Food and Agriculture Organization of the United Nations

UNDP

Building resilience in the Egyptian livestock subsector

Climate change impacts and scaling up solutions

Building resilience in the Egyptian livestock subsector

Climate change impacts and scaling up solutions

Prepared by

Mohamed Abdel Monem,
International Consultant for climate change and rural development

Krystal Nicole Crumpler,
Food and Agriculture Organizationof the United Nations, Rome

Fatma Abouzeid
Food and Agriculture Organizationof the United Nations, Cairo

Published by
Food and Agriculture Organization of the United Nations
Cairo, 2025

Required citation:
Abdel Monem, M., Crumpler, K.N. & Abouzeid, F. 2025. *Building resilience in the Egyptian livestock subsector – Climate change impacts and scaling up solutions.* Cairo, FAO. https://doi.org/10.4060/cd4914en

ISBN 978-92-5-139717-6 [FAO]

Contents

Figures

Tables

Boxes

Foreword

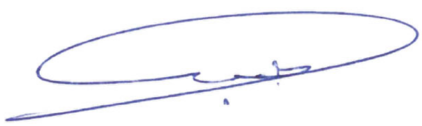
Livestock has been an integral part of Egypt's agricultural system for millennia, providing essential nutrition, livelihoods, and economic security for millions of rural households. Today, as climate change poses unprecedented challenges to food systems globally, Egypt's livestock sector stands at a critical juncture that demands urgent attention and innovative solutions.

The impacts of climate change on livestock production in Egypt are already apparent and are expected to escalate further. Rising temperature and their cascading impacts pose significant challenges to animal health, reproduction, and productivity, while also jeopardizing the availability and quality of feed resources. At the same time, the livestock sector is a notable contributor to greenhouse gas emissions, presenting a complex challenge that necessitates balancing the pressing demands of food security with the imperative of environmental sustainability.

This comprehensive report arrives at a crucial moment, offering valuable insights into the current state of Egypt's livestock sector and presenting practical, climate-smart solutions that can enhance resilience while reducing environmental impact. Through detailed analysis and extensive field research across six governorates, it provides evidence-based recommendations for transforming livestock practices to meet the triple challenge of increasing productivity, adapting to climate change, and reducing emissions.

A key strength of this report lies in its focus on practical, market-driven solutions that engage the private sector. From innovative feed production technologies to renewable energy applications in livestock farming, it presents concrete opportunities for businesses to invest in climate-smart livestock (CSL) practices. These opportunities not only promise environmental benefits but also offer compelling economic returns that can drive sustainable transformation of the sector.

The findings and recommendations presented here align closely with FAO's commitment to supporting sustainable food systems and climate action. They provide a roadmap for policymakers, investors, and practitioners to implement climate smart livestock (CSL) practices that can enhance food security and resilience of the livestock sector while contributing to Egypt's climate commitments under the Paris Agreement.



Assistant Director-General

Regional office for the Near East and North Africa

Acknowledgements

This report, titled **"Building resilience in the Egyptian livestock subsector: Climate change impacts and scaling up solutions",** was developed by Mohamed Abdel Monem (Senior Climate Change and Rural Development), Krystal Nicole Crumpler (FAO office of Climate Change, Biodiversity and Environment), and Fatma Abouzeid (FAO Egypt). This work is part of the Scaling up Climate Ambition on Land Use and Agriculture through nationally determined contributions and National Adaptation Plans (SCALA), program, a joint FAO-United Nations Development Programme (UNDP) initiative funded by the German Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection (BMUV) through the International Climate Initiative (IKI). The project addresses climate challenges and promotes resilience within agricultural and land-use sectors.

The authors extend their heartfelt gratitude to The Ministry of Agriculture and Land Reclamation (MoALR) of Egypt and the local authorities for their invaluable support in facilitating the field visits, surveys, and group discussions. Special thanks are due to the dedicated individuals and entities who manage and operate the livestock and dairy production farms in the governorates of Beni Suef, Menya, Suhag, Behera Monofya, and Sharqia. Their cooperation and assistance were crucial to the successful completion of this report.

The authors would like to express their deep appreciation to Dcode Economic and Financial Consulting Company (Dcode EFC) for their pivotal role in executing this study. Their expertise and dedication have been invaluable in shaping the research. Additionally, we extend our sincere gratitude to Fidaa Haddad (FAO Regional Office for Near East and North Africa), Mohamed Yaqoub (FAO Egypt), Adel Gohar (Cairo University), Aly El Sherei and Mohamed Yousef (Dcode EFC), Climate Vision Consulting Company and Cairo Center for Development Benchmarking (CBD) for their outstanding contributions and unwavering support throughout the study.

Abbreviations

AI	artificial insemination
BMUV	German Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection
BSDA	Bioenergy for Sustainable Development Association
CAPMAS	Central Agency for Public Mobilization and Statistics
CSA	climate-smart agriculture
CSL	climate-smart livestock
FAO	Food and Agriculture Organization of the United Nations
FMD	foot-and-mouth disease
GDP	gross domestic product
GHG	greenhouse gas
IPCC	Intergovernmental Panel on Climate Change
IRR	internal rate of return
LSD	lumpy skin disease
MoALR	Ministry of Agriculture and Land Reclamation (Egypt)
NDC	nationally determined contribution
OECD	Organization for Economic Co-operation and Development
RCP	representative concentration pathways
RVF	Rift Valley fever
SCALA	Scaling up Climate Ambition on Land Use and Agriculture
SHARP+	Self-evaluation and Holistic Assessment of Climate Resilience of Farmers and Pastoralists
THI	temperature-humidity index
UNDP	United Nations Development Programme
USD	united states dollar
WOAM	World Organization of Animal Health

Chemical formulae and units of measurement

kg	kilogram
kgCO_2eq	kilograms of carbon dioxide equivalent
GtCO_2eq	gigatonnes of carbon dioxide equivalent
Gg CO_2e	gigagrams of carbon dioxide equivalent
Mt	metric tonnes
CH_4	methane
CO_2	carbon dioxide
kg/ha	kilograms per hectare
kg/year	kilograms per year
kg/cm^2	kilograms per square centimeter
W	watt

Executive summary

The livestock sector is a cornerstone of Egypt's agricultural economy, contributing approximately 37.5 percent of the country's total agricultural production value. It plays a vital role in food security, providing essential nutritional products such as milk and meat, while also supporting the livelihoods of millions of smallholder farmers and rural families. However, this sector is facing increasing threats from climate change, which is exacerbating existing vulnerabilities and creating new challenges. In light of these developments, this report, provides an in-depth analysis of the current state of livestock production in Egypt, the impacts of climate change, and potential strategies to build resilience by scaling up climate-smart livestock (CSL) practices.

The primary objective of this study is to enhance the resilience of Egypt's livestock subsector to climate change by identifying and promoting the implementation of climate-smart practices. More specifically, the study aims to assess the current livestock practices, evaluate the challenges posed by climate change, and explore the role of livestock in both contributing to and being affected by climate change. Additionally, the report seeks to identify practical adaptation and mitigation measures that can transition Egypt's livestock sector toward more sustainable and resilient pathways. A key focus is on developing a roadmap for private sector engagement, outlining opportunities for investment and collaboration to scale up CSL practices across the country.

The study employed a mixed-methods approach that combined both primary and secondary data sources. The Self-evaluation and Holistic Assessment of Climate Resilience of Farmers and Pastoralists (SHARP+), a comprehensive tool developed by the Food and Agriculture Organization (FAO), was utilized to gather detailed insights from livestock farmers across six key governorates: Behera, Monofya, Sharqia, Beni Suef, Menya, and Suhag. These governorates collectively account for approximately 50 percent of Egypt's total livestock population. Data was collected from 1036 participants, providing a robust snapshot of the socioeconomic and environmental factors influencing the resilience of livestock farming systems in Egypt. The SHARP+ tool allowed the research team to assess vulnerabilities at both the household and community levels while identifying opportunities for targeted interventions to enhance the resilience of smallholder farmers.

The findings of this study highlight the significant economic value of the livestock subsector in Egypt. Livestock production contributes approximately USD 8 billion annually to the national economy, with cattle and buffaloes being the primary sources of milk and meat. Egypt produces roughly 6 million tonnes of milk and 0.5 million tonnes of meat each year, making livestock an essential component of the country's food supply. Over 1.8 million households are engaged in livestock farming, and for many of these rural families, livestock is not only a source of income but also a form of financial security. In times of economic hardship or climate-induced shocks, livestock serves as a critical safety net, providing households with a buffer against food insecurity and income loss.

However, the livestock sector is highly vulnerable to the impact of climate change. Rising temperatures, erratic rainfall patterns, and an increasing prevalence of livestock diseases are already affecting productivity and threatening the livelihoods of millions of smallholder farmers. Heat stress, for example, is projected to reduce livestock productivity by 10–25 percent globally by 2050, with losses in tropical regions, including Egypt, potentially exceeding 30 percent. In Egypt, heat stress is leading to lower milk yields, reduced meat production, and a decline in reproductive success, particularly during the summer months. Conception rates for dairy cows can drop by as much as 20–27 percent during periods of extreme heat, further compounding the challenges faced by farmers.

Feed and water availability are also major concerns. Climate change is expected to reduce global feed crop yields by 10–20 percent, which will have severe implications for Egypt's livestock sector, given the country's heavy reliance on imported feed. Water scarcity is another significant issue, particularly in Upper Egypt, where rainfall is minimal, and water resources are increasingly strained by rising temperatures.
The SHARP+ survey revealed that 66 percent of livestock farmers in Egypt are engaged in smallholder farming systems, which are particularly vulnerable to these environmental stressors. Many smallholder farmers rely on crop–livestock integration to improve resilience, with 50 percent practicing partial integration and 38 percent engaging in full integration of their farming operations. However, the success of these systems is contingent on the availability of both water and feed, both of which are becoming increasingly scarce due to climate change.

In addition to being affected by climate change, the livestock sector is also a significant contributor to greenhouse gas (GHG) emissions. Globally, livestock production accounts for 26 percent of total GHG emissions from agri-food systems, with cattle and buffaloes responsible for the majority of these emissions. Within the livestock sector, beef production is particularly emissions-intensive, generating approximately 295 $kgCO_2eq$ per kilogram of protein produced. In comparison, chicken egg protein generates only 31 $kgCO_2eq$ per kilogram. The dairy sector also contributes significantly to global GHG emissions, with 1 kg of milk producing approximately 2.4 $kgCO_2eq$. In Egypt, the livestock sector's carbon footprint is expected to grow in the coming decades unless significant improvements in productivity and resource efficiency are made. Without intervention, livestock-related emissions could increase by 40 percent, reaching 9.1 $GtCO_2eq$ by 2050, which would account for up to 50 percent of total agri-food system emissions.

To address these challenges, this report identifies several CSL practices that can be implemented to enhance resilience and reduce emissions. One of the key interventions highlighted is improving animal feed production by utilizing agricultural waste, producing densified complete feed blocks, and promoting the cultivation of silage. These practices can help alleviate feed shortages and reduce dependency on imported feed, which is both costly and environmentally unsustainable. The report also highlights the potential of azolla, a nitrogen-fixing aquatic plant, as a viable nutritional supplement in animal feed. azolla has the potential to improve the nutritional quality of feed while reducing the need for synthetic inputs, thereby enhancing both economic and environmental sustainability.

Improved manure management and biogas production are also identified as crucial strategies for reducing methane emissions from livestock operations. By converting manure into biogas, farmers can reduce methane emissions while generating renewable energy for rural communities. This approach not only mitigates the environmental impact of livestock production but also provides farmers with an additional income stream. Another innovative solution is the integration of agrivoltaics – combining solar energy production with livestock farming. This approach offers multiple benefits, including reducing heat stress on animals by providing shade, generating clean energy for local communities, and creating new economic opportunities for farmers.

Breeding climate-resilient livestock through genetic selection and crossbreeding is another important strategy for building resilience in the sector. By selecting breeds that are more tolerant of heat stress and disease, farmers can improve the productivity and survival rates of their animals under increasingly challenging environmental conditions. The study also emphasizes the importance of exploring plant-based alternatives, particularly plant-based milk, as a way to reduce the environmental impact of dairy production. Plant-based milk has a lower carbon footprint and requires fewer resources than traditional dairy farming, making it a promising option for meeting the growing demand for sustainable food products.

The private sector has a critical role to play in scaling up these CSL practices. The study outlines several opportunities for private sector engagement, including investing in sustainable feed production, developing biogas and renewable energy solutions, and collaborating with smallholder farmers to implement innovative livestock management practices. The private sector can also play a key role in promoting financial products that incentivize farmers to adopt climate-smart technologies, such as low-interest loans or insurance products that reward sustainable farming practices.

To ensure the successful implementation of these CSL practices, the report recommends the development of a comprehensive strategy that includes policy support, capacity-building initiatives, and research and development. The government will need to play a central role in creating an enabling environment for the adoption of climate-smart practices, including providing subsidies for sustainable technologies and implementing regulatory frameworks that encourage private sector investment. Capacity-building programs will also be essential to equip farmers with the knowledge and skills needed to implement these practices effectively. Additionally, ongoing research into livestock genetics, feed production, and disease management will be critical to ensure that the sector remains resilient in the face of future climate shocks.

The report suggests roadmap for enhancing private sector engagement in Egypt's livestock sector focuses on creating a favorable environment for collaboration and investment in climate-smart practices. It emphasizes the need for supportive policies and regulatory frameworks, including clear guidelines, tax incentives, and simplified investment processes to encourage

private sector participation. Capacity building is also a key priority, with efforts to engage private enterprises in training farmers and producers on sustainable technologies, facilitating technology transfer, and fostering cooperative models that promote inclusivity, particularly for women and youth.

To drive private sector investment, the roadmap highlights financial incentives for projects such as biogas production, sustainable feed manufacturing, and agrivoltaics, while developing markets for climate-smart products through certification and branding. Sustainable financing mechanisms, such as blended financing models, international climate funds, and carbon market opportunities, are proposed to de-risk investments and expand access to credit for smallholder farmers and agribusinesses. Additionally, private companies are encouraged to participate in monitoring and evaluation processes, using measurable indicators and feedback systems to improve strategies and measure successful initiatives. Together, these measures aim to strengthen private sector engagement, fostering innovation and resilience in the livestock sector.

In conclusion, Egypt’s livestock sector is at a critical juncture. The impacts of climate change are already being felt, and without significant interventions, the sector’s long-term sustainability is at risk. However, by adopting climate-smart practices, improving resource efficiency, and engaging the private sector, Egypt’s livestock sector can enhance its resilience and continue to provide essential food and economic security for millions of people. The solutions outlined in this report offer a clear pathway toward a more sustainable and climate-resilient livestock sector, benefiting both farmers and the environment while contributing to global efforts to combat climate change.


3488
3468

CHAPTER 1. Objectives, approach and methodology

1.1 Objectives

Overall objective: To enhance Egypt's livestock sector resilience to climate change through the identification, promotion, and implementation of climate-smart practices, while fostering robust private sector participation.

The specific objectives of the study:

- Assess the current state and challenges of livestock practices in Egypt examining the impacts of climate change on livestock and the role of livestock as a driver of climate change.
- Identify and promote climate smart livestock (CSL) interventions identifying the economic feasible adaptation and mitigation measures that contribute to the transition towards resilient livestock sector in Egypt.
- Develop a comprehensive roadmap for implementation and opportunities for private sector engagement, outlining the necessary actions and possible prospects for including the private sector to adopt and implement climate-smart practices emphasizes engaging with local farmers and livestock producers to ensure practical and effective implementation.

1.2 Approach and methodology

To enhance climate-resilient livestock production in Egypt, this study is reviewing existing livestock practices, gather data from the field on key challenges focusing on climate change on livestock, engage stakeholders, and develop case studies. Scenario analysis and policy recommendations will guide sustainable transitions, while a private sector engagement strategy and comprehensive implementation roadmap will support the adoption of climate-smart practices, aiming to build a low-carbon agrifood system.

- This study employed a mixed-methods approach, integrating primary and secondary research data, including reports, studies, and government records. An integrated analysis was conducted to gain insights into the key elements of the production system, with a focus on opportunities for private sector engagement and investment in transformative climate action interventions. Qualitative data was gathered using SHARP +, facilitating the collection of in-depth insights from various stakeholders.

SHARP+ is a comprehensive tool developed to evaluate the resilience of farmers and pastoralists to climate change at the household level (FAO, 2022a). It uses a holistic approach, considering socioeconomic, environmental, and agronomic aspects of the farming system. The tool helps identify areas of weak resilience and provides a baseline for implementing changes to improve resilience. It also includes a participatory self-assessment component, allowing farmers to reflect on and prioritize aspects of their farming system that need improvement. It involves several steps:

- **Data collection:** Using a digital tablet application, data is collected on various aspects of the farming system and household. This includes socioeconomic factors, environmental conditions, and agronomic practices.

- **Resilience scoring:** The collected data is used to calculate resilience scores for different modules, providing a quantitative measure of the household's resilience.
- **Identifying vulnerabilities:** The tool helps identify specific vulnerabilities within the farming system, allowing for targeted interventions to strengthen resilience.
- **Participatory approach:** Farmers are involved in the assessment process, encouraging them to reflect on their practices and prioritize areas for improvement.
- **Baseline establishment:** The assessment provides a baseline against which future changes and improvements can be measured.

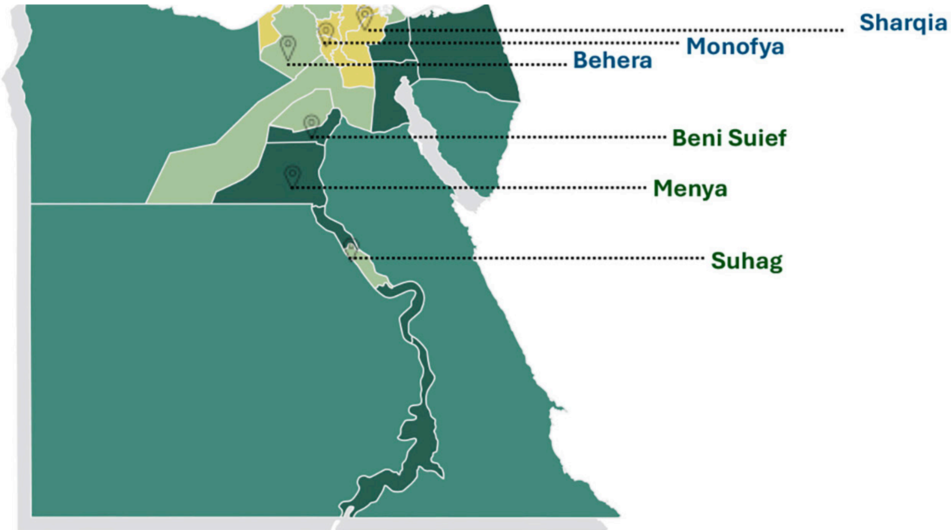
In this study, SHARP+ has been used to assess the socioeconomic and environmental drivers of vulnerability and climate risk in the livestock system in Egypt. This data is being used to establish the resilience levels of smallholder farmers, ultimately informing the development of local, transformative adaptation solutions. The suggested solutions focus on enhancing the resilience and adaptive capacities of smallholder farming communities facing climate shocks. The survey has encompassed key livestock and dairy production areas within six governates, collecting information and data from total of 1036 participants in the six governorates presented in figure 1, namely Behera, Monofya, Sharqia in the Nile Delta, and Beni Suief, Menya and Suhag in Upper Egypt (see Table 1). These governorates collectively account for approximately 50 percent of the nationwide livestock count, which stands at 4,239,838 according to Central Agency for Public Mobilization and Statistics (CAPMAS, 2021).

