmnl
25. effect of population on demand= WITH LOOKUP (population/reference population, ([(0,0)-(10,10)],(0,0),(0.329603,0.227273),(0.7733,0.409091),(1.17897,0.590909),(1.7114,0.681818),(2.07904,0.909091),(2.54809,1.21212),(3.23265,1.43939),(3.87918,1.69697),(4.475,3.396)))
Units: Dmnl

26. effect of price on demand= EXP(-price elasticity*LN(meat price/minimum average meat price))
Units: Dmnl
27. effect of productivity on per unit enteric methane emission= WITH LOOKUP (relative meat productivity, ([(0,0)-(10,10)],(0.93529,1.53788),(0.988,1.32375),(1.03429,1.32576),(1.10653,1.32576),(1.34467,1.30303),(1.8798,1.378)))
Units: Dmnl
28. effect of temperature on disease prevalence= WITH LOOKUP (relative temperature,([(0,0)-(10,10)],(0,0.3706),(0.2768,0.504),(0.926,1),(0.940548,1.51136),(0.9708,2.185)))29
Units: Dmnl
29. effect of temperature on feed consumption per unit= WITH LOOKUP (relative temperature, ([(0,0)-(10,10)],(0,1.01818),(0.404533,1.01364),(0.926,1),(0.9372,1),(0.9708,0.97)))
Units: Dmnl
30. effect of temperature on feed density = WITH LOOKUP (relative temperature, ([(0,0)-(10,10)],(0.6,1.0968),(0.72,1.08),(0.88,1.05),(1,1),(1.12,0.8544),(1.2,0.90316)))
Units: Dmnl
31. effect of temperature on meat productivity= WITH LOOKUP (relative temperature, ([(0,0)-(10,10)],(0,0.9037),(0.926,1),(0.9484,0.954),(0.9596,0.9817),(0.9708,0.968)))
Units: Dmnl
32. effect of temperature on water required per units= WITH LOOKUP (relative temperature, ([(0,0)-(10,10)],(0,1),(0.926,1),(0.9596,1.06),(0.9708,1.1)))
Units: Dmnl
33. emission disposal= greenhouse gas (GHG) concentrations /time to dispose emission
Units: Kg CO_2/Year
34. emission growth= enteric methane emission + manure emission + grazed land*grazed land emission factor + forest land converted to grazing land*land use change emission factor
Units: Kg CO_2/Year
35. enteric methane emission= livestock*enteric methane emission per unit
Units: Kg CO_2/Year

36. enteric methane emission per unit= normal enteric methane emission per unit*effect of productivity on per unit enteric methane emission
Units: Kg CO_2/(Year*TLU)
37. feed available= INTEG (feed production-feed consumption,5.12837e+10)
Units: Kg
38. feed available per units= feed available/livestock

Units: Kg/TLU

39. feed consumption= livestock*average feed consumption per unit
    Units: Kg/Year
40. feed density=minimum feed density*effect of temperature on feed density
    Units: Kg/(Year*Hectare)
41. feed production= crop residue*fraction of crop residue used for feed + grazing land*feed density + supplement feed
    Units: Kg/Year
42. forest land= total land area*fraction of forest land
    Units: Hectare
43. forest land converted to grazing land= forest land*fraction of land converted to grazing land
    Units: Hectare
44. fraction of agricultural household= 0.614
    Units: Dmnl
45. fraction of crop residue used for feed= 0.6
    Units: Dmnl
46. fraction of cultivated land= 0.15
    Units: Dmnl
47. fraction of forest land= 0.122
    Units: Dmnl
48. fraction of grazed land= 0.23
    Units: Dmnl
49. fraction of grazing land= 0.18
    Units: Dmnl
50. fraction of land converted to grazing land= 0.00089
    Units: Dmnl
51. fraction of water used for livestock= 0.345
    Units: Dmnl
52. grazed land= grazing land*fraction of grazed land
    Units: Hectare
53. grazed land emission factor= 15310
    Units: Kg CO2/Hectare/Year
54. grazing land= total land area*fraction of grazing land + forest land converted to grazing land
    Units: Hectare
55. greenhouse gas (GHG) concentrations= INTEG (emission growth-emission disposal, 3.66331e+10)
    Units: Kg CO2
56. household= population/average household size
    Units: Household