Table 1. Number of participants in the SHARP+ survey (October-November 2024)

Governorate	Nile Delta			Upper Egypt			Total
	Behera	Sharqia	Monofya	Menya	Beni Suief	Suhag	
Number	172	168	176	170	175	175	**1 036**

Source: Authors' elaboration.

Figure 1. **Egypt's map showing the surveyed six governorates**



Source: Adapted by the author **Nations Online Project.** n.d. *Political Map of Egypt*. Accessed February 6, 2025. https://www.nationsonline.org/oneworld/map/egypt_map.htm

Note: The boundaries and names shown and the designations used on this map do not imply the expression of any opinion whatsoever on the part of FAO concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers and boundaries.

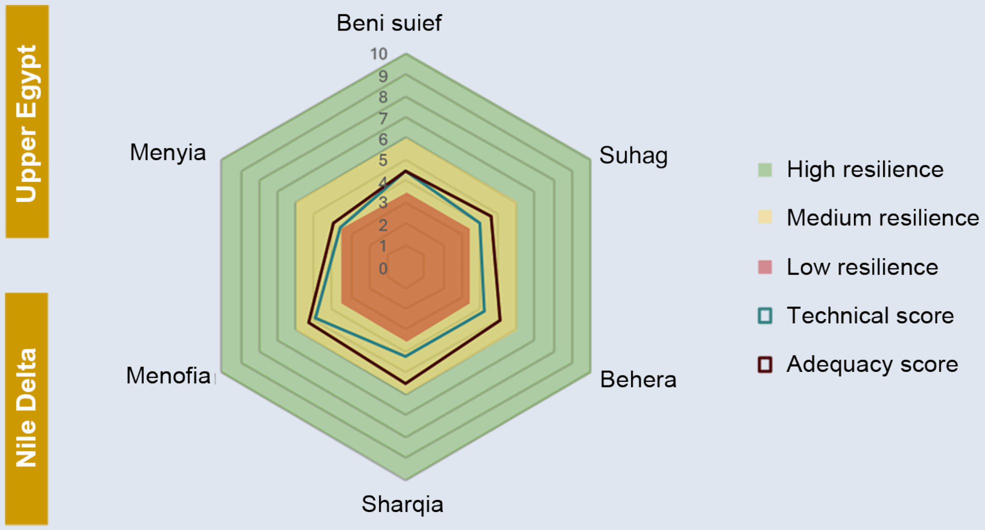
1.2.1 Characteristics of areas surveyed by SHARP+

The surveyed sample, entirely composed of individuals engaged in livestock farming, showcases a broad spectrum of agricultural practices. Crop production is the primary income source for 55 percent of participants, while 23 percent identify livestock as their main income source. The highest reliance on livestock income is observed in Monofya (30 percent) and the lowest in Menya (16 percent). Additionally, 66 percent of the sample operates smallholder livestock farms. Regarding production and commercialization, 31 percent of participants are involved in subsistence farming, 39 percent engage in small-scale production, and 30 percent target the local market. The level of crop–livestock integration varies, with 12 percent reporting no integration, 50 percent practicing partial integration, and 38 percent engaging in full integration. Notably, women represent 7 percent of the sample, and only 5.4 percent of participants are under 29 years old. Men account for 81 percent of the decision-makers in the surveyed group. Box 1 illustrate the degree of resilience indicated by the SHARP+ survey for the farming systems in the selected six governorates.

Box 1. Resilience of farming systems

Data collected through SHARP+ indicate that most respondents have an average compound resilience score of 9.2 out of 20, placing them within the medium resilience range. A closer analysis of the technical resilience scores reveals that, although only a few households practice intercropping, farmers generally consider their crops well-adapted to local conditions. Additionally, most households keep livestock, integrating both crops and livestock into their farming systems. This integration supports effective manure management, which is widely used for soil fertilization.

In assessing the resilience of farming systems across six selected governorates in Egypt, it is evident that the three governorates in Upper Egypt exhibit lower resilience compared to those in the Nile Delta region. Specifically, Menya has the lowest resilience values, while Sharqia boasts the highest resilience.



Source: **Johnston, S., Lepers, L. & Abdel Monem, M.** 2024. *Livestock and dairy farming households resilience: assessment report of livestock and dairy farming households, using the SHARP+ methodology (internal report)*. [Unpublished].

CHAPTER 2. Livestock production and management in Egypt: current practices, climate change challenges, and future directions

2.1 Supply and demand of the livestock sector: a global perspective

Livestock plays a crucial role in the economy of global food production, contributing approximately 40 percent of agricultural output in developed countries and 20 percent in developing countries (Organization for Economic Co-operation and Development "OECD" and FAO, 2017). It represents a vital economic sector, particularly in developing nations, where it supports the livelihoods of an estimated 1.7 billion people, with women comprising 70 percent of the workforce. Livestock serves as a source of income, capital, and risk insurance for many, particularly the poor, and can facilitate transitions to more prosperous livelihoods (Tarawali *et al.*, 2019). Globally, livestock contributes 40 percent to agricultural gross domestic product (GDP), reaching 53 percent in industrialized nations and ranging from 15 percent to 85 percent in developing countries (World Bank, 2020). This sector has experienced rapid growth in developing countries, averaging 2.5 percent annually over the past two decades.

Beyond its economic impact, livestock provides essential nutrients, particularly high-quality protein and micronutrients crucial for development and health, especially in vulnerable and remote communities (FAO, 2023). In low- and middle-income countries, livestock offers additional benefits, including draught power, transport, manure for soil enrichment, and social security (FAO, 2022a). Furthermore, livestock can be instrumental in accelerating food system transitions and ensuring healthy diets for growing populations, particularly women and children (FAO, 2022a).

The cattle industry, a vital component of the livestock sector, is constantly evolving, shaped by supply and demand factors. Supply is influenced by breeding practices, feed efficiency, land availability, climate conditions, and technological advancements. Genetic selection, artificial insemination, and embryo transfer have improved breeds for enhanced meat and milk production. Improved feed and feeding practices contribute to production efficiency, while research continues to optimize growth and yield. Land availability and climate are crucial for cattle rearing, with intensive farming adopted in land-scarce regions (Thornton, 2010). Demand for beef and milk is rising with the global population, especially in developing countries (Delgado, 2003). However, animal health issues like foot-and-mouth disease can significantly disrupt the supply chain (Knight-Jones & Rushton, 2013).

The global dairy industry, valued at USD 893 billion in 2022, is projected to reach USD 1.243 trillion by 2028, driven by both traditional practices and innovation. Cow's milk dominates the market, with India having the largest cow population and the European Union leading in production. Significant growth is evident in markets like China, which has added nine million cows in the past decade. Global milk production reached

852 million metric tonnes (Mt) in 2019, with cow's milk comprising 81 percent, buffalo milk 15 percent, and other milk sources 4 percent (Statista, 2023). Production is projected to grow by 1.6 percent annually, reaching 997 Mt by 2029. This growth is fueled by rising demand for fresh dairy in developing economies, driven by income and population growth, with per capita consumption expected to increase by 1.0 percent annually over the next decade. International trade focuses on processed dairy, with China a major importer of whole milk powder, alongside other importers like Japan, the Russian Federation, Mexico, and countries in the Middle East and North Africa (Mordor Intelligence, 2023).

The anticipated 20 percent increase in demand for animal products by 2050, driven by a projected global population of 10 billion, underscores the need for sustainable livestock practices (FAO, 2023). Meat consumption is projected to rise by 14 percent by 2030, with poultry meat expected to represent 41 percent of all meat protein sources. Increased per capita meat consumption, particularly in Asia and the Near East, is expected to drive international meat trade expansion (OECD & FAO, 2021).

Livestock products contribute significantly to global food loss and waste. According to FAO (2012) estimation, for every kilogram of meat produced worldwide, around 200 grams are either lost or wasted. Similarly, for every liter of milk or its dairy equivalents, between 100 ml and 250 ml are lost or wasted, depending on the region. Meat losses are particularly high in industrialized regions, especially at the consumer level, which accounts for approximately half of all meat losses. In developing countries, 40 percent of food losses occur post-harvest. For meat and meat products, losses in developing regions are more evenly distributed across the supply chain, though high losses at the production stage are linked to poor animal health care. Addressing these losses through a region-specific approach could enhance efficiency and sustainability within the supply chain.

Karwowska *et al.* (2021) report that up to 23 percent of total production in the meat sector is lost or wasted. The majority of this waste – 64 percent – occurs at the consumption level, followed by 20 percent in manufacturing, 12 percent in distribution, and 3.5 percent during primary production and post-harvest stages. These findings highlight the importance of targeting consumer behavior and improving processing and distribution practices to reduce waste in the meat supply chain.

2.2 The dynamic interaction of livestock and climate change

The relationship between livestock and climate change is a complex phenomenon that involves both the adverse effects of climate change on livestock and the impact of livestock on climate change through GHG emissions.

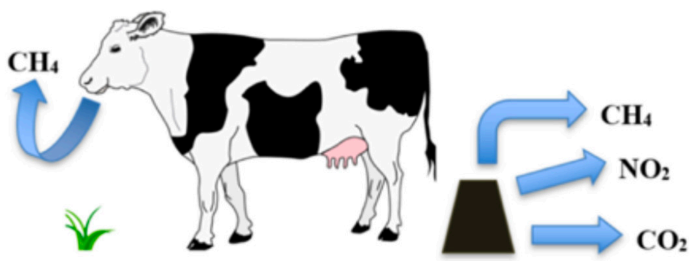
Climate change has multiple effects on livestock production. Climate change negatively impacts livestock through increased temperatures and precipitation variations (Rojas-Downing *et al.*, 2017). The direct and indirect effects of climate change on livestock productivity are well-established. Sejian *et al.* (2016) highlighted that as temperatures rise, animals experience heat stress, which reduces milk output (with shifts in milk components like fat, lactose, and fatty acids), lowers meat production, and causes a 20–27 percent decline in conception rates for dairy cows during the summer months. On the indirect side, climate change disrupts feed and water availability, alongside increasing disease prevalence. Changes in rainfall patterns and heightened water demand for forage crops diminish both the quality and quantity of feed, while water shortages negatively impact animal health, body weight, reproductive success, and resistance to disease. Moreover, warmer conditions enhance the survival and spread of disease vectors, leading to a rise in livestock disease outbreaks (Sejian *et al.*, 2016).

Heat stress causes a USD 1.7 billion to USD 2.4 billion annual loss in the US livestock industry, while globally, heat stress could decrease livestock productivity by 10–25 percent by 2050, with losses exceeding 30 percent in tropical regions. Feed crop yields could decline by 10–20 percent globally, and pasture availability could decrease by 20–30 percent, leading to a 15–25 percent reduction in ruminant production. Mortality rates for dairy cows in the hottest regions could increase by 20–30 percent, and their fertility rates could decrease by 20–30 percent (Cheng *et al.*, 2022).

The impact of a changing climate on animal health could be extreme (FAO, 2020a). This includes potential disruptions to disease patterns, rendering outbreaks more challenging to manage, and posing threats to the stability of animal-dependent livelihoods. These effects may establish directly through climate-induced variations in environmental conditions, such as droughts, fires, floods, heat stress, and erratic weather, which can alter the physiological and immune responses in livestock. Indirect implications arise as climate change influences the occurrence, spread, and predictability of animal diseases. Elevated temperatures and changing precipitation patterns may expedite the spread of pathogens and parasites, impacting the distribution and prevalence of vector-borne pests and bringing forth new diseases. Vector-borne diseases that are strongly associated with vector amplification due to climate variability include Rift Valley fever (RVF), West Nile Virus Bluetongue and Trypanosomosis. RVF in East Africa is strongly associated with extreme events, such as heavy rains and floods, caused by the El Niño events, which are expected to occur more frequently in the future as an effect of global climate change (FAO, 2015). This assessment is particularly frightening in developing nations (Spiller *et al.*, 2023). The vulnerability of livestock to the effects of climate change is determined by factors such as the duration, frequency, and severity of climate shocks, the breed and the health status of animals, and the location of relevant assets such as feedstock, housing, and water points (FAO, 2023a).

On the other hand, livestock production contributes significantly to climate change as a major source of GHG emissions. Figure 2 illustrates in a simple way the livestock GHG emission (Van der Merwe, 2024).

Figure 2. **Livestock greenhouse gas emission**



Source: **Van der Merwe, J.** 2024. *Livestock emissions and diesel: A challenge for agriculture carbon targets*. Freight News. https://www.freightnews.co.za/article/livestock-emissions-and-diesel-pose-puzzle-agri-carbon-targets

The livestock sector plays a substantial role in global GHG emissions, contributing 26 percent of the total emissions from agri-food systems (FAO, 2023a, 2023b). This contribution is primarily driven by the resource-intensive nature of livestock production, encompassing feed production, enteric fermentation (methane produced during digestion), and manure management. Beef production stands out as particularly carbon-intensive, with cows and buffaloes accounting for 70 percent of all livestock-related GHG emissions.

The high carbon footprint of beef is evident in the emission of 295 kgCO_2eq per kilogram of protein produced, significantly higher than the 31 kgCO_2eq emitted for the same amount of chicken egg protein. Furthermore, milk production exhibits a wide range of emission intensities (2–20 kgCO_2eq per kilogram of fat and protein corrected milk) depending on regional variations in production efficiency. Less efficient systems, often found in less developed regions, particularly in milk production, contribute disproportionately higher emissions. Projections indicate a potential 40 percent increase in livestock emissions, reaching 9.1 GtCO_2eq by 2050, without significant interventions and productivity improvements. This could represent up to 50 percent of total agri-food system emissions when considering both upstream (for example feed production) and downstream (such as processing and transport) emissions.

The dairy sector faces substantial environmental challenges, accounting for approximately 4 percent of global GHG emissions with 1 kg of milk generates an average of 2.4 kg of carbon dioxide (CO_2) equivalent (FAO, 2010). This growth in absolute emissions, linked to an 11 percent expansion of the global dairy herd and a 15 percent increase in average milk yields, is tempered by improved production efficiencies.

Emission intensities, measured as GHG emissions per kilogram of fat-and-protein corrected milk decreased by nearly 11 percent between 2005 and 2015, reflecting advancements in on-farm practices and animal management. However, significant regional disparities persist, with developed dairy regions exhibiting lower emission intensities (1.3 to 1.4 kg CO_2eq per kg milk) compared to developing regions like South Asia, Sub-Saharan Africa, West Asia, and North Africa (4.1 to 6.7 kg CO_2eq per kg milk).

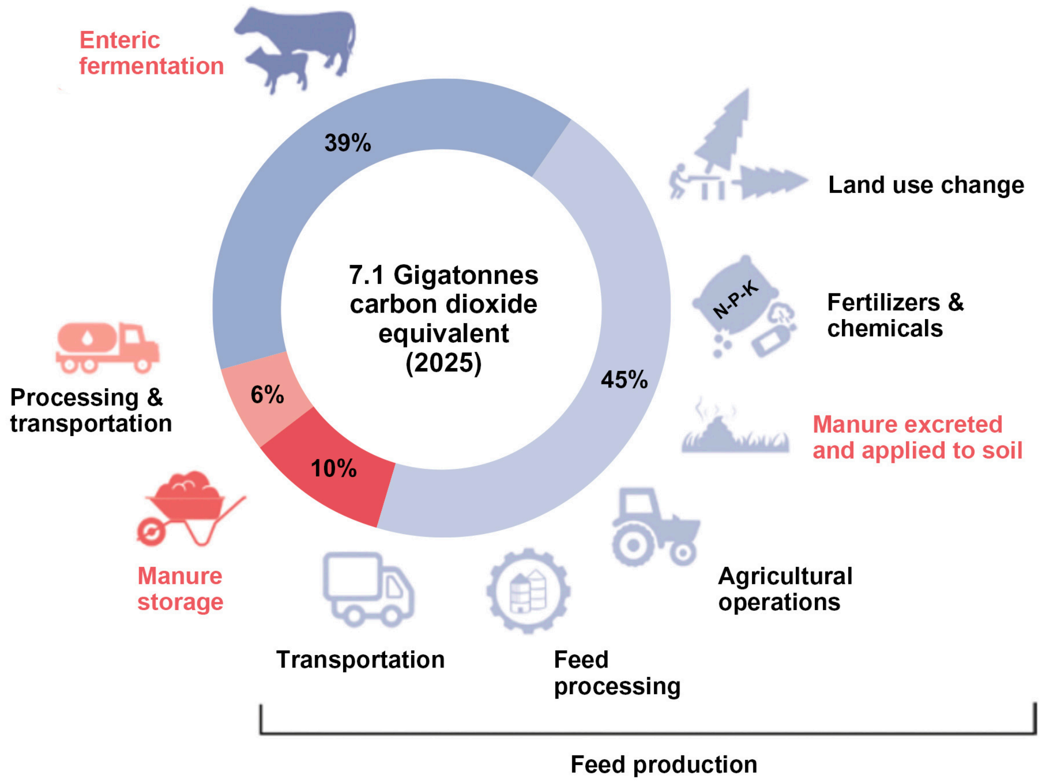
Consequently, there is increasing emphasis on sustainable intensification and the exploration of plant-based alternatives, which offer lower GHG emissions and reduced resource use compared to traditional cow's milk. This trend aligns with evolving consumer preferences and nutritional considerations, as plant-based options are often nutritionally fortified to match dairy milk. Despite these challenges, major dairy industry players continue to expand, underscoring the sector's importance in global food systems while navigating the complexities of environmental sustainability and international trade.

The growth in livestock populations has been a significant factor in the increasing emissions from the sector. This expansion in livestock production contributes to the sector's overall share of 14.5 percent of all human-induced GHG emissions (Gerber *et al.*, 2013). Figure 3, visually represents the breakdown of livestock emissions by source, including direct animal emissions (39 percent), feed production (45 percent), and manure management (16 percent).

Analysis of historical methane emissions from livestock reveals a quadrupling of emissions between 1890 and 2019, primarily driven by the growth of non-dairy cattle populations (Zhang *et al.*, 2022). While developed regions like Europe, Russia, the United States, Oceania, and China have experienced a plateau or decline in emissions since the 1990s, developing regions, particularly South Asia, tropical Africa, and Brazil, continue to see rising emissions, influenced by factors such as population growth, increasing income levels, policy changes, dietary shifts, improvements in livestock productivity, and international trade patterns.

Studies have provided detailed quantifications of the carbon footprint associated with different livestock products. Poore and Nemecek (2018) found that producing 100 grams of beef protein results in 50 kgCO_2eq emissions. This high carbon intensity is further emphasized by Ritchie (2024), who reported that one tonne of beef protein generates 499 tonnes of CO_2eq, significantly more than the 57 tonnes generated by the same amount of chicken protein. Emissions Gap Report (UNEP, 2023) highlighted record-high global GHG emissions of 57.4 GtCO_2e, a 1.2 percent increase from 2021, with the livestock sector contributing an estimated 10-15 percent of all anthropogenic GHG emissions and 32 percent of anthropogenic methane emissions (UNEP, 2023; FAO, 2023b). Meat production, as a whole, comprised 54 percent of total agricultural emissions (on a CO_2eq basis) during the 2018-2020 period, with a projected 5 percent increase by 2030, largely driven by the increasing contribution of poultry production (OECD & FAO, 2021). A missing table, referenced in the original text, would ideally provide a more granular breakdown of GHG emissions from enteric fermentation and manure storage, categorized by animal type.

Figure 3. **Breakdown of livestock emissions by source**



Source: **Gerber, P.J., Steinfeld, H., Henderson, B., Mottet, A., Opio, C., Dijkman, J., Falcucci, A. & Tempio, G.** 2013. *Tackling climate change through livestock: a global assessment of emissions and mitigation opportunities*. Rome, FAO. 139 pp. Available at: www.fao.org/3/i3437e/i3437e.pdf (accessed 10 March 2021).

Note: Direct livestock emissions are shown in red.

Sustainable livestock production requires a paradigm shift towards low-carbon practices, balancing the crucial role of animal products in providing essential nutrients with the imperative to minimize GHG emissions. While meat, dairy, and eggs are vital for addressing global hunger and malnutrition, their production must be optimized to mitigate environmental impact. FAO (2019) outlines key strategies for achieving this, including enhancing production and resource efficiency, promoting circular bioeconomy principles through intensified recycling and loss reduction, leveraging nature-based solutions for carbon offsets, advocating for healthy and sustainable diets that consider protein alternatives, and implementing effective policy interventions to drive systemic change.

Numerous mitigation options exist to reduce GHG emissions across diverse livestock systems. These focus on improving feed and feeding practices, utilizing methane inhibitors to address enteric fermentation, enhancing animal health and husbandry, advancing animal genetics and breeding for increased productivity, optimizing manure management through biogas production and cropland recycling, and promoting genetic improvement.

Implementing such technical interventions can yield substantial environmental benefits, with studies by Mottet *et al.* (2016) and Arango *et al.* (2020) indicating a potential reduction in livestock's environmental impact by 14 percent to 41 percent. Furthermore, the FAO (2023a) estimates that widespread adoption of best practices across various livestock systems could reduce GHG emissions by at least 30 percent.

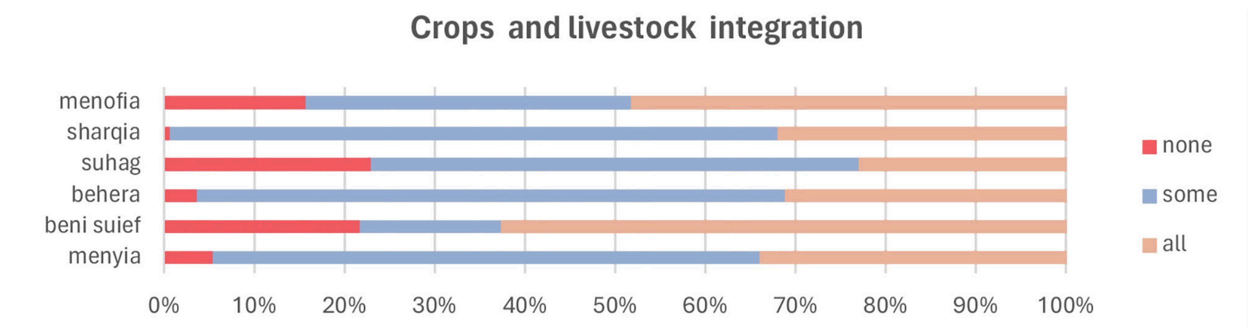
2.3 Current state of livestock production in Egypt

2.3.1 Economic value of the livestock subsector

While the agricultural sector contributes 11 percent of the GDP in Egypt (Statista 2023), the livestock component constitutes 37.5 percent the value of agricultural production, providing essential protein and micronutrient for food security and nutrition for the Egyptian population (FAO, 2022b). The cattle and buffaloes generate about 6 million tonnes of milk and 0.5 million tonnes of meat per year. About 53 percent of all milk and 86 of meat come from cattle, with the remainder coming from buffaloes. The total output from cattle and buffaloes is valued at USD 8 billion per year. Egypt is a net importer of both beef and milk. Per capita consumption of beef and cow milk is 9 kg and 75 liters per year, respectively (FAO, 2020).

The SHAPP + survey results conducted under this study, reveal a strong integration between crop and livestock production across the six governorates in Egypt. Figure 4 clearly illustrates that Monofya, Sharqia, and Menya have the highest levels of crop–livestock integration. In contrast, the proportion of agricultural activities involving only crops without livestock is notably low.

Figure 4. Crop–livestock integration in the six governorates under the SHARP+ survey



Source: **Johnston, S., Lepers, L. & Abdel Monem, M.** 2024. *Livestock and dairy farming households resilience: assessment report of livestock and dairy farming households, using the SHARP+ methodology (internal report).* [Unpublished].

Livestock is an essential means of protection during times of crisis and is crucial for farm resilience and contributes in several ways to the family's daily subsistence (FAO, 2016). In farming systems like in Egypt, where the land property is too small, the integration of livestock offers a vital pathway to building alternative livelihood support. Figure 5, illustrate this integration in the Menya governorate. The livestock provides the opportunity to build up resilience livelihood, especially against climate change and extreme weather events, through providing an additional source of income for small-scale farmers, reducing their dependence on a single crop. Livestock is integrated into the Egyptian farming system, with over 1.8 million households in Egypt raising bovine animals, primarily for commercial purposes (see Figure 5). Bovines are an asset, representing a regular source of cash through the sale of milk and providing inputs for increasing crop productivity in mixed crop–livestock systems.

This diversification helps mitigate the risks associated with climate variability and market fluctuations. Income from livestock sales can support farmers during periods of crop failure or low yields. Study of Saad (2024) at different regions of Egypt showed that, the livestock sector serves as a cornerstone of rural economic stability in Egypt, providing critical pathways for poverty alleviation and economic resilience among agricultural communities. This vital agricultural subsector acts as a fundamental safety net for rural households, particularly benefiting landless farmers and smallholders.

Figure 5. Livestock is integrated in the Egyptian farming system

Livestock products, including the meat and dairy products of the buffalo, cattle, goats, and sheep supplement the diets of small-scale farmers, ensuring better nutrition and food security, especially during times when crop production is affected by extreme weather events. The small-scale (peri) urban livestock production systems are important in Egypt where 35 percent of the cattle and 27 percent of small ruminants are reared in peri-urban production systems. These systems are quickly becoming more importance to many of the poor urban households, therefore it is essential to obtain more information on the actual extent of these systems (Van de Steeg & Tibbo, 2012).

The traditional family farming system in Egypt usually include multi-animal species-herds composed of large ruminants (cattle and/or buffalo), small ruminants (sheep and goats), and eventually camels in desert areas, with backyard poultry (Abdelsabour *et al.* 2022) reported that under the irrigated farming system in Egypt with cultivated forage crops like berseem and corn the majority of farmers attempt to keep a mixed multi-species flock with large ruminants (like cattle or buffalos) and small ruminants (sheep and goats).
In these irrigated zones, the majority of milk self-consumption is based on the large ruminant flock, while in the rain fed tree-crop-small ruminant systems that is the dominant system in rainfed area of the Northwest coast of Egypt, there is a sort of trade-off between tree and livestock investments according to the climatic year. Tree plantation allows to invest in the flock after destocking in a drought-period and vice versa the flock secures the income in case of drought that affects directly the olive and fig trees.

Livestock production in Egypt differs between the Delta region and Upper Egypt due to varying cropping patterns and socioeconomic factors. A study conducted by Fahim *et al.* (2018) compared buffalo production in both regions and found that the average household in Upper Egypt owned no more than three animals, while Delta households owned an average of ten. Buffaloes accounted for 66 percent of all ruminants in the Delta region, but only 44 percent in Upper Egypt. The limited availability of feeding resources and infrastructure is responsible for the low number of animals in both regions. Cattle are the second most common ruminants in all farms' herds, while sheep and goats accounted for 25 percent of herds raised in Upper Egypt compared to 13 percent in the Delta region. The study also found that 94 percent of buffalo farmers in Upper Egypt used some of their raw milk to produce dairy products such as cheese, cream, and butter, while only 78 percent of buffalo farmers in the Delta region did the same.

Basic processing methods were utilized in both regions, and family members consumed some of the liquid milk and dairy products, while the rest was sold through village markets. This dynamic role of the livestock diversity can be related with the notion of plasticity and or flexibility of livestock as capital, income generation at different time scale and food self-sufficiency. The results of study by Alary *et al.* (2015) showed that sheep and goats provided the main source of income to landless and very small landowners to escape the poverty trap in Egypt. The SHAPP survey results conducted under this study reveal that 81 percent of the study participants, responded that their animal production consisting mainly of ruminants.

In Egypt, women are responsible for taking care of livestock and poultry. However, they face significant gender gaps when it comes to decision-making about agricultural and animal resources. About 29 percent of households in rural Egypt own livestock, with only 26 percent of rural female-headed households owning livestock compared to 30 percent of rural male-headed households owning them (FAO, 2022b).

2.3.2 Egyptian livestock management systems

Livestock is an important component of the Egyptian agrifood system contributing to the food security at the farm as well as the national level. Over 1.8 million households keep animals, largely for commercial purposes. Livestock are an asset, representing a regular source of cash through the sale of milk and providing inputs for increasing crop productivity in mixed crop–livestock systems (FAO, 2020). However, livestock production in Egypt is mainly limited to irrigated cropping areas, as there are few natural forage resources in the Egyptian desert to support grazing by small numbers of camels, sheep, and goats. While livestock production complements irrigated crop production in many ways, it also competes with crop production in others. During the winter months, almost half of Egypt's agricultural land is used to grow berseem (Egyptian clover) for livestock feeding, which could otherwise be used to grow wheat, beans, or other food crops. In the summer, there is a severe shortage of forage and roughage material for livestock feed. According to FAO (2020a) report; in Egypt there is over 5.1 million cattle and buffaloes generate about 6 million tonnes of milk and 0.5 million tonnes of meat per year. About 53 percent of all milk and 86 of meat come from cattle, with the remainder coming from buffaloes. The tota5 output from cattle and buffaloes is valued at USD 8 billion per year. Egypt is a net importer of both beef and milk.

There are three main production systems that dominate Egypt's livestock sector. These systems have unique approaches to raising and managing cattle and buffaloes, and they play a significant role in determining the quality and quantity of the final products.

- **The intensive bovine production system is a significant part of Egypt's livestock sector.** It is a large-scale, high-input, and high-output system that accounts for about 6 percent of the country's total beef and dairy cattle and buffalo population (FAO, 2020a). There are around 14 000 registered intensive cattle and buffalo farms, with herd sizes that vary from 100 to over 1 000 animals (Goma and Phillips, 2022). Modern farms, representing 5 percent of the dairy animal inventory, operate as large-scale businesses with over 100 cows (see Figure 6). They focus on efficiency and productivity, achieving an annual yield of 4700 kg per head (ILO, 2020). Although these large-scale farms account for 5–7 percent of the total number of cows and buffaloes, they contribute significantly to the milk production sector, producing 10 percent of the national milk output.

  Dairy farms usually employ exotic breeds, while both exotic and crossbred animals are used for meat production. Productivity is high since farmers have access to sufficient finances to purchase quality feed and veterinary services. Additionally, the government carries out large-scale vaccination campaigns to ensure the animals are vaccinated (Omambia *et al.*, 2017). Intensive beef and dairy farms produce around 84,000 tonnes of meat and 5 million tonnes of milk annually (FAO 2020a), The beef animals are sold through formal chains to butchers in large cities or directly to slaughterhouses. However, the system relies heavily on imported feed, which raises sustainability concerns due to unexpected risk that might happen in the value chain. Increasing domestic feed production could reduce reliance on imports and improve the sustainability of the system. The intensive bovine production system is essential for Egypt's food security, providing a significant portion of the country's milk and beef supply. However, its reliance on imported feed ingredients and potential environmental impacts poses challenges for long-term sustainability (Garnett *et al.*, 2009).

Figure 6. The intensive livestock production system in Monofya governorate (Nile Delta)

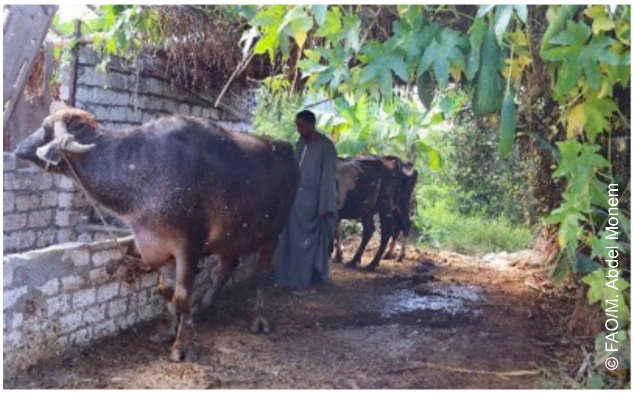
- **The semi-intensive bovine production system is a form of livestock production** that utilizes modern production and husbandry practices but exhibits mixed levels of efficiency. The system involves keeping a herd size ranging from 10 to 100 heads of cattle and buffaloes, which often varies by season (see Figure 7). This production system accounts for approximately 35 percent of all bovines in the country (FAO, 2020a). Although modern practices are used in semi-intensive bovine production, it remains inefficient due to various factors such as varied production practices, a scattered and unorganized farmer community, limited infrastructure, and unregulated value chains. Improved local breeds dominate the system due to their adaptability to the local environment and their ability to produce milk and meat efficiently (FAO, 2017). Farmers who practice semi-intensive livestock production keep mostly local breeds and produce both milk and meat for the market. They have access, although not necessarily on a regular basis, to both private and public veterinary services. They also vaccinate their animals during government vaccination campaigns. However, producers depend on private practitioners for emergency and regular veterinary services, with limited access to governmental veterinary services (FAO, 2020a).

Figure 7. Semi-intensive livestock production system in Suhag governorate (Upper Egypt)

- **The extensive bovine production system is the type of livestock production system** where farmers keep a small number of indigenous cattle and buffaloes (usually between 1 to 10) along with some cropland (see Figure 8). The system requires less input and produces low output, and farmers have limited access to production inputs, including veterinary services (FAO, 2020a). The primary sources of feed for these animals are the berseem, corn leaves (darawa), hay, and straw, with the latter becoming more prevalent during the summer months. Milk production from this system serves multiple purposes, including self-consumption, calf feeding, and local sales to neighbors or milk collectors, however, only a small portion of the milk produced is processed to make cheese and ghee (FAO, 2018).

Although about 59 percent of all cattle and buffaloes are kept in this system in Egypt, accurate statistics are not available as farms are often unregistered (FAO, 2020a). The extensive bovine production system plays a crucial role in rural livelihoods, providing both income and a source of protein for many households. However, the productivity and profitability of this system remain low due to a lack of proper management practices and poor breeding techniques (Hussein & Abd El-Rahman, 2012).

Figure 8. **Extensive livestock production system in Behera (left) and Sharqia (right) governorates of the Nile Delta**



2.3.3 Key challenges facing the livestock sector in Egypt

Detailed information on the significant decrease in the number of livestock animals in Egypt are reported by Mohamed *et al.* (2024) According to the numbers, there has been a notable decline of 29.5 percent in cattle, 54.3 percent in buffalo, 59.6 percent in sheep, and 68.7 percent in goats between 2017 and 2022. These figures highlight the alarming decrease in livestock numbers, which clearly indicates the challenges faced by the livestock subsector in Egypt.

Several factors have been suggested by Goma and Phillips (2021) as contributors to this decline in livestock numbers. One of the major factors is the economic challenges that Egypt has faced in recent years. These challenges include the high cost of production, unavailability of animal feed limited access to credit, and fluctuating market prices, have made it difficult for small-scale farmers to sustain their livestock operations. Additionally, climate change has played a significant role in impacting both the animals and the feed components.

Higher temperatures, increased humidity, and the emergence of new animal and plant diseases have negatively affected the livestock sector. Heat stress negatively affects livestock production by reducing growth, milk production, and reproductive performance and in severe cases, it can even lead to death. Another factor contributing to the decline in livestock numbers is the changing preferences of consumers. The higher prices of animal products and increased awareness of health and environmental concerns have led consumers to seek alternative protein sources, such as plant-based products. This shift in consumer behavior has further impacted the livestock subsector in Egypt.

Animal feed in Egypt can be categorized into three main types: green feed, dry feed, and concentrated feed. Green feed is cultivated during three seasons: winter, summer, and Nile seasons. Winter feed is the most extensive, covering about 89.3 percent of the total cultivated area.

During the winter season, sustained Berseem is the most widely grown green feed, occupying approximately 54.3 percent of the winter feed area and around 48.4 percent of the total green feed area. Berseem is the second most prevalent winter green feed, accounting for about 13.7 percent of the total green feed area. Summer green feed represents approximately 7.6 percent of the green feed area, with drawa being the most popular, followed by corn (sweet), and sorghum. Sustained clover, clover, and alfalfa are the most significant green feeds, collectively accounting for roughly 63.5 percent of the total green feed area.