57. income elasticity= 0.933
    Units: Dmnl
58. income per agricultural household= total livestock value/agricultural household
    Units: ETB/Household
59. income per capita: RAW
    Units: ETB/Person
60. land use change emission factor= 38300
    Units: Kg CO2/Hectare/Year
61. leather= livestock*leather per unit
    Units: Kg
62. leather per unit= 17
    Units: Kg/TLU
63. leather price= 10
    Units: ETB/Kg
64. leather value= leather*leather price
    Units: ETB
65. livestock= INTEG (births-deaths-slaughter, 2.06846e+07)
    Units: TLU
66. livestock density= livestock/grazing land
    Units: TLU/Hectare
67. livestock unit per agricultural household= livestock/agricultural household
    Units: TLU/Household
68. manure emission= livestock*per unit manure emission
    Units: Kg CO2/Year
69. meat demand-supply ratio= average meat demand per capita/meat supply per capita
    Units: Dmnl
70. meat price= minimum average meat price*effect of meat demand-supply ratio on price
    Units: ETB/Kg
71. meat productivity= average weighted feed quality*effect of disease prevalence on meat productivity*effect of consumption available on meat productivity*effect of temperature on meat productivity*normal average weighted meat productivity
    Units: Kg/TLU
72. meat supply= livestock*meat productivity
    Units: Kg
73. meat supply per capita= meat supply/population
    Units: Kg/Person
74. meat supply per household= meat supply/household
    Units: Kg/Household
75. meat supply value= meat supply*meat price
    Units: ETB
76. minimum average meat price= 320

Units: ETB/Kg

77. minimum disease prevalence= 0.1785
    Units: Dmnl
78. minimum feed density= 1580
    Units: Kg/(Year*Hectare)
79. net population growth rate= 0.03
    Units: Dmnl/Year
80. normal average feed consumption per units= 1596
    Units: Kg/(Year*TLU)
81. normal average weighted meat productivity= share of improved breeds*normal improved breed meat productivity+(1-share of improved breeds)*normal indigenous breed meat productivity
    Units: Kg/TLU
82. normal birth rate= 0.22
    Units: Dmnl/Year
83. normal death rate= 0.067
    Units: Dmnl/Year
84. normal enteric methane emission per unit= 1288
    Units: Kg CO2/(Year*TLU)
85. normal improved breed meat productivity= 156
    Units: Kg/TLU
86. normal indigenous breed meat productivity= 108
    Units: Kg/TLU
87. normal slaughter rate= 0.019
    Units: Dmnl/Year
88. normal temperature= 25
    Units: C
89. normal water required per units= 9125
    Units: Liter/TLU/Year
90. per unit manure emission= 53.2
    Units: Kg CO2/TLU/Year
91. population= INTEG (population growth, 6.70319e+07)
    Units: Person
92. population growth= population*net population growth rate
    Units: Person/Year
93. price elasticity= 0.733
    Units: Dmnl
94. reference greenhouse gas (GHG) concentrations= 3.66331e+10
    Units: Kg CO2
95. reference income= 5576.85
    Units: ETB/Person

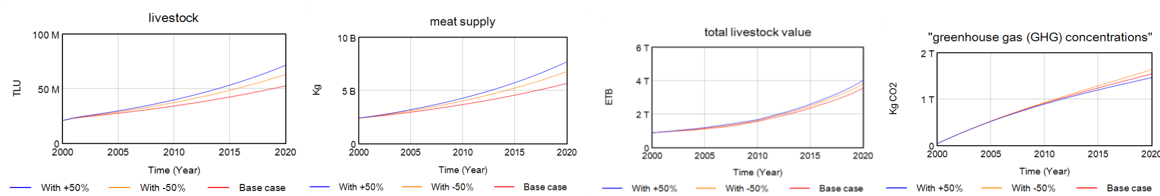
96. reference population= 6.70319e+07
Units: Person
97. relative disease prevalence= disease prevalence/minimum disease prevalence
Units: Dmnl