Table 2. Production of animal feed in Egypt during the period (2002-2022) in thousand tonnes

Year	Green feed	Dry feed	Concentrated feed	Total (thousand tonnes)
2002	70 677	8 470	7 678	86 825
2007	66 987	8 549	8 633	84 169
2012	54 575	9 181	6 669	70 425
2017	55 170	8 268	6 834	70 272
2022	50 186	15 302	6 233	71 721
Average	59 519	9 954	7 209	**7 686**

Source: Adapted from Mohamed, A. 2023. *An economic study of the impact of animal feed production capacity on livestock development in Egypt. Scientific Journal of Agricultural Sciences*, 5(4): 308–334. https://doi.org/10.21608/sjas.2023.248388.1360

Dry feed is produced using crop by-products such as straw from wheat, barley, beans, lentils, clover, soybeans, corn stalk, and rice hay. However, due to its lower nutritional value, dry feed is typically combined with green fodder during the winter or supplemented with concentrated feed to provide animals with the necessary nutrients. Wheat straw is the most common type, representing about 90.3 percent of total production. Barley straw ranks second, accounting for around 5.5 percent of the total straw, followed by bean straw at approximately 3.9 percent. Figure 9 shows examples of dry feed for cattle in Menya.

Concentrated feed is a highly nutritious type of animal feed used to promote animal growth, especially during periods when green fodder is scarce, which is often the case for most months of the year. There are two types of concentrated feed available in Egypt. The first type is manufactured concentrated feed, produced by crushing cottonseed, castor seed, flaxseed, sunflower, and soybean. The second type is grain concentrated feed, made from grains such as maize, sorghum, barley, beans, and wheat bran. Among the raw materials used, bran is the most common, accounting for 31.2 percent of the total amount, followed by corn at 28.1 percent. Soybean, cottonseed, Srsah (animal feed, derived from a specific plant cultivated in Egypt used as nutritional supplement for farm animals), and rice bran represent approximately 15 percent, 12.2 percent, 5.8 percent, and 2.5 percent of the total amount used, respectively (Moussa *et al.*, 2011).

Figure 9. **Dry feed for cattle in Menya**

The animal production sector in Egypt is currently facing a shortage of animal feed production, which has led to higher prices. Compound feed is a mixture of raw materials and supplements fed to livestock, sourced from either plant, animal, organic or inorganic substances, or industrial processing, whether or not containing additives. While soybean, corn, barley, wheat, and sorghum are the most used raw materials, vitamins, minerals, and amino acids are the most common additives blended to form compound feed (see Figure 10) shows factory for feed production in Suhag (see Figure 11) shows local feed merchant in Menya governorate.

The Egyptian compound feed market has been experiencing significant growth, driven by factors such as rising consumption of animal-based food products across Egypt. The market is estimated to be USD 2.35 billion in 2024 and is projected to reach USD 2.78 billion by 2029 due to the increasing demand for meat and dairy products domestically and internationally.

However, Egypt produces only 35 percent of its national feed requirements, leading to a reliance on imports, and international feed prices impact the Egyptian market, affecting the size of the herd and slaughter rates.

Figure 10. **Factory for feed production in Suhag**

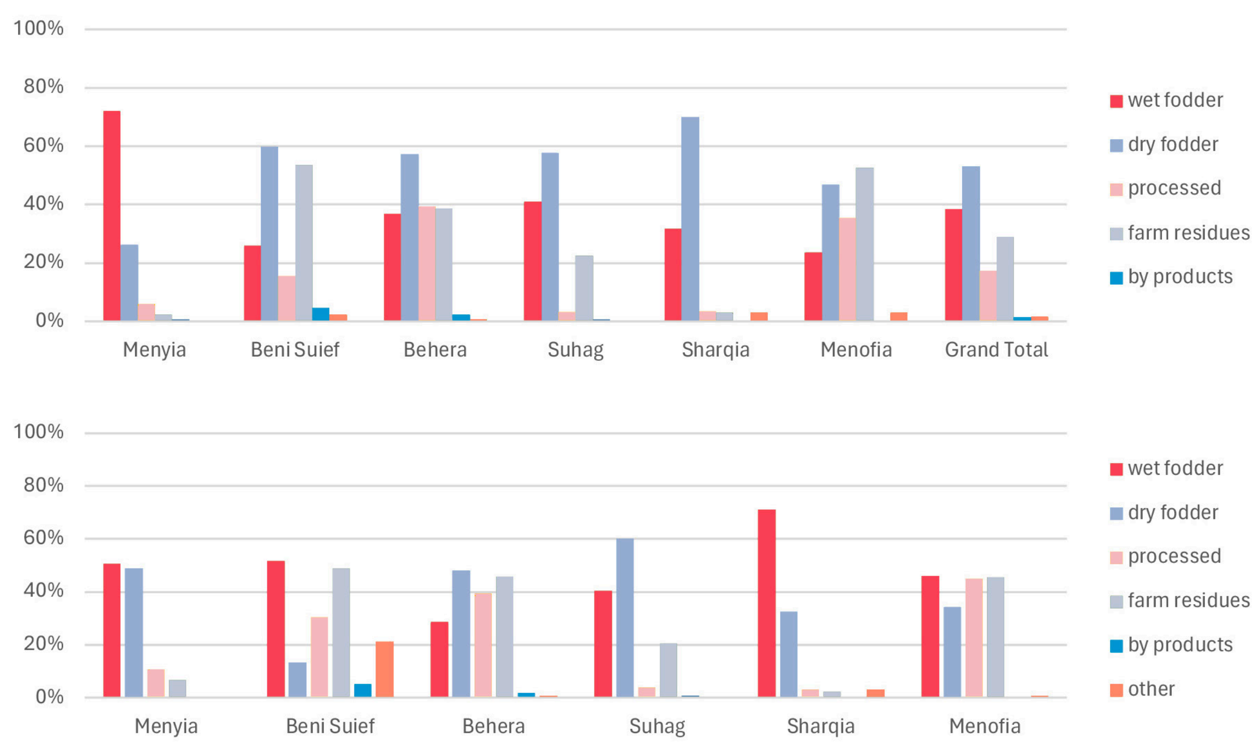
Figure 11. **Local Feed Merchant in Minya**

Between 2002 and 2022, Egypt's annual average feed production was approximately 76.86 million tonnes. According to Mohamed (2023), this total is composed of 77.6 percent green feed, 13 percent dry feed, and 9.4 percent concentrated feed, as illustrated in table 2.

To meet the nutritional requirements of one animal unit each year, approximately 3.3 tonnes of green feed, 800 kg of dry feed, and 1.33 tonnes of concentrated feed are necessary. While green fodder production shows a surplus, cultivated on around 2.5 million feddans, the country experiences a significant shortfall in concentrated feed, with a deficit of roughly 7.34 million tonnes (Al-Sharqawi *et al.*, 2019). To address this gap, Egypt requires annual imports of about 9 million tonnes of maize, 3 million tonnes of cereals, 1 million tonnes of wheat bran, rice ore, and corn gluten, as well as 0.35 million tonnes of feed additives (Shoukry, 2021).

The SHARP+ survey reveals seasonal shifts in livestock feeding practices, with green fodder usage averaging 48.2 percent in winter and dropping to 38.4 percent in summer, while dry fodder increases from 39.2 percent in winter to 53 percent in summer. Processed feed sees a slight decline from 22.2 percent in winter to 17.2 percent in summer, and farm residues remain relatively stable, rising slightly from 28.4 percent to 28.9 percent. By-products and other feed types show minimal changes between seasons. Overall, farmers adjust their feeding strategies based on resource availability and seasonal conditions.

Figure 12. Animal feed in summer (upper) and in winter (down) in six governorates under SHARP+ survey



Source: **Johnston, S., Lepers, L. & Abdel Monem, M.** 2024. *Livestock and dairy farming households resilience: assessment report of livestock and dairy farming households, using the SHARP+ methodology (internal report)*. [Unpublished].

2.4 Climate change interactions with livestock systems in Egypt

2.4.1 Contribution of livestock to greenhouse gas emission

Although data on the livestock sector's contribution to GHG emissions in Egypt is limited, Omran *et al.* (2020) reported that in Egypt, buffaloes are more eco-friendly than cattle with a buffalo produces 157 grams of methane per day, whereas a cow emits 376 grams per day, which means buffaloes produce 58 percent less methane compared to cows. On other hand, Maza *et al.* (2024) employed the Tier 1 approach from the Intergovernmental Panel on Climate Change (IPCC) 2006 guidelines, refined in 2019, to estimate CO_2 emissions. Their study calculated CH_4 emissions from livestock, focusing on two primary sources: enteric fermentation and manure management, with an emphasis on cattle and buffaloes from 1989 to 2021. The findings revealed that cattle and buffaloes accounted for 82 percent to 90 percent of total methane emissions from livestock GHG emissions, with buffaloes contributing more to methane emissions from enteric fermentation for most of the study period.

Methane emissions from both enteric fermentation and manure management exhibited fluctuating trends over the study period. The highest average total emissions ranged between 15 600 Gg CO_2e per year, with a notable decrease to 7 100 Gg CO_2e per year in recent years, primarily due to a reduction in livestock numbers during the last three years of the study. Additionally, Maza *et al.* (2024) reported that methane emissions from manure management comprised 5.2 percent to 6.2 percent of total enteric fermentation emissions throughout the study period.

From a geographical perspective, methane emissions concentrated in Egypt's agriculturally rich areas, particularly the Nile Delta. The governorates from entire Egypt with the highest methane emissions from cattle and buffaloes were Behera, Sharqia, Menya, and Suhag. Behera stood out with the highest average emissions from enteric fermentation, reaching an average of 1 311 Gg CO_2e per year.

2.4.2 Impacts of climate change on livestock production in Egypt

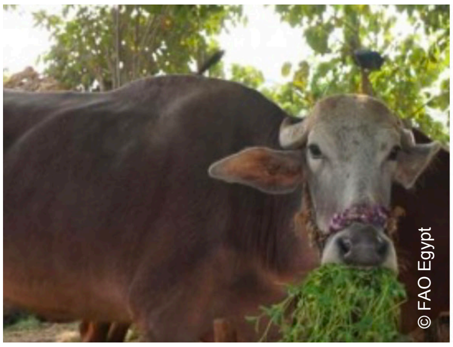
Impact of climate change on animal feed

Livestock in the hot semi-arid environments like in Egypt, are for the most part reared in extensive systems. The productive potential of livestock in these areas is influenced by their exposure to harsh climatic factors. Climate changes could increase thermal stress for animals and thereby reduce their production and profit ability by lowering feed efficiency, growth rates and repro duction rates (Henry *et al.*, 2018). The great concern regarding the impact of climate change on crop yields should not overshadow of its impact on livestock, especially for vulnerable communities like those in Egypt where livestock can serve as a vital resource and safe guard particularly in cases of crop failure. These animals, especially the indigenous local bread are invaluable assets, functioning as lifelines for the communities they sustain.

Changes in temperature, precipitation patterns, and extreme weather events have a significant impact on the availability and quality of feed resources for livestock in Egypt. Therefore, it is imperative to fully understand the sensitivity of these crops to climate change in order to develop effective adaptation strategies:

- **Egyptian clover, or Berseem (*Trifolium alexandrinum L.*), is the main winter forage in Egypt** and a vital component of the agricultural systems of the Nile Valley and Delta. It occupies about a third of the cultivated area in Egypt during winter and provides high forage yields of exceptional value. Given the shortage of agricultural land in Egypt, there is competition between wheat (to feed humans) and berseem (to feed cattle), requiring important policy choices. Increasing wheat area at the expense of berseem could lead to a major rise in prices of animal products, and even their import may become necessary. It has been estimated that the average intake of berseem by buffalo is around 32 kg per day (MoALR, 2022). Berseem also is a better choice for soil improvement with its ability to add nitrogen up to 297–400 kg/ha. Every year more than 714 000 tonnes of nitrogen are fixed in Egypt (FAO, 2014). However, it has received limited attention regarding its genetic diversity, making it susceptible to climate change. To develop resilient Berseem cultivars, exploring its genetic resources is crucial for enhancing the diversity within its germplasm, thereby optimizing breeding programs (Mohamed *et al.*, 2024).

Figure 13. **Berseem is the main green feed for livestock in winter at the small and medium farms**



- **Climate change, particularly the increase in temperature and changes in rainfall patterns, can significantly impact the irrigation requirements of the Berseem.** In his study examining the impact of climate change on future irrigation requirements in Egypt's Upper Region, Gabr (2023) found that the overall net irrigation water requirement (NIWR) for Berseem, is projected to increase by 5.1 percent and 5.9 percent under the medium greenhouse emission representative concentration pathways (RCP) 4.5 scenario for the periods 2023–2080 and 2081–2100, respectively. Under the high emission RCP 8.5 scenario, the total NIWR for all crops is expected to increase by 7.7 percent and 9.7 percent for the same periods. Understanding genetic diversity and developing resilient Berseem cultivars is crucial for its sustainability in the face of climate change (Mohamed *et al.*, 2024).
- **Corn is a crucial crop used in livestock feed in Egypt,** especially in summer. However, the production of corn is not sufficient to meet the demands of the livestock sector. Domestic consumption was about 16.36 million tonnes and the gap was estimated at about 8.96 million tonnes, which led to an increase in the amount of corn imports and an increase in the deficit in the trade balance (Abosena, 2023). The main reason for this gap is the limited availability of water resources and land for corn cultivation, along with the increasing demand for corn as a primary ingredient in livestock feed. Box (2), produced a case study of the climate change impact on changing the crop rotation and introducing soybean in El Amodin village, Menya
- **The production of corn in Egypt is facing the threat of climate change due to the expected increase in evapotranspiration** between 2.4 percent to 16.2 percent in the Delta region, between 5.9 percent to 21.1 percent in the Middle Egypt region and 5.8 percent to 22.5 percent in the Upper

Egypt region up to the year 2100 as compared to the current situation (Ali *et al.*, 2021) and consequently the increase in water requirement. Perez *et al.* (2021) reported that compared to a scenario without climate change, yields for food crops, including maize, are projected to decline by over 10 percent by 2050 due to higher temperatures and water stress, as well as increased salinity of irrigation water.

The results of the SHAPP+ survey indicate that most farmers (79 percent) believe their crops are suitably adapted to the prevailing climate conditions, against 21 percent of farmers surveyed indicated that their crops are not adequately adapted to the current climate. This difference is particularly evident in the Souag governorate of Upper Egypt, an area characterized by consistently high and escalating temperatures. Within Souag, a significantly higher percentage of farmers, 35 percent, reported that their current crops are not appropriately adapted to the existing and increasingly challenging climatic conditions indicating higher vulnerability to climate change impacts within this governorate.

Box 2. Climate change impact on feed production: the case of soybean in El Amodin village, Menya

El Amodin is a medium-sized village located in the Samalot District of Menya governorate, Upper Egypt. The village has a population of around 40 000 people and covers an area of approximately 1 000 feddans. About 40 percent of the farmers in El Amodin own less than 3 feddans of land. Soybean plays an important role in the village's farming system. Traditionally, potatoes have been one of the main crops, particularly for small-scale farmers, providing a significant source of income. However, in recent years, farmers have observed a noticeable decrease in potato production, which they attribute to rising temperatures caused by climate change.

In response to this challenge, many farmers have adjusted their cropping patterns. One of the major changes has been the introduction of a second soybean planting, as it is more resilient to the increasing temperatures compared to potatoes. This shift reflects the farmers' adaptive strategies to maintain their livelihoods in the face of changing climatic conditions (see Figure 14).

Figure 14. Introducing a second plantation of soybean in Menya

Source: Authors' elaboration.

- **In their review of the impact of climate change on plant pests, IPPC Secretariat. (2021) identified Fall Armyworm (FAW)** (*Spodoptera frugiperda*) as a new pest that have been expanded its distribution due to climate change and reported in Egypt starting 2019. Timilsena *et al.* (2022) emphasized the role of climate change in facilitating the invasion of the FAW pest. The study revealed that the accumulation of heat stress, has created favorable conditions for the FAW to invade Egypt (see Figure 15). This has led to significant damage to corn crops in the country. The initial presence of FAW was documented in the governorates of Aswan, Luxor, and Qena in Upper Egypt. Over a span of two years, the pest has spread to 13 governorates in Egypt, with corn crops experiencing an average infection rate of 1.5 percent. This indicates the rapid and widespread impact of FAW on corn production in Egypt.

Figure 15. **Fall Armyworm infestation in corn field in Menya (Upper Egypt)**

- **Sorghum is a significant summer grain crop in Egypt, ranking just behind rice and corn in importance.** It is primarily used for livestock feed and is often compared to corn due to its similar feed value. According to Sorghum Checkoff (2019), the feeding value of sorghum ranges from 90 percent to nearly equal to that of maize. Although whole grain sorghum contains more protein than maize, it is lower in vitamins. In 2022, Egypt produced 750 000 metric tonnes of sorghum, achieving a productivity rate of 4.9 tonnes per hectare (Statista, 2024). Annually, approximately 400 000 feddans are allocated for sorghum cultivation. About 80 percent of this area is concentrated in the governorates of Fayoum, Assiut, and Suhag (Singer, 2024). Sorghum can be utilized in various feed ingredients, including its grain, stalks, and leaves. The crop is drought-resistant, making it an economical option for feed formulations. Additionally, it is readily accepted by livestock. Nutritionally, sorghum offers a composition similar to corn, with slightly higher levels of protein and energy value (Zarie *et al.*, 2022).
- **Sorghum, often referred to as “the camel of cereals”, is a climate-resilient food crop that demonstrates substantial tolerance to climate change.** However, studies indicate that climate change could negatively impact sorghum yields. According to Chadalavada *et al.* (2021), sorghum yields are projected to decrease by 7 percent by 2020, 11 percent by 2050, and 32 percent by 2080 due to climate change. The crop is particularly vulnerable during its reproductive and grain-filling stages, which can lead to significant losses. Furthermore, Carbon Brief (2017) reports that sorghum is susceptible to additional heat stress as average temperatures rise. They estimate a yield loss of 10 percent for each degree Celsius of warming. These findings suggest largely adverse biophysical effects of climate

change by 2050. Compared to a no-climate-change scenario, yields for food crops, including sorghum, are projected to decline by over 10 percent by 2050 due to higher temperatures, water stress, and increased salinity of irrigation water (Chadalavada *et al.*, 2021).

- **Climate change can create favorable conditions for the growth of fungi, increasing the risk of mycotoxin contamination in the animal feed** (Magan *et al.*, 2011). Mycotoxins can reduce the nutritional value of feed and pose health risks to animals, leading to reduced productivity and increased susceptibility to diseases (Gomez *et al.*, 2022). Sorghum is currently threatened by several fungal diseases that have reduced crop yields and quality, resulting in substantial economic losses. The main fungi that infect sorghum grains belong to the Aspergillus and Fusarium genera, which are associated with the production of aflatoxins, fumonisins, zearalenone, and deoxynivalenol, with aflatoxins posing the greatest risk in this crop. The presence of these fungi in sorghum grains not only affects their nutritional and commercial value, but also represents a risk to the health of consumers due to their ability to produce mycotoxins (Ráduly *et al.*, 2020). It was concluded that climate change can alter the composition and nutritional value of feed resources.

Impact of climate change on the cattle and buffaloes

Under Egyptian conditions, cattle and buffaloes already suffer heat stress periods in summer. The predicted increases in temperature as result of climate change will affect livestock production by reducing growth and milk production because of appetite suppression and conception rate reductions that will increase animal welfare concerns. In severe cases, these effects can result in death (Goma & Phillips, 2021). The hot weather and high humidity during the summer months in Egypt cause significant heat stress for livestock. Predicted climate change suggests that these conditions will worsen over the course of this century (Goma & Phillips, 2022). Chichester and Mader (2012) defined the Thermal Comfort Zone for livestock as the range of temperatures within which animals do not need to expend extra energy to maintain their normal body temperature.

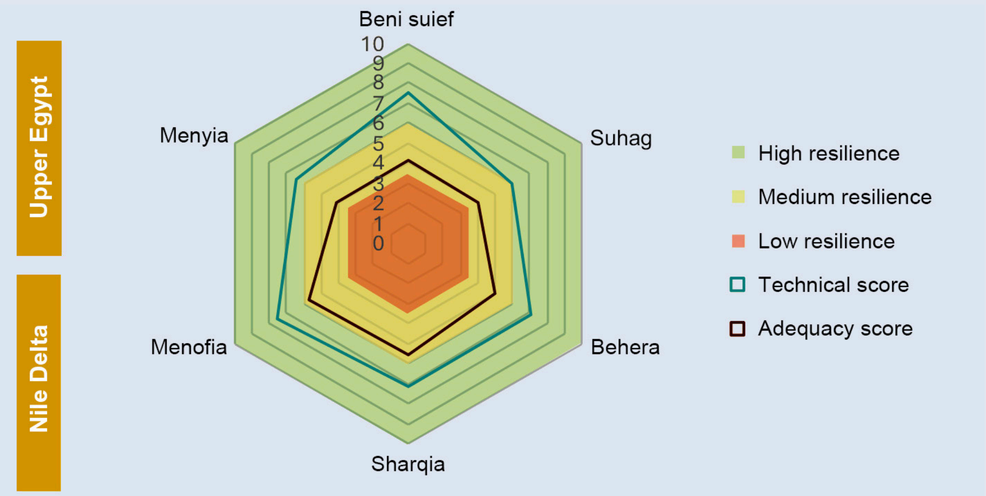
This zone varies depending on the species, age, and breed. For dairy cattle, the most comfortable environmental temperature range is between 5 °C and 25 °C. Heat stress in livestock, as defined by Goma and Phillips (2022), is the discomfort and physiological anxiety experienced by animals when environmental temperatures and humidity levels exceed their thermal comfort zones. In Egypt, the geographical location and the rising temperatures, which can exceed 40 °C due to climate change, combined with increasing humidity levels, significantly extend the duration and severity of heat stress.

The anticipated increase in temperature due to climate change is expected to exacerbate the amount of time livestock are exposed to heat stress, making it a growing concern for livestock production systems in Egypt, especially during the summer months. This can lead to reduced production efficiency, injury, and even death if mitigation measures are not implemented promptly. Research conducted in Egypt by Habeeb *et al.* (2018) concluded that exposure to heat stress induces a series of drastic changes in the biological functions of animals.

Box 3. Assessing the resilience of animal production in Egypt

An analysis of data collected through the SHARP+ survey evaluated the resilience of animal production in Egypt by examining the diversity of species and breeds raised, production systems, adaptability of raised species and breeds to local conditions, and manure management practices.

Across the six governorates surveyed, farmers achieved an average resilience score of 11.7 out of 20, indicating a moderate level of resilience. The results reveal that Suhag scored the lowest overall resilience value, while Monofia scored the highest. Notably, Upper Egypt governorates, characterized by limited animal diversity and breeds, demonstrated lower resilience to climate change, particularly in coping with rising temperatures. In contrast, the Nile Delta region, with its higher presence of intensive large-scale livestock production systems, exhibited greater resilience.



Source: **Johnston, S., Lepers, L. & Abdel Monem, M.** 2024. *Livestock and dairy farming households resilience: assessment report of livestock and dairy farming households, using the SHARP+ methodology (internal report)*. [Unpublished].

These changes include a decrease in feed intake, feed efficiency, and utilization, disorders in water, protein, energy, and mineral balances, alterations in enzymatic activities, hormonal secretions, and blood.

Effects of heat stress on milk yield and composition in Egypt was reported by Gaafar *et al.* (2011), in their comprehensive eight-year study where meteorological data was gathered from Kafr El-Sheikh governorate in Egypt's North Delta for 581 Friesian cows to assess effects of heat stress on milk yield and composition during the peak summer months of July and August. The findings revealed a significant impact of heat stress, with 39 percent reduction in total milk yield, decrease in milk quality, evidenced by a 7.92 percent and 4.06 percent reduction in fat and protein content, respectively, when compared with the winter season. Goma and Phillips (2021) predicted milk availability per person will decline significantly, from 61 kg/year in 2011 to 26 kg/year in 2064 due to climate change, population growth, and the impact of higher temperatures on cow productivity.

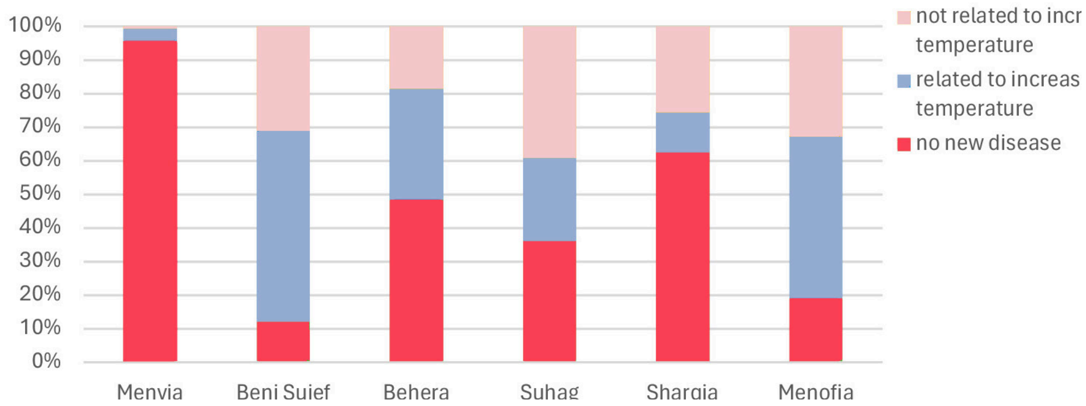
The impact of heat stress on the daily body weight gain (DBWG) of buffalo and bovine calves in Egypt has been well documented. Habeeb *et al.* (2014) researched impact of heat stress on the DBWG of buffalo and bovine calves in Egypt, revealing significant reductions due to high temperatures. buffalo calves exposed to 36.0 °C and 32.0 °C saw DBWG reductions of 22.6 percent and 16.5 percent, respectively, compared to those at 18.0 °C, while purebred and crossbred bovine calves experienced declines in DBWG by 52.8 percent and 43.3 percent during summer compared to winter. Omran *et al.* (2020) highlighted the temperature-humidity index (THI) as a comprehensive metric that encapsulates the cumulative effects of air temperature and humidity, serving as a prime indicator of heat stress in animals within Egypt's environmental conditions. Despite the Egyptian buffalo's adaptation to local climates and management practices, Omran and Fodda (2023) observed a 20 percent rise in abortion rates and a 10 kg reduction in average birth weight correlating with increased THI levels.

The impact of a climate change on animal health was reported in Egypt as mainly related to the increase in temperature that led to the spread of pathogens and parasites, impacting the distribution and prevalence of vector-borne pests and bringing out new diseases with higher risk of morbidity, mortality, and associated economic implications.

- **Foot-and-mouth disease (FMD) is a severe, highly transmissible viral disease of livestock** that has a significant economic impact. The disease is estimated to circulate in 77 percent of the global livestock population, in Africa, the Middle East and Asia, as well as in a limited area of South America (World Organization of Animal Health "WOAM", 2019). Mun *et al.* (2023) found that increasing number of the higher-temperature days was associated with having a FMD outbreak. In Egypt FMD is known to cause high mortality rates sometimes reaches 100 percent among calves younger than 2 months, while the mortality rate among adult buffaloes aged more than 2 years was about 26 percent (El Damaty *et al.*, 2021).
- **The emergence and spread of the Lumpy Skin Disease (LSD) is associated with climate change** in various regions. Climatic conditions that favor vector replication, contribute to the spread of LSD (Hider *et al.*, 2024). LSD as it is an arthropod-borne infectious disease (Eom *et al.*, 2023). It is a highly contagious viral infection that primarily affects cattle and buffaloes (Jamil *et al.*, 2022). This disease can cause significant economic losses, including leather damage, decreased milk production, abortion, and mortality in infected ruminants (Eom *et al.*, 2023). The disease has spread rapidly through the Middle East and has become endemic in Egypt since 2013 (Eom *et al.*, 2023). According to a study conducted in the Northern Delta of Egypt, the overall percentage of LSD infection among cattle was 19.5 percent (Selim *et al.*, 2021). LSD caused sickness and death rates of 22.3 percent and 6.6 percent respectively for the Frisian cattle breed in the Nile Delta, respectively (Ali *et al.*, 2021).

  Ticks are widespread across all continents, making them a significant vector-borne threat globally. They are highly sensitive to climate change due to their external environment lifestyle. Studies have shown shifts in tick ranges and population increases, along with associated diseases (Gilbert, 2021). The impact of climate change on ticks and infections is well documented. Nuttal (2022) reported that a 2–3 °C rise in land surface temperature over 30 years has led to the spread of Ixodes scapularis (Lyme borreliosis vector) in Canada. In Egypt, tick-borne diseases pose a significant threat to animal health, particularly to cattle and buffalo, potentially undermining livelihoods (AL-Hosary *et al.*, 2018).

Figure 16. **Observed new animal diseases in the last 5 years the six governorates under the SHARP+ survey**



Source: **Johnston, S., Lepers, L. & Abdel Monem, M.** 2024. *Livestock and dairy farming households resilience: assessment report of livestock and dairy farming households, using the SHARP+ methodology (internal report).* [Unpublished].

The SHARP+ survey results reveal varying perceptions among farmers (see Figure 16) regarding the link between new animal diseases observed in the last five years and rising temperatures. While 45.8 percent of farmers reported no new diseases, a notable 29.5 percent attributed new diseases to increased temperatures, while 24.6 percent believed observed diseases were unrelated to temperature changes. This variation is evident across governorates. For instance, in Menya, an overwhelming majority (95.6 percent) reported no new diseases, while in Beni Suief, a majority (56.7 percent) linked new diseases to rising temperatures. Suhag presents a more divided picture, with 36.2 percent reporting no new diseases, 24.5 percent attributing them to temperature increases, and 39.3 percent seeing no connection. This regional variation highlights the complexity of farmers' experiences with animal diseases and perceived climate change impacts.

CHAPTER 3. Leveraging private sector engagement in climate-smart livestock practices in Egypt

3.1 Climate-smart livestock solutions

Climate-smart livestock (CSL) involves implementing climate-smart agriculture (CSA) principles in the livestock sector. This includes adopting practices and technologies that increase productivity, enhance resilience to climate change, and reduce greenhouse gas emissions. Strategies for CSL include improving animal feed quality and digestibility to reduce methane emissions, implementing rotational grazing systems to promote soil carbon sequestration, breeding more climate-resilient livestock breeds, and implementing sustainable manure management to produce biogas and reduce methane emissions (FAO, 2017a). CSA is an approach that guides actions to transform agrifood systems towards more productive, sustainable, and resilient practices. It is organized around three main pillars: 1) sustainably increasing agricultural productivity and incomes; 2) adapting and building resilience to climate change; 3) reducing and/or removing GHG emissions, where possible.

While the principles of CSL apply globally, it is essential to adapt solutions to Egypt's specific livestock production systems. These systems include intensive (large-scale), semi-intensive (modern practices), and extensive (small-scale with indigenous animals) approaches, often integrated with crop farming. Customizing CSL practices to each system enhances sustainability and resilience.

The following are recommended CSL interventions that also provide agribusiness investment opportunities for private sector.

3.1.1 Climate-resilient sustainable animal feed production

Utilizing agricultural waste to produce animal feed in Egypt

Producing animal feed from agricultural waste in Egypt presents a compelling opportunity for both economic growth and environmental sustainability. By investing in the development and optimization of processes to convert these residues into high-quality feed ingredients, the private sector can address nutritional deficiencies in animal feed while reducing environmental pollution. Egypt produces approximately 33.4 million tonnes of agricultural residues annually on a dry matter basis, including wheat straw (6.9 million tonnes), sugar cane residues (6.8 million tonnes), corn residues (4.5 million tonnes), and rice straw (see Figure 17), a major by-product of summer rice cultivation (3.6 million tonnes) (Elfeki *et al.*, 2017) which present significant environmental challenges if not managed effectively. Traditionally, these residues have been used for fodder, cooking fuel, and fencing, or have been burned. According to Hassan et (2014) regional concentrations of crop waste vary, with corn waste production being highest in the Delta (48.8 percent), sorghum in Upper Egypt (63.8 percent), rice straw in the Delta (99.7 percent), and cotton also predominantly in the Delta (87.5 percent). However, the current management of these agricultural wastes is largely inefficient with 18 percent of the waste used as soil amendments, 30 percent is directed towards animal fodder, while 52 percent remains unused, often being burned in the fields or in inefficient burners (Elfeki *et al.*, 2017). The integration of agricultural by-products such as straw and crop residues into livestock feed is a promising strategy to mitigate feed costs and reduce the environmental impact of dedicated feed crop cultivation.

Figure 17. **Agricultural wastes prepared as animal feed in Sharqia (Nile Delta)**

Producing densified complete feed blocks for livestock

Densified complete feed blocks offer an efficient way to provide balanced nutrition to animals, as highlighted by Magan *et al.* (2013). Densified feed refers to animal nutrition that has been compressed into a more compact and concentrated form, such as pellets, cubes, or blocks. This process simplifies storage and transportation, making both more efficient and cost-effective, while also minimizing waste during feeding. Additionally, densification ensures more nutrients reach the animals, improving overall consumption. Private sector companies are increasingly investing in technologies to densify locally available resources.

These compact blocks are formed under specific conditions, typically at a natural dried moisture content of 10–12 percent and a pressure of 418.5 kg/cm² (Magan *et al.*, 2011). The general composition of these feed blocks includes 86 parts straw, 10 parts molasses, 2 parts mineral nutrient mix, 1 part urea, and 1 part salt. To ensure the durability and rigidity of the feed blocks, various binders such as lime, molasses, cement, and bentonite are used in the manufacturing process (Magan *et al.*, 2011). These blocks are not only easy to transport and handle but are also considered a crucial element in feeding livestock during periods of fodder scarcity (Machen, 2011).

In Egypt, there is a growing emphasis on developing low-cost feed alternatives, such as feed blocks, by utilizing affordable agro-industrial by-products. These by-products could include tomato pulp, molasses, crude sesame or sunflower cake, and citrus pulp, which would help reduce dependence on grains like corn. EL-Shabrawy and Al-Rajhi (2020) successfully developed a prototype of animal feed blocks using agricultural residues by compressing and thermally molding a mixture of chopped residues and molasses. Their research encourages the private sector to invest in the development and production of feed blocks made from agricultural residues, as the study demonstrates that such blocks can be effectively produced and offer a promising alternative to traditional animal feeds. The cost/benefit ratio for this approach was estimated at 1:1.19.

Producing silage for animal feed

Animal feed from silage production offers significant economic returns for the private sector in addition to its environmental benefits. Investing in this area can lead to substantial cost savings for dairy farmers and profitable opportunities for companies involved in the production and sale of silage products. The economic potential of silage production is further highlighted by studies that show a high cost/benefit ratio, making it a lucrative investment for private enterprises seeking both profitability and sustainability. According to Abo-Donia *et al.* (2024), co-ensiling rice straw with sugar beet has been shown to substantially improve the nutritional value of the feed, leading to higher milk production and better feed conversion ratios in lactating cows. This translates into lower feed costs for dairy farmers while increasing their overall productivity. As feed typically accounts for a significant portion of operating expenses in dairy farming, reducing the cost of feed while improving its quality can dramatically enhance a farm's profitability. This is where private sector investment in silage production becomes particularly attractive: by providing a cost-effective, high-quality feed product, companies can help farmers reduce operating costs while simultaneously increasing their milk yields.

From an investment standpoint, the economic return of silage production is highly favorable. For example, Gaafar *et al.* (2018) calculated the cost/benefit ratio of producing silage from corn in Egypt to be 1:2.1. While this specific study focused on corn, the principles apply similarly to the co-ensiling of rice straw and sugar beet, where the low cost of raw materials and the high demand for nutritious, cost-effective animal feed create the potential for similar, if not greater, returns on investment. Moreover, the market for ready-made silage products offers additional revenue streams for private companies. By producing, packaging, and distributing enhanced silage, businesses can cater to a growing number of dairy farms that prefer to purchase pre-made silage rather than producing it themselves. This market segment is particularly attractive in regions where dairy farms are expanding but may lack the infrastructure or expertise to produce high-quality silage on-site. Figure 18 illustrate silage production at large scale and small scale in the Nile Delta.

Figure 18. **Silage production at large scale in Monofya and small scale in Sharqia (Nile Delta)**

Utilizing azolla as a Nutritional Supplement in Animal Feed

The use of azolla as a feed supplement not only supports livestock productivity but also aligns with climate-smart agricultural practices, promoting resource efficiency and environmental sustainability (Pandey *et al.*, 2014) as aquatic fern it can be grown in small water bodies or paddy fields, utilizing minimal resources while fixing atmospheric nitrogen, which benefits the soil in addition of being rich in protein, essential amino acids, vitamins, and minerals, making it a highly nutritious feed supplement for livestock contributing to sustainable agricultural practices and reduces the need for chemical fertilizers. When used as a supplement, it has been shown to improve milk yield and quality in dairy cows, increase weight gain in beef cattle. This improved productivity translates into higher economic returns for farmers, making azolla an attractive investment for agribusinesses and feed manufacturers Kumar *et al.* (2012).

In Egypt, incorporating azolla into livestock feed can lead to substantial cost savings, as feed typically accounts for about 70–80 percent of animal production costs. By reducing the reliance on traditional concentrate feeds, farmers can lower their feed expenses while maintaining, or even enhancing, animal health and growth Soliman *et al.* (2024).