98. relative feed consumption= average feed consumption per unit/desired feed consumption per unit
Units: Dmnl
99. relative meat productivity= meat productivity/normal average weighted meat productivity
Units: Dmnl
100. relative temperature= temperature/normal temperature
Units: Dmnl
101. share of improved breeds= 0.022
Units: Dmnl
102. slaughter= livestock*slaughter rate
Units: TLU/Year
103. slaughter rate= normal slaughter rate*effect of meat demand-supply ratio on slaughter rate
Units: 1/Year
104. supplement feed= 6.1416e+07
Units: Kg/Year
105. temperature= normal temperature*"effect of greenhouse gas (GHG) on temperature
Units: C
106. time to dispose emission= 15
Units: Year
107. total land area= 1.1043e+08
Units: Hectare
108. total livestock value= leather value + meat supply value
Units: ETB
109. water available= INTEG (water production-water consumption, 6.9e+11)
Units: Liter
110. water available per unit= water available/livestock
Units: Liter/TLU
111. water consumption= livestock*water required per units
Units: Liter/Year
112. water production= water supply*fraction of water used for livestock
Units: Liter/Year

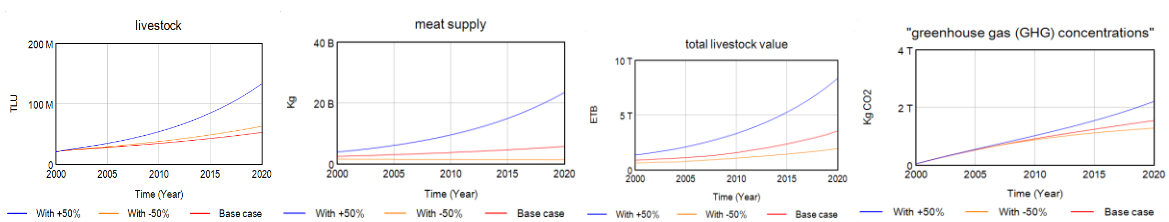
113. water required per units= normal water required per units*effect of temperature on water required per units
Units: Liter/(Year*TLU)
114. water supply= 1.85e+12
Units: Liter/Year

Appendix B: Sensitivity results of selected parameters

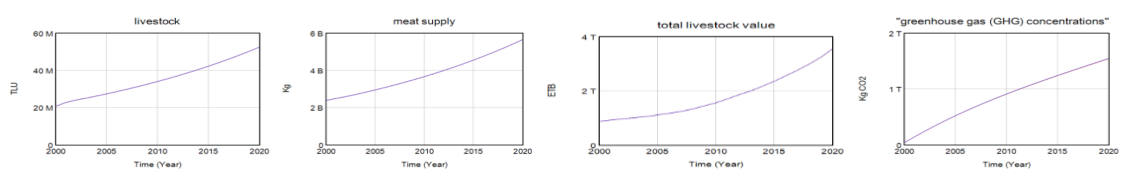
a. The sensitivity analysis of livestock, meat supply, total livestock value with the slaughter rate (sensitive to all)



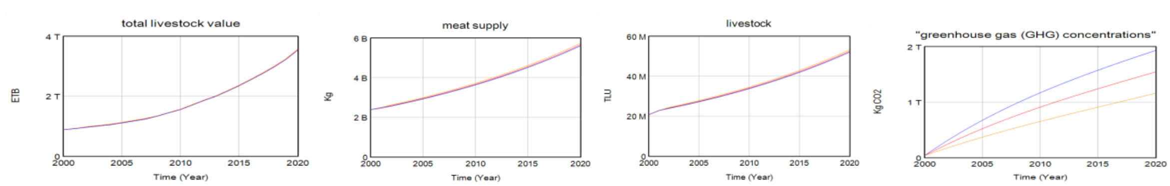
b. The sensitivity analysis of livestock, meat supply, total livestock value with the feed consumption per capita (sensitive to all)