3.1.2 Reducing GHG emission from the livestock production system

Manure management and biogas production

Manure management plays a crucial role in reducing GHG emissions in Egypt. Proper handling and storage of manure can minimize these emissions, thus contributing to a reduction in the overall greenhouse gas emissions from the livestock sector. Additionally, manure is a valuable source of nutrients like nitrogen and phosphorus, which can be recycled back into the soil as organic fertilizers. This not only reduces the need for synthetic fertilizers that contribute to GHG emissions but also improves soil health and structure, enhancing its ability to sequester carbon (Pandey & Sharma, 2014). Manure undergoes anaerobic digestion to produce biogas, which can be utilized for energy generation such as electricity, heat, and vehicle fuel or upgraded to renewable natural gas. The process also results in digestate, which serves as a valuable resource for producing organic fertilizer contributing to sustainable agricultural practices and waste management.

Egypt produces approximately 11 million tonnes of cattle manure annually (Abou Hussein and Sawan, 2010), which, when not properly managed, contributes to methane emissions. This is another opportunity for private sector engagement that could further enhance environmental sustainability and resource efficiency. The use of anaerobic digesters (see Figure 19) to convert livestock manure into biogas offers a dual benefit: reducing methane emissions and providing renewable energy for local communities. Box (4) provide details about the Bioenergy for Sustainable Development Association Biogas Production in Egypt (BSDA). Abdel Monem *et al.* (2022) documented the successful conversion of livestock waste into biogas in some regions of Upper Egypt, particularly Luxor. Box 4 illustrates brief description of the Egyptian non-governmental organization.

Figure 19. Anaerobic digesters to convert livestock manure into biogas in Behera (Nile Delta)

Box 4. Bioenergy for sustainable development association in Egypt

BSDA is a non-governmental organization, establishment in 2009 that promotes and supports biomass technology applications in Egypt.

Main objectives:

1. Raise awareness of bioenergy technologies.
2. Facilitate development, transfer and application of biomass technologies tailored to the Egyptian market.
3. Overcome technical, institutional, informational, and financial barriers to create enabling environment for sustainable bioenergy projects.

Main achievements:

1. Implemented 1 743 biogas units across 19 governorates, with a production capacity of 1.8 million cubic meters.
2. Benefitted more than 9 000 citizens by reducing their reliance on LPG cylinders.
3. Produced 45 000 tonnes of organic fertilizer, enough to fertilize over 4 700 Feddan.
4. Support establishing 31 start-ups in the bioenergy sector.

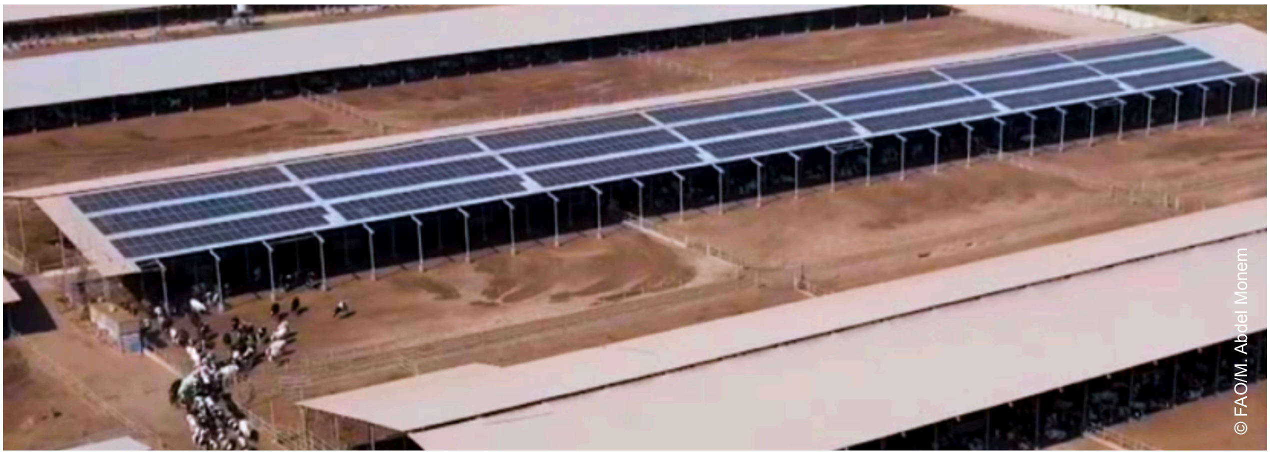
BSDA is institutionally supported by the Egyptian Ministry of Environment and collaborates with relevant stakeholders including beneficiaries and developing partners.

Source: BSDA (Bioenergy for Sustainable Development Association). 2022. Biogas production in Egypt. Masr El Kadima, Cairo. Available at: https://bio-egypt.org/

Agrivoltaics livestock farming in Egypt

- **Using solar panels to provide artificial shade for animals** is a CSL practice that offers multiple benefits. This concept, known as “Animal Agrivoltaics”, positively impacts both livestock and the environment. Solar panels strategically placed above grazing areas create shaded zones, allowing animals to escape direct sunlight and heat. In a study by Faria *et al.* (2023), dairy cows experienced improved thermal comfort, through relieving their heat load, and cooling their body surfaces. Beyond shade, the solar panels generate renewable electricity. This energy can power various farm operations, reducing reliance on grid electricity or fossil fuels. The co-generation of shade and electricity makes Animal Agrivoltaics an efficient approach. The study estimated that 63.5 g of methane emitted per animal per day could be offset by the electricity generated from solar panels. To achieve net-zero emissions for enteric methane, approximately 4.1 m^2 of solar panels (with a nominal power of 335 W) per cow would be needed. In Egypt, some of the large-scale farms in Monofya have implemented solar energy system that provides about 70 percent of the energy needs for the different activities at the farm including reducing the operational costs and, decreasing the carbon foot print of the dairy production and enhancing sustainability as shown in Figure 20.This is an opportunity for the private sector to scale up at the medium and small-scale farms as well.

Figure 20. **Solar energy for at a large-scale farm in Monofya**



- **Solar-Powered milk chilling units,** designed specifically for dairy farms of smaller scale, provide efficient means to cool and store milk temporarily during on-farm storage and transportation. By preventing bacterial growth and spoilage, they ensure that the milk remains fresh and safe for consumption. The use of solar energy in these chilling units not only enhances milk quality but also represents an eco-friendly alternative to conventional refrigeration methods, which often depend on fossil fuels (FAO, 2022a). By transitioning to solar power, dairy farms can significantly cut down on their carbon footprint, as solar-powered cooling requires less energy than traditional methods. This technology, therefore, contributes to the global effort to reduce GHG emissions and combat climate change. In addition to environmental benefits, solar-powered milk chilling systems provide economic advantages. By improving milk preservation and reducing waste, they can boost productivity and efficiency on dairy farms. Furthermore, local economies can benefit from the potential for manufacturing components like milk cans and other system parts, creating new business opportunities and supporting the agricultural value chain.

3.1.3 Breeding climate-resilient livestock through genetic selection

- Selective breeding for cattle with reduced carbon footprints represents a promising approach to mitigate greenhouse gas emissions in dairy production. This strategy focuses on key traits including survival rates, feed efficiency, and residual methane production. Research indicates that optimization of breeding indices can achieve emission reductions of 6–10 kg CO_2-eq per tonnes of milk produced (Wang *et al.*, 2025). However, this reduction represents only 0.25–0.42 percent of the global average dairy emissions of 2 400 kg CO_2-eq per tonnes of milk (FAO, 2010). While breeding programs offer potential for long-term emission reductions, they must be carefully designed to balance carbon mitigation goals with other essential breeding objectives such as productivity, fertility, and animal welfare. This integrated approach ensures that emission reductions do not come at the expense of overall health and dairy production efficiency.

- **Genetic selection of climate-resilient livestock breeds is a crucial strategy for addressing adverse climatic conditions** (Nardone, 2010). In Egypt, crossbreeding between local Baladi cattle and European breeds offers several significant advantages in livestock management. Baladi cattle, well-adapted to local environmental conditions, particularly heat stress, pass on their heat tolerance to offspring when crossbred with European breeds. This inherited resilience enables the crossbred animals to better withstand high temperatures, making them particularly suited to tropical climates. Simultaneously, European breeds contribute to higher milk and beef production, resulting in improved overall productivity in the crossbred offspring. This strategic combination of local and European genetics creates a synergy that enhances both adaptation and productivity. A study by Abdelharith (2019) further supports these benefits, reporting on a crossbreeding program aimed at improving milk and meat production in Egyptian Baladi cattle through crossing Baladi cows with two French breeds, Abondance and Tarentaise demonstrating genetic improvement in birth weight of the resulting crossbred calves.
- **Promoting artificial insemination (AI) technologies for increased productivity,** prevention, eradication, and control of livestock diseases, and selection of low methane-producing animals is one of the most widespread sets of CSA practices in livestock production (World Bank, 2018). Genetic improvement and selective breeding through AI provide access to genes from proven sires, improving genetic quality with desirable qualities. AI enables more precise control over breeding, allowing farmers to manage herd size more effectively. Smaller herds can reduce greenhouse gas emissions, as fewer animals contribute to methane production (Kandulu *et al.*, 2024). AI minimizes the risk of sexually transmitted diseases that can occur during natural mating. Disease control is crucial for maintaining healthy herds, especially with changing climate conditions. Healthy animals are better equipped to cope with environmental stressors, such as extreme temperatures and disease outbreaks (Thibier and Wagner 2022). AI allows farmers to use semen from a single bull to inseminate multiple cows, enhancing resource efficiency. This reduces the need for maintaining multiple bulls on the farm, thereby requiring less land for grazing and fewer resources for their care (FAO, 2022). The expansion of artificial insemination in the recent years in Egypt causes milk productivity increase per head for both buffaloes and cows from 1990 to 2019. El Eraky *et al.* (2022) explained that while the proportion of artificially inseminated cattle increased from 8.6 percent in 2000 to 22.1 percent in 2019, the rates for buffaloes remain modest.

  The private sector in Egypt has several opportunities to invest in the livestock artificial insemination industry, contributing to climate change solutions for livestock production challenges. Key areas include equipment supply and services, and genetic improvement programs to support genetic advancement. The compound annual growth rate for the Egypt animal artificial insemination market is projected to be 5.6 percent during the forecast period from 2024 to 2030. Soliman, and Mashhour, (2021) conducted a feasibility study on establishing a network of AI centers and units to serve the Egyptian buffalo population. Their analysis estimated the internal rate of return (IRR) and payback period for the AI network. The estimated IRR and payback period for the AI-Unit were 35 percent and 2.49 years, respectively. The IRR estimates significantly exceeded the Central Bank of Egypt's 2017 market discount rate of 17.5 percent, indicating feasible investment opportunities in the AI sector.

CHAPTER 4. Roadmap for implementation and opportunities for private sector engagement

Based on the findings of the study, this roadmap focuses on actions that lead transitioning Egypt's livestock sector towards climate-resilient and low-carbon practices, emphasizing private sector involvement and collaboration with local farmers and producers. It's structured around five key pillars.

4.1 Pillar 1: Primary analysis and policy framework

Objective: Establish a supportive regulatory and institutional environment for CSL practices.

Actions

- **Policy review and development:** align national policies with climate and agricultural goals, promoting sustainable livestock practices. reform subsidies to prioritize sustainability and reduce reliance on imported feed. integrate circular bioeconomy principles.
- **Data collection and analysis:** conduct comprehensive assessments of the livestock sector's GHG emissions using tools like SHARP+, identifying emission hotspots and developing region-specific action plans.
- **Regulatory framework for private sector:** creates clear guidelines for private sector participation, ensuring transparency, accountability, and incentives. simplify administrative processes for investments in sustainable technologies.

4.2 Pillar 2: Capacity-building and technology dissemination

Objective: Enhance the technical and institutional capacities of farmers, producers, and private sector stakeholders.

Actions

- **Farmer engagement and training:** conduct participatory workshops with local farmers and producers to raise awareness of climate change impacts and solutions, leveraging SHARP+ results. provide practical training on climate-resilient practices (for example utilizing agricultural waste for feed, producing silage and densified feed blocks, implementing manure management systems).
- **Technology transfer:** facilitate the introduction of innovative technologies (for example genetic improvement, methane inhibitors, agrivoltaics). partner with international organizations and research institutions for technology transfer.

- **Smallholder support:** establish cooperatives to enable resource pooling and access to modern technology. provide financial and technical assistance for adopting sustainable practices.
- **Inclusion of women and youth:** empower women and youth through tailored training and resource access. address gender gaps in decision-making and ownership.

4.3 Pillar 3: Private sector investment and collaboration

Objective: Mobilize private sector resources and expertise to scale up climate-smart practices and drive innovation.

Actions

- **Incentivize investments:** offer tax breaks, grants, and loans to encourage private investment in biogas plants, sustainable feed manufacturing, research on plant-based milk alternatives, and agrivoltaics projects through public–private partnerships.
- **Market development:** create markets for CSL products. strengthen value chains by connecting companies with smallholder farmers through contract farming. promote branding and certification of sustainable products.
- **Technology and infrastructure:** collaborate with technology providers to introduce digital tools for livestock management. invest in infrastructure for processing and distributing climate-smart products (such as cold storage, biogas processing units).
- **Research and innovation:** partner with research institutions to develop cost-effective climate-smart solutions. encourage private sector participation in pilot projects.

4.4 Pillar 4: Monitoring, evaluation, and continuous improvement

Objective: Establish a robust system to track progress, identify challenges, and ensure long-term sustainability.

Actions

- **Performance indicators:** develop measurable indicators to assess the adoption of climate-smart practices (such as GHG emission reductions, increased use of sustainable feed, improved productivity and resilience). utilize SHARP+ for measuring resilience at the household level.
- **Stakeholder involvement:** engage farmers, private sector players, and policymakers in the monitoring and evaluation process. establish feedback mechanisms.
- **Policy feedback loops:** use results to refine policies and programs. share success stories and lessons learned.
- **Knowledge sharing and scaling up:** develop platforms to disseminate best practices and innovations. scale up successful pilot projects for nationwide impact.

4.5 Pillar 5: Financing and resource mobilization

Objective: Mobilize sustainable financial resources to drive private sector engagement and support the adoption of CSL practices.

Actions

a. Public–private financing mechanisms:

- Establish blended financing models that combine public funds, private investments, and international climate finance to de-risk investments in climate-smart technologies.
- Create climate resilience funds to support agribusiness initiatives, focusing on sustainable feed production, biogas, and renewable energy projects.
- Leverage Egypt's Green Climate Fund readiness program to channel international funding into livestock-related climate-smart projects.

b. Access to credit and microfinance:

- Partner with financial institutions to provide low-interest loans and microcredit tailored for smallholder farmers and livestock producers adopting sustainable practices.
- Develop loan guarantee schemes to reduce risks for financial institutions and incentivize lending to climate-smart agribusiness risks.

c. Subsidy reform and incentives:

- Review and adjust existing agricultural subsidies to prioritize climate-smart interventions, such as methane reduction technologies, manure management systems, and renewable energy solutions.
- Offer tax incentives and grants to private companies investing in sustainable livestock production and processing technologies.

d. Private sector partnerships:

- Build partnerships between farming businesses, banks, and international donors to create new financial solutions that support climate-friendly livestock farming.
- Attract investments from private companies and venture capitalists to support startups working on plant-based milk, better livestock breeds, and digital tools to help manage livestock.

e. Carbon markets and ecosystem services:

- Create carbon offset programs focused on livestock, allowing private companies to earn money by reducing emissions through projects like biogas production and better feed practices.

f. Capacity-building for financial knowledge:

- Train farmers and small agribusinesses on financial management, grant applications, and accessing credit facilities.
- Work with local cooperatives to build their capacity in mobilizing resources for large-scale climate-resilient livestock projects.

CHAPTER 5. Key messages

1. The livestock sector contributes 37.5 percent of Egypt's agricultural production value, generating USD 8 billion annually. Over 1.8 million households depend on livestock farming, which is integral to rural livelihoods and food security. Egypt produces approximately 6 million tonnes of milk and 0.5 million tonnes of meat annually, with cattle and buffaloes being the primary sources of these essential food products.
2. Rising temperatures, erratic rainfall, and increased disease incidence are major risks to livestock productivity. Heat stress is expected to reduce productivity by over 30 percent in tropical regions like Egypt by 2050. Heat stress is significantly reducing the reproductive success of livestock, with dairy cow conception rates dropping by 20–27 percent during extreme heat, further straining the sector's productivity.
3. Global feed crop yields are projected to decline by 10–20 percent due to climate change, heavily affecting Egypt's livestock sector, which relies on imported feed. Water scarcity is another pressing issue, particularly in Upper Egypt.
4. Greenhouse Gas Emissions: Livestock production is a major source of GHG emissions, contributing 26 percent of emissions from global agri-food systems. Beef production, in particular, generates 295 $kgCO_2eq$ per kg of protein, compared to 31 $kgCO_2eq$ for chicken eggs.
5. Without significant improvements in efficiency and sustainability, livestock-related emissions could increase by 40 percent by 2050, accounting for nearly 50 percent of agri-food system emissions globally.
6. Innovative feed solutions include utilizing agricultural waste, producing complete feed blocks, and promoting silage cultivation are key climate-smart strategies for reducing feed shortages, improving feed conversion ratios, and lowering reliance on costly feed imports.
7. Climate smart solutions include manure management solutions, such as biogas production, offer dual benefits of methane reduction and renewable energy generation. Agrivoltaics (combining solar power and livestock farming) further enhances resilience by providing shade and clean energy.
8. Agrivoltaics for energy and livestock farming through Integrating solar energy production with livestock farming (agrivoltaics) offers multiple benefits, including reducing heat stress by providing shade for animals, generating clean energy, and diversifying income for farmers.
9. The private sector plays a transformative role in scaling CSL practices. By investing in sustainable feed production, renewable energy solutions like biogas, and innovative livestock management systems, private companies can lead the transition toward a more sustainable and resilient sector while creating economic opportunities for rural communities.
10. The government is essential in fostering private sector participation by creating an enabling environment. This includes implementing supportive policies, reforming subsidies to prioritize sustainable practices, and providing clear regulatory frameworks that incentivize private investment in climate-smart technologies.
11. Public–private partnerships are essential for implementing CSL practices. Private enterprises are key to capacity building, technology transfer, and strengthening market development for certified sustainable products. The roadmap emphasizes collaboration to scale innovative practices such as biogas production and agrivoltaics, supported by targeted financial mechanisms and robust monitoring systems to ensure progress.

12. It is essential to integrate livestock systems with sustainable land management practices in Egypt to enhance productivity and build climate resilience. Promote crop–livestock integration by utilizing organic manure to improve soil fertility and reduce dependence on chemical fertilizers. Incorporate crop rotation systems, including legumes such as clover and alfalfa, which serve as animal feed while enhancing soil fertility through atmospheric nitrogen fixation.
13. Women play a vital role in livestock management in Egypt but face significant challenges in ownership and economic power. Addressing these disparities through targeted interventions, such as access to credit, training, and inclusive policies, is essential to enhance productivity, equity, and the sustainability of CSL systems.

CHAPTER 6. Summary for the policy makers

The Egyptian livestock subsector plays a crucial role in the national food security, livelihoods, and economic development. However, it faces increasing pressure from climate change impacts, including rising temperatures, water scarcity, and extreme weather events. These challenges threaten productivity, animal health, and the overall sustainability of the subsector. This summary for the policy makers highlights the key findings of the report **"Building resilience in the Egyptian livestock subsector: climate change impacts and scaling up solutions"** and proposes policy recommendations for enhancing its resilience to climate change.

A. CLIMATE CHANGE IMPACTS ON THE EGYPTIAN LIVESTOCK SUBSECTOR

- **Egypt's livestock sector, a cornerstone of the national economy** and supporting millions of livelihoods, is increasingly threatened by climate change. The country faces a warming trend, with projections indicating further temperature increases, shifts in precipitation, rising sea levels, and more frequent extreme weather events. These changes severely impact livestock production, which is highly sensitive to environmental fluctuations. Smallholder farmers, most livestock producers, are particularly vulnerable due to their reliance on climate-sensitive resources like water and inadequate feed production system, coupled with limited adaptive capacity and financial resources. This vulnerability necessitates urgent, targeted interventions to build resilience and mitigate the adverse effects of climate change within Egypt's livestock systems.
- **The economic consequences of these climatic shifts are already evident.** Heat stress reduces milk yields, increasing cooling and feed costs, Egypt's reliance on importing 60 percent of its animal feed amplifies these cost pressures. The dairy sector, representing 30–35 percent of livestock revenue, is particularly vulnerable, with a 1 °C temperature increase above a cow's comfort zone decreasing milk yields by 5–10 percent globally, an effect worsened by Egypt's hot climate. Smallholder farmers, facing reduced income and limited adaptability, often resort to selling livestock, further jeopardizing their livelihoods.
- **The broader economic implications include rising meat and milk prices,** reduced exports, and increased food insecurity. A 2015 FAO report projects a potential 8 percent reduction in Egypt's agricultural GDP by 2050, with livestock losses playing a significant role. Addressing these challenges requires significant investment in CSL practices, estimated to cost hundreds of millions of dollars over the coming decades, to improve productivity, reduce mortality, and protect the livelihoods of millions dependent on this vital sector.

B. BUILDING RESILIENCE THROUGH ADAPTATION AND MITIGATION

B.1. Mitigation measures to reduce greenhouse gas emissions

- **Resilient breeds and genetic improvements** offer a crucial strategy for mitigating climate change impacts and enhancing livestock productivity. Crossbreeding local, heat-tolerant breeds, such as Baladi cattle, with European breeds known for higher productivity, create a more resilient and efficient herd. This approach reduces the overall number of animals required to meet production demands, thereby minimizing the environmental footprint of livestock farming. Furthermore, expanding artificial insemination programs enables selective breeding for traits like lower methane emissions and higher feed efficiency. This targeted approach accelerates genetic progress towards more sustainable and climate-resilient livestock systems.

- **Improved manure management** offers a dual approach to mitigating climate change impacts on agriculture and enhancing productivity. Expanding the use of anaerobic digesters converts livestock manure into biogas, a renewable energy source, while simultaneously reducing methane emissions. Furthermore, promoting the production of organic fertilizer from manure improves soil health and reduces reliance on chemical fertilizers, which contribute to greenhouse gas emissions.
- **Animal agrivoltaics** presents a multi-faceted solution for mitigating climate change impacts and enhancing livestock productivity. Integrating solar panels over animal production areas provides shade, reducing heat stress on livestock, a critical concern under rising temperatures. Simultaneously, these panels generate renewable electricity, offsetting emissions from farm operations. Further integration of solar power can extend to essential farm systems, such as water pumps, lighting, and refrigeration. Specifically, promoting solar-powered milk chilling units reduces spoilage and significantly decreases emissions associated with traditional fossil fuel-powered refrigeration.
- **Feed innovations** offer a promising pathway towards mitigating climate change impacts from livestock production. Incorporating methane inhibitors into livestock feed directly targets enteric fermentation, a significant source of methane emissions. Developing and promoting high-quality, low-emission feed formulations enhances feed efficiency, reducing emissions per unit of livestock product. Furthermore, utilizing agricultural residues, such as rice straw and wheat bran, as alternative feed sources minimize emissions associated with dedicated feed crop cultivation. This multi-pronged approach to feed innovation contributes to a more sustainable and climate-resilient livestock sector.
- **Plant-based alternatives** offer a significant opportunity to mitigate the environmental impact of food production. Expanding the production and market acceptance of plant-based milk provides a low-emission alternative to traditional dairy, reducing greenhouse gas emissions and land use associated with dairy farming. Simultaneously, promoting plant-based protein options diversifies diets, reducing reliance on resource-intensive livestock systems and contributing to a more sustainable and resilient food system.
- **Carbon offset programs** provide an incentive-based approach to encourage the adoption of sustainable livestock practices. Establishing such programs rewards farmers for implementing low-emission strategies, like biogas production from manure, which reduces methane emissions and provides a renewable energy source. Furthermore, incentivizing the use of solar energy in livestock operations displaces fossil fuel-based electricity, further lowering the carbon footprint of livestock farming. These programs create a financial mechanism to support the transition towards more environmentally friendly livestock production systems.

B2. Adaptation strategies

- **Improved animal management** represents a critical adaptation strategy in livestock farming to enhance resilience against climate challenges. Breeding programs focused on heat tolerance development create robust animal populations better equipped to maintain productivity under rising temperatures. Strategic shelter construction and advanced ventilation systems effectively shield livestock from heat stress while optimizing their comfort and well-being. Complementing these measures, carefully calibrated feeding strategies – including adjusted feed composition and timing – help maintain animal performance during heat stress periods, ensuring consistent productivity despite challenging environmental conditions.

- **Fodder security focuses** on ensuring a stable and sustainable feed supply for livestock, even under challenging environmental conditions. Promoting the cultivation of drought-resistant fodder crops, such as varieties that use less water and tolerate water scarcity, helps mitigate the impacts of climate variability on feed availability. Additionally, developing alternative feed resources, including the use of non-conventional feed sources like agricultural residues, provides farmers with more diverse and resilient options for livestock nutrition.
- **Effective disease management** is crucial for maintaining healthy livestock populations and minimizing economic losses. Strengthening veterinary services, including expanding access to veterinary care and diagnostic facilities, enables timely diagnosis and treatment of animal diseases. Implementing early warning systems allows for rapid detection and response to disease outbreaks, preventing widespread transmission. Promoting regular vaccination campaigns provides preventative protection against common livestock diseases, further safeguarding animal health and productivity.

C. POLICY RECOMMENDATIONS

C.1. Strengthening institutional capacity

- **Investing in research and development** is critical to advancing CSL practices. Establishing dedicated research programs that focus on heat-tolerant breeds, efficient feed formulations, and renewable energy integration can drive innovation in the sector. Collaborating with international research institutions and universities enables access to cutting-edge technologies and knowledge-sharing opportunities. Additionally, developing climate-resilient fodder varieties, such as drought-resistant Berseem and enhanced corn hybrids, strengthens feed security and supports sustainable livestock production.
- **Enhancing veterinary services** is essential to safeguard livestock health, particularly in the face of climate-related challenges. Expanding access to veterinary care in underserved regions, such as Upper Egypt, through increased veterinary clinics and mobile healthcare units ensures timely disease prevention and treatment. Strengthening disease surveillance systems improves the ability to monitor and respond to outbreaks of climate-sensitive diseases like foot-and-mouth disease (FMD) and lumpy skin disease (LSD). Continuous training for veterinarians on emerging climate-related health risks and modern diagnostic techniques further bolsters the resilience of livestock systems to health challenges.
- **Building the capacity of agricultural extension workers** is vital for the effective dissemination of CSL practices. Providing targeted training programs equips extension workers with the knowledge and skills to offer practical advice and technical support to farmers. Developing standardized training modules and certification programs ensures consistent and high-quality knowledge transfer, empowering extension workers to be effective agents of change in promoting sustainable livestock management.
- **The establishment of regional livestock resilience centers** is key to promoting innovation and collaboration in livestock systems. These centers of excellence, located in key livestock-producing regions, can serve as hubs for research, training, and resource distribution. By facilitating partnerships between farmers, researchers, and the private sector, these centers enable the testing and scaling of climate-smart solutions, contributing to the development of resilient and sustainable livestock systems.

C2. Financial incentives and support

- **Providing financial incentives** through subsidies encourages the adoption of climate-smart technologies within the livestock sector. Offering subsidies to offset the initial costs of implementing renewable energy systems, such as solar-powered pumps and biogas units, makes these technologies more accessible to farmers. Furthermore, providing financial support for purchasing drought-resistant fodder seeds and veterinary supplies for disease prevention enhances farmers' resilience to climate change impacts.
- **Grant programs** can effectively incentivize the adoption of sustainable livestock management practices. Allocating grants to farmers who implement best practices like rotational grazing, improved manure management, and silage production promotes wider adoption of these beneficial methods. Establishing competitive grant programs specifically focused on innovation in CSL solutions, such as novel feed formulations and methane inhibitors, further drives the development and implementation of cutting-edge technologies.
- **Facilitating access to tailored financial products** empowers farmers to invest in climate resilience. Partnering with financial institutions to create loan products with favorable interest rates specifically designed for investments in climate-smart technologies enables farmers to access the capital needed for these often-costly improvements. Developing livestock insurance programs that provide payouts triggered by climate events, such as droughts or extreme heat, protects farmers from devastating financial losses associated with climate-related risks.
- **Strategic tax policies** can create a supportive environment for CSL farming. Offering tax incentives for investments in sustainable practices, such as composting manure or installing renewable energy systems, encourages adoption by reducing the financial burden on farmers. Exempting imported climate-smart equipment, such as feed processing machinery or biogas digester components, from tariffs further lowers costs and facilitates access to advanced technologies.
- **Equipping farmers with financial management skills** is essential for the successful implementation of climate-smart practices. Providing training on applying for loans, managing finances, and understanding the economic benefits of adopting climate-smart practices empowers farmers to make informed decisions. Establishing resource centers that assist smallholder farmers with grant applications and navigating subsidy programs further ensures that these resources reach those who can benefit most.

C3. Integrating climate change into policy frameworks

- **Aligning national policies with global climate goals** is crucial to ensure livestock systems contribute to sustainable development. Integrating livestock-specific adaptation and mitigation targets into Egypt's nationally determined contributions (NDCs) under the Paris Agreement establishes a clear framework for addressing emissions and resilience in the sector. Developing a national strategy for CSL systems with defined objectives and timelines provides a roadmap for reducing emissions, enhancing resilience, and achieving long-term sustainability.
- **Reforming agricultural subsidies** is key to incentivizing climate-smart practices and discouraging unsustainable approaches. Redirecting subsidies away from water-intensive crops and unsustainable livestock practices towards interventions such as silage production, biogas systems, and drought-resistant fodder crops encourages sustainable resource use. Introducing performance-based subsidies that reward measurable improvements in productivity, resilience, or emissions reductions further motivates farmers to adopt climate-smart solutions, fostering efficiency and sustainability.

- **Strengthening regulatory frameworks** ensures compliance with climate-smart standards and promotes sustainable livestock management. Establishing clear guidelines for manure management, feed production, and disease prevention helps align practices with environmental objectives. Policies that encourage sustainable land use and crop–livestock integration enhance ecosystem health and productivity, contributing to more resilient and efficient agricultural systems.
- **Supporting cross-sectoral collaboration** is essential to address the interconnected challenges of livestock systems, water resources, and emissions reduction. Fostering partnerships between the Ministry of Agriculture, Ministry of Environment, and Ministry of Energy ensures a coordinated approach to policy development and implementation. Promoting collaboration between government agencies, private sector stakeholders, and research institutions drives innovation, mobilizes resources, and accelerates the adoption of CSL practices.
- **Promoting regional and international cooperation** enables the sharing of best practices and access to technical expertise for advancing CSL systems. Leveraging platforms like the Arab Organization of Agricultural Development and FAO facilitates knowledge exchange, funding opportunities, and capacity-building initiatives. Engaging in knowledge-sharing programs with countries facing similar climate challenges helps replicate successful adaptation and mitigation strategies, strengthening global efforts to address climate change impacts on livestock systems.

D. PRIVATE SECTOR ENGAGEMENT IN CLIMATE-SMART LIVESTOCK SOLUTIONS

- **The private sector plays a fundamental role** in driving innovation, investment, and scalability of CSL practices in Egypt. By collaborating with smallholder farmers, agribusinesses, and government institutions, private companies can contribute to transforming the livestock sector into a more climate-resilient and sustainable industry.
- **Opportunities for private sector investment** include the development of renewable energy systems, such as biogas plants and solar-powered infrastructure, which reduce greenhouse gas emissions while improving farm productivity. Companies specializing in animal nutrition can invest in research and production of high-quality, low-emission feed formulations, including methane inhibitors and agricultural residue-based alternatives. Furthermore, private firms can support the introduction of advanced breeding technologies, such as artificial insemination and genetic improvements, to enhance the adaptability and productivity of livestock under climate stress.
- **Private sector engagement can be facilitated through public–private partnerships** and financial incentives. Tax breaks, grants, and subsidies can encourage investment in climate-smart technologies like agrivoltaics, sustainable feed manufacturing, and digital livestock management tools. Companies can establish supply chain linkages with smallholder farmers through contract farming, enabling knowledge transfer, access to resources, and market opportunities for CSL products. Additionally, businesses can invest in value-added processing infrastructure, such as cold storage or biogas processing units, to ensure sustainable production and distribution of livestock products. These initiatives not only support the private sector's financial growth but also contribute to national goals of reducing greenhouse gas emissions, improving food security, and protecting livelihoods.
- **To further incentivize private sector participation,** Egypt can establish carbon offset programs and integrate livestock projects into global carbon markets. By investing in emission-reduction initiatives, such as biogas production and improved manure management, private companies can generate carbon credits while supporting the transition to sustainable livestock systems.

- **The private sector also has the potential to lead in branding and certification of CSL products,** creating new markets for environmentally conscious consumers and strengthening the competitiveness of Egypt’s livestock sector on a global scale. With strategic partnerships and targeted investments, the private sector can unlock significant opportunities to enhance resilience and ensure the long-term sustainability of Egypt’s livestock industry.

References

Abdelharith, H. 2019. *Estimation of genetic and crossbreeding parameters for birth weight in Baladi cattle and their crosses with Abondance and Tarentaise breeds in Egypt. Journal of Animal and Poultry Production*, 10 (6): 181–184.

AbdelMonem, M., Wong, T., Elbadawy, O., Faurès, J., Tawfic, M., Abouzeid, F. & Matteoli, F. 2022. *Towards climate-smart agriculture in Egypt – Scaling up sustainable practices for enhancing agrifood system resilience and adaptive capacity*. Cairo, FAO. https://doi.org/10.4060/cc2917en

Abdelsabour, T., Alary, V., Aboulnaga, A., Osman, M., Messad, S., Juanes, X., Elsayed, M. & Mansour, H. 2022. *Analysis of livestock assets, diversity and resilience for family farm systems in three different agro-ecological zones in Egypt. Options Méditerranéennes*, 7: 29–2022.

Abo-Donia, F.M., Elsheikh, H.A., Esh, A.M.H. 2024. *Co-ensiled rice straw with whole sugar beet and its effect on the performance of lactating cows*. Trop Anim Health Prod 56, 173 (2024). https://doi.org/10.1007/s11250-024-03945-9

Abosena, S.M. 2023. *An economic study of corn crop in Ismailia Governorate. Alexandria Science Exchange Journal*, 15 (44): 271–286.

Abou Hussein, S.D. & Sawan, O.M. 2010. *The utilization of agricultural waste as one of the environmental issues in Egypt (a case study). Journal of Applied Sciences Research*, 6 (8): 1116–1124.

Alary, V., Aboul-Naga, A., El Shafie, M., Abdelkrim, N., Hamdon, H. & Metawi, H. 2015. *Roles of small ruminants in rural livelihood improvement – Comparative analysis in Egypt. Revue Élev. Méd. Vét. Pays Trop.*, 68 (2–3): 79–85.

Alary V., Aboul-Naga A., El Shafie M., Abdelkrim N., Hamdon H., Metawi H. 2015. *Roles of small ruminants in rural livelihood improvement – Comparative analysis in Egypt*. Rev. Elev. Med. Vet. Pays Trop., 68 (2-3): 79-85.

Al-Sharqawi, E.M., Saleh, O.E., Ahmed, M.A., Abdel Razek, Y.S. & Mohamed, E.A. 2019. *Animals' need of feed, economies of their production and consumption in Egypt. Alexandria Science Exchange Journal*, 40: 87–103.

AL-Hosary A, Ahmed L, Ahmed J, Nijhof A, Clausen PH. 2018. Ep*idemiological study on tropical theileriosis (Theileria annulata infection) in the Egyptian Oases with special reference to the molecular characterization of Theileria spp*. Ticks Tick-Borne Dis. 9:1489–93. doi: 10.1016/j.ttbdis.2018.07.008.

Arango, J., Ruden, A. & Chirinda, N. 2020. *Ambition meets reality: achieving GHG emission reduction targets in the livestock sector of Latin America*. Front. Sustain. Food Syst., 4:65. doi:10.3389/fsufs.2020.00065.

Carbon Brief. 2017. Global warming could cause yield of sorghum crops to drop 'substantially'. Available at: https://www.carbonbrief.org/global-warming-could-cause-yield-sorghum-crops-drop-substantially/

Chadalavada, K., Kumari, B.D.R. & Kumar, T.S. 2021. Sorghum mitigates climate variability and change on crop yield and quality. *Planta*, 253:113. https://doi.org/10.1007/s00425-021-03631-2

Cheng, M., McCarl, B. & Fei, C. 2022. Climate change and livestock production: A literature review. *Atmosphere*, 13(1):140. https://doi.org/10.3390/atmos13010140

Delgado, C.L. 2003. Rising consumption of meat and milk in developing countries has created a new food revolution. The Journal of Nutrition, 133(11):3907S–3910S.

El Damaty, H.M., Fawzi, E.M., Neamat-Allah, A.N.F., Elsohaby, I., Abdallah, A., Farag, G.K., El-Shazly, Y.A. & Mahmmod, Y.S. 2021. Characterization of foot-and-mouth disease virus serotype SAT-2 in swamp water buffaloes (*Bubalus bubalis*) under the Egyptian smallholder production system. *Animals*, 11(6):1697. https://doi.org/10.3390/ani11061697

El-Eraky, M., Gomaa, R., Bakri, E. & Sarhan, H. 2022. Trends of milk production in Egypt. *Egyptian Journal of Agricultural Economics*, 32(3):715–730. https://doi.org/10.21608/meae.2022.152762.1077

Elfeki, M., Elbestawy, E. & Tkadlec, E. 2017. Bioconversion of Egypt's agricultural wastes into biogas and compost. *Polish Journal of Environmental Studies*, 26(6):2445–2453.

El-Shabrawy, T.H. & Al-Rajhi, M.A. 2020. Prototype for animal feed blocks. *Journal of Soil Sciences and Agricultural Engineering*, Mansoura University, 11(11):601–608.

Eom, H.J., Lee, S. & Yoo, H.S. 2023. Lumpy skin disease as an emerging infectious disease. *Journal of Veterinary Science*, 24(3). https://doi.org/10.4142/jvs.23016

Fahim, N.H., Abdel-Salam, S., Mekkawy, W., Ismael, A., Abou-Bakr, S., El Sayed, M. & Ibrahim, M.A.M. 2018. Delta and Upper Egypt buffalo farming systems: A survey comparison. Egyptian Journal of Animal Production, 55(2):95–106.

FAO. 2010. *Greenhouse gas emissions from the dairy sector: A life cycle assessment*. Rome, FAO. Available at: https://www.fao.org/3/k7930e/k7930e.pdf

FAO. 2012. *Food wastage footprint: Impacts on natural resources*. Technical report. Rome, FAO. Available at: https://www.fao.org/4/ar429e/ar429e.pdf

FAO. 2014. *Egyptian clover (Trifolium alexandrinum): King of forage crops*. Rome, FAO. Available at: https://openknowledge.fao.org/server/api/core/bitstreams/947fa627-c9f2-4f67-b725-e0ef30d220c7/content

FAO. 2016. *Livestock in protracted crises: The importance of livestock for resilience-building and food security of crisis-affected populations*. Rome, FAO.

FAO. 2017. *Africa Sustainable Livestock 2050: Egypt country brief*. Rome, FAO. (I7312EN/1/05.1). Available at: https://www.fao.org/documents/card/en/c/I7312EN

FAO. 2017a. *Climate-Smart Agriculture Sourcebook*. Rome, FAO. Available at: http://www.fao.org/climate-smart-agriculture-sourcebook/en/

FAO. 2018. *Livestock production systems spotlight: Cattle and buffaloes and poultry sectors in Egypt*. Rome, FAO. (I8477EN/1/01).

FAO. 2019. *The State of Food and Agriculture 2019: Moving forward on food loss and waste reduction*. Rome, FAO.

FAO. 2020. *Animal health and climate change*. Rome, FAO. Available at: https://openknowledge.fao.org/server/api/core/bitstreams/da3f8543-c638-4d98-9e23-d5a0db708ff3/content

FAO. 2020a. *The long-term future of livestock and fishery in Egypt: Production targets in the face of uncertainty*. Rome, FAO. Available at: https://doi.org/10.4060/ca9574en

FAO. 2022a. *Self-evaluation and holistic assessment of climate resilience of farmers and pastoralists (SHARP+)*. Rome, FAO. https://openknowledge.fao.org/server/api/core/bitstreams/70d979e6-a299-4aa5-8bd7-e8a018cacb3d/content

FAO. 2022b. *Country Gender Assessment of the Agriculture and Rural Sector: Egypt – Brief. Country gender assessment series – Near East and North Africa*. Cairo. https://doi.org/10.4060/cb7909en

FAO. 2023a. *Unlocking the potential of sustainable livestock production*. Rome, FAO. Available at: https://www.fao.org/newsroom/detail/unlocking-the-potential-of-sustainable-livestock-production/en

FAO. 2023b. *FAO Global Conference on Sustainable Livestock Transformation (GC–SLT)*. Rome, FAO. Available at: https://www.fao.org/3/cc6913en/cc6913en.pdf

Faria, A.F.P.A., Maia, A.S.C., Moura, G.A.B., Fonsêca, V.F.C., Nascimento, S.T., Milan, H.F.M., & Gebremedhin, K.G. 2023. *Use of solar panels for shade for Holstein heifers*. Animals 2023, 13, 329. Available at: https://doi.org/10.3390/ani13030329

Gaafar, H.M.A., El-Gendy, M.E., Bassiouni, M.I., Shamiah, S.M., Halawa, A.A., & Abu El-Hamd, M.A. 2011. *Effect of heat stress on performance of dairy Friesian cows: 1–Milk production and composition*. Researcher, 3(5):85-93. Available at: http://www.sciencepub.net

Gaafar, H.M.A., Riad, W.A., & El-Esawy, G.S. 2018. *Nutritional and economical evaluation of Watania corn hybrids silages*. Journal of Animal and Poultry Production, 9(4), 211-218. doi:10.21608/jappmu.2018.39815

Gabr, M.F. 2023. *Impact of climatic changes on future irrigation water requirement in the Middle East and North Africa region: A case study of Upper Egypt*. Applied Water Science, 13:158. Available at: https://doi.org/10.1007/s13201-023-01961-y

Garnett, T., Appleby, M.C., Åström, S., Björnström, B., & Green, R.E. 2009. *Sustainable intensification in agriculture: Premises, potentials, and negative impacts*. Current Opinion in Environmental Sustainability, 1(1), 5-11.

Gilbert, L. 2021. *The impacts of climate change on ticks and tick-borne disease risk*. Annual Review of Entomology, 66, 2021.

Goma, A.A., & Phillips, C.J.C. 2021. *The impact of anthropogenic climate change on Egyptian livestock production*. Animals, 11(11), 3127. Available at: https://doi.org/10.3390/ani11113127

Goma, A.A., & Phillips, C.J.C. 2022. *'Can they take the heat?'–The Egyptian climate and its effects on livestock*. Animals, 12, 1937. Available at: https://doi.org/10.3390/ani12151937

Hassan, H.A., El Gebaly, M.R., Ghani, S., & Hussein, M. 2014. *An economic study of recycling agricultural wastes in Egypt*. Middle East Journal of Agriculture Research, 3(3), 592-608.

Habeeb, A.A.M., El-Masry, K.A., & Atta, M.A.A. 2014. *Growth traits of purebred and crossbred bovine calves during winter and summer seasons*. The 4th International Conference on Radiation Sciences and Applications, 13-17 October 2014, Taba, Egypt, PP:1-10.

Habeeb, A.A.M., Gad, A.E., & El-Tarabany, A.A. 2018. *Negative effects of heat stress on growth and milk production of farm animals*. Journal of Animal Husbandry and Dairy Science, 2(1), 1-12.

Haider, A., Abbas, Z., Taqveem, A., Ali, A., Khurshid, M., Naggar, R.F.E., Rohaim, M.A., & Munir, M. 2024. *Lumpy skin disease: Insights into molecular pathogenesis and control strategies*. Vet. Sci., 11, 561. Available at: https://doi.org/10.3390/vetsci11110561

Henry, B.K., Eckard, R.J., & Beauchemin, K.A. 2018. *Review: Adaptation of ruminant livestock production systems to climate changes*. Animal, 12(s2), pp. s445–s456. Available at: https://doi.org/10.1017/S1751731118001301

Hussein, M.H., & Abd El-Rahman, A.A. 2012. *Comparative study on milk production and its composition from Holstein Friesian and Egyptian Baladi cow under extensive and semi-intensive grazing systems*. Journal of Animal and Veterinary Advances, 11(6), 838-845.

International Labor Organization (ILO). 2020. *Developing the dairy value chain in Egypt's Delta market system analysis*. Available at: https://www.ilo.org/publications/developing-dairy-value-chain-egypts-delta-market-system-analysis

Jamil, M., Latif, N., Bano, R., Ali, S.A., Qaisar, M.A., Ullah, N., *et al.* 2022. *Lumpy skin disease: An insight in Pakistan*. Pak J Med, 16, 824–827. Available at: https://doi.org/10.53350/pjmhs22166824

Kandulu, J., Zuo, A., Wheeler, S., Dusingizimana, T., & Chagunda, M. 2024. *Impact of climate-smart technologies on livestock productivity in East Africa*. Journal of Agricultural Sustainability, 31(1), 45-63. Available at: https://doi.org/10.1007/s11027-025-10220-x

Karwowska, M., Łaba, S., & Szczepański, K. 2021. *Food loss and waste in the meat sector–Why the consumption stage generates the most losses?* Sustainability, 13, 6227. doi:10.3390/su13116227

Knight-Jones, T.J.D., & Rushton, J. 2013. *Economic impacts of foot-and-mouth disease: A global review*. Preventive Veterinary Medicine, 112(4), 161-173. Available at: https://doi.org/10.1016/j.prevetmed.2013.07.013

Kumar, P., Garg, A.K., & Dass, R.S. 2012. *Nutritional evaluation of azolla (azolla pinnata) as a protein supplement for livestock and poultry*. Indian Journal of Animal Sciences, 82(7), 698-700.

Magan, N., Medina, A., & Aldred, D. 2011. *Climate change effects on mycotoxin contamination in cereals*. Plant Pathology, 60(1), 150-163. Available at: https://doi.org/10.1111/j.1365-3059.2010.02346.x

Machen, R. 2011. **Tending cattle after the winter storm**. Texas Extension Disaster Education Network, Texas A&M AgriLife Extension Service. Accessed September 1, 2012. Available at: http://texaseden.org/disaster-resources/wp-content/uploads/2011/05/Tending-Cattle-afterthe-Storm.pdf

Maze, M., Taqi, M.O., Tolba, R.A.A., & Lohakare, J. 2024. *Estimation of methane greenhouse gas emissions from livestock in Egypt during 1989 to 2021*. Scientific Reports, 14(1), 1–15. Available at: https://doi.org/10.1038/s41598-024-63011-0

Ministry of Agricultural and Land Reclamation (MoALR). 2022. *Dairy buffalo feed: By the numbers - How to prepare the first ton*. Cairo, Egypt.

Mohamed, H.M., El-Assal, S.M., Gamal El-Din, A.Y., & El-Khishin, D.A. 2024. *Analysis of genetic diversity and population structure in some Egyptian Berseem (Trifolium alexandrinum) accessions based on ISSR, SCoT and SRAP markers*. Journal of Genetic Resources and Crop Evolution. Available at: https://link.springer.com/article/10.1007/s10722-024-01940-5

Moussa, H.M., Barghash, R.M., & Hassan, A.A. 2011. *Current situation of the animal feed gap in Egypt*. Journal of Basic and Applied Sciences Research, 1(7), 713-720. Available at: https://www.textroad.com/pdf/JBASR/J.%20Basic.%20Appl.%20Sci.%20Res.,%201(7)713-720,%202011.pdf

Mottet, A., Henderson, B., Opio, C., Falcucci, A., Tempio, G., Silvestri, S., Chesterman, S., & Gerber, P.J. 2016. *Climate change mitigation and productivity gains in livestock supply chains: insights from regional case studies*. Regional Environmental Change, 17, 129–149. doi:10.1007/s10113-016-0986-3

Mordor Intelligence. 2023. *Dairy market size & share analysis - growth trends & forecasts up to 2029*. Available at: https://www.mordorintelligence.com/industry-reports/dairy-products-market

Nardone, A., Ronchi, B., Lacetera, N., & Bernabucci, U. 2010. *Effects of climate changes on livestock production and sustainability*. Livestock Science, 130(1-3), 57-69. Available at: https://doi.org/10.1016/j.livsci.2010.02.011

Mun, W., Garroutte, E., & Obasanjo, I. 2023. *Rising temperatures and spatiotemporal patterns of foot-and-mouth disease in Mongolia*. International Journal of Environmental Research and Public Health, 20(8), 5468. Available at: https://doi.org/10.3390/ijerph20085468

Nuttall, P.A. 2022. *Climate change impacts ticks and tick-borne diseases*. Biologia, 77(6), 1503-1512. Available at: https://doi.org/10.1007/s11756-021-00927-2

Organization for Economic Co-operation and Development (OECD) and FAO. 2017. *Agricultural Outlook 2017–2026*. Paris, OECD Publishing. Available at: http://www.oecd-ilibrary.org/agriculture-and-food/oecd-fao-agricultural-outlook-2017-2026_agr_outlook-2017-en

OECD and FAO. 2021. *OECD-FAO Agricultural Outlook 2021-2030*. Paris, OECD Publishing. Available at: https://doi.org/10.1787/19428846-en

Omambia, A.N., Shemsanga, C., & Hernandez, I.A.S. 2017. *Climate change impacts, vulnerability, and adaptation in East Africa (EA) and South America (SA)*. In *Handbook of Climate Change Mitigation and Adaptation*.

Omran, F., Khali, A., & Fooda, T. 2020. *Physiological responses & hematological aspects of buffaloes and cows under different climatic conditions in Egypt*. Egyptian Journal of Agricultural Research, 98(1), 64-79.

Omran, F., & Fooda, T. 2023. *Impact of chronic heat stress on buffalo dams in the Nile Valley*. The Egyptian Journal of Agricultural Research. Available at: https://doi.org/10.21608/EJAR.2023.155364.1265

Pandey, D.N., & Sharma, L. 2014. *azolla: A Sustainable Feed Supplement for Livestock*. Agricultural Research, 3(2), 137-141.

Poore, J., & Nemecek, T. 2018. *Reducing food's environmental impacts through producers and consumers*. Science, 360(6392), 987-992. Available at: https://doi.org/10.1126/science.aaq0216

Ráduly, Z., Szabó, L., Madar, A., Pócsi, I., & Csernoch, L. 2020. *Toxicological and medical aspects of Aspergillus-derived mycotoxins entering the feed and food chain*. Frontiers in Microbiology, 10, 2908. Available at: https://doi.org/10.3389/fmicb.2019.02908

Ritchie, H. 2024. *What are the trade-offs between animal welfare and the environmental impact of meat?* Our World in Data. Available at: https://ourworldindata.org/what-are-the-trade-offs-between-animal-welfare-and-the-environmental-impact-of-meat

Rojas-Downing, M.M., Nejadhashemi, P.A., Harrigan, T., & Woznicki, S.A. 2017. *Climate change and livestock: Impacts, adaptation, and mitigation*. Climate Risk Management. Available at: http://hdl.handle.net/11427/28501

Saad, B.H. 2024. *Assessment of Rural Livelihood Resilience in Egypt*. Alexandria Science Exchange Journal, 45(4), 617-632.

Sejian, V., Gaughan, J.B., Bhatta, R., & Naqvi, S.M.K. 2016. *Impact of climate change on livestock productivity*. Feedipedia, No. 26, February 2016. Retrieved 1 February 2024, from www.feedipedia.org

Selim, A., Manaa, E., & Khater, H. 2021. *Seroprevalence and risk factors for lumpy skin disease in cattle in Northern Egypt*. Tropical Animal Health and Production, 53, 350. Available at: https://doi.org/10.1007/s11250-021-02786-0

Singer, A.M. 2024. *Effect of feeding sorghum husk treated with urea on nutrient digestibility in Saidi male lambs*. Egyptian Journal of Nutrition and Feeds, 27(1), 11-20.

Shoukry, M.M. 2021. *The future of livestock development in Egypt: Current and future challenges*. Egyptian Journal of Nutrition and Feeds, 24(2), 1-7. Available at: https://ejnf.journals.ekb.eg/article_210568.html

Sorghum Checkoff. 2019. *The Resource Conserving Crop*. Retrieved 1 February 2024, from https://www.sorghumcheckoff.com

Soliman, A.H., El-Hady, S.M., & Mohamed, S.A. 2024. *The Effect of azolla Inclusion in Livestock Diets on Animal Performance and Economic Returns*. Tropical Animal Health and Production, 56(1), 45-54.

Soliman, I., & Mashhour, A.F. 2021. Feasibility of artificial insemination network for Egyptian buffalo development.

Statista. 2023. *Global dairy industry statistics & facts*. Retrieved 1 February 2024, from https://www.statista.com/topics/4649/dairy-industry/

Statista. 2024. *Sorghum production in Egypt*. Retrieved 1 February 2024, from https://www.statista.com/statistics/1066586/egypt-sorghum-production-volume/

Tarawali, S., Amanor Boadu, V., Baltenweck, I., de Haan, N., Kohler-Rollefson, I. 2019. *Innovation for sustainable livestock: livelihoods and economic growth*. Background paper for the 9th annual Multi-stakeholder Partnership Meeting of the Global Agenda for Sustainable Livestock, 9–12 September 2019, Manhattan, KS, United States of America. Available at: www.livestockdialogue.org/fileadmin/templates/res_livestock/docs/2019

Thibier, M., & Wagner, H.G. 2022. World statistics for artificial insemination in cattle. *Livestock Production Science*, 74(2), 203-212. https://doi.org/10.1016/S0301-6226(01)00297-3

Timilsena, B.P., Nassy, S., Kimathi, E.M., Abdel Rahman, E.M., Seidl Adams, I., Wamalwa, M., Tonnang, H.E.Z., Ekesi, S., Hughes, D.P., Rajotte, E.G., & Subramanian, S. (2022). *Potential distribution of fall armyworm under climate change scenarios. Scientific Reports*, 12, 14369. https://doi.org/10.1038/s41598-021-04369-3

Thornton, P.K. 2010. Livestock production: Recent trends and future prospects. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 365(1554), 2853-2867. https://doi.org/10.1098/rstb.2010.0134

United Nations Environment Programme (UNEP). 2023. *Emissions Gap Report 2023: Broken Record – Temperatures hit new highs, yet world fails to cut emissions (again)*. Nairobi. https://doi.org/10.59117/20.500.11822/43922

Van de Steeg, J., & Tibbo, M. 2012. *Livestock and climate change in the Near East region*. Cairo: FAO. https://www.fao.org/3/i2714e/i2714e.pdf

Wang, B., Meng, F., Wang, W., Wang, G., Sun, C., Yang, Z., Wang, Y., Han, H., Meng, Y., He, J., Wang, Y., Liao, M., Wu, B., & Sun, B. 2025. Current carbon policies and emerging emission control technologies in the dairy supply chain: A global review. Retrieved from https://doi.org/10.21203/rs.3.rs-5672225/v1

WOAH. 2019. World Organization of Animal Health report on foot-and-mouth disease. Retrieved 1 February 2024, from https://www.woah.org/en/disease/foot-and-mouth-disease/

World Bank. 2018. *Scaling up climate-smart agriculture through the Africa Climate Business Plan*. Washington, DC: World Bank.

World Bank. 2020. *PovcalNet: an online analysis tool for global poverty monitoring*. World Bank, Washington, DC, United States of America. Available at: http://iresearch.worldbank.org/PovcalNet/home.aspx (accessed on 10 March 2021).

Zarei, M., Amirkolaei, A.K., Trushenski, J.T., Sealey, W.M., Schwarz, M.H., Ovissipour, R. 2022. Sorghum as a potential valuable aquafeed ingredient: Nutritional quality and digestibility. *Agriculture*, 12, 669. https://doi.org/10.3390/agriculture12050669

Zhang, L., Tian, H., Shi, H., Pan, S