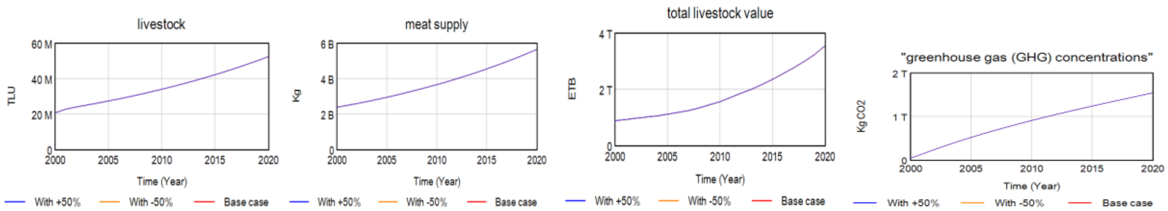
c. The sensitivity analysis of livestock, meat supply, total livestock value with the feed fraction of converted land (not sensitive at all)



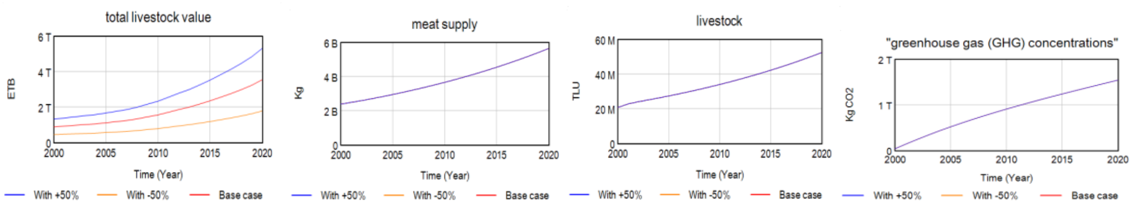
d. The sensitivity analysis of livestock, meat supply, total livestock value with the fraction of grazed land (not sensitive except for greenhouse gas)



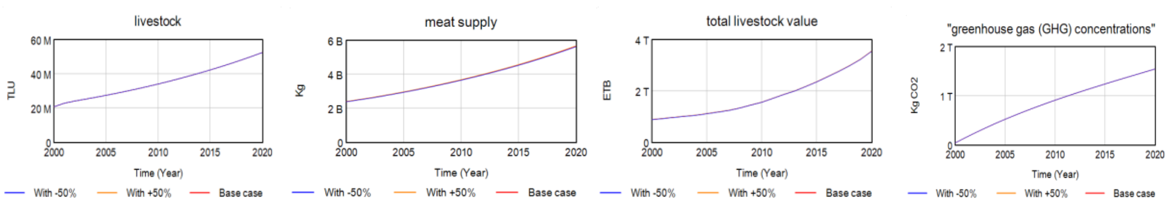
e. The sensitivity analysis of livestock, meat supply, total livestock value with the leather price (not sensitive at all)



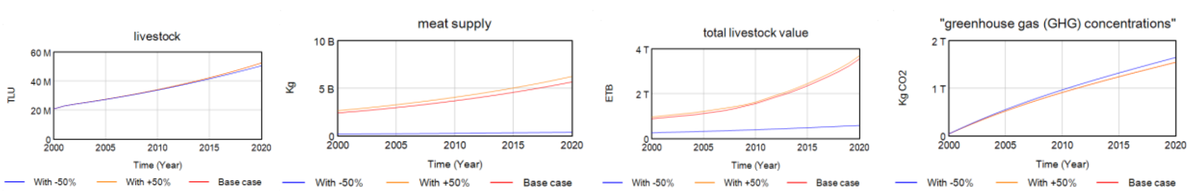
f. The sensitivity analysis of livestock, meat supply, total livestock value with the meat price (not sensitive except for total livestock value)



g. The sensitivity analysis of livestock, meat supply, total livestock value with the breed (not sensitive at all)



h. The sensitivity analysis of livestock, meat supply, total livestock value with the feed quality (sensitive to meat supply, total livestock value and greenhouse gas (GHG))



i. The sensitivity analysis of livestock, meat supply, total livestock value with the prevalence of disease (not sensitive at all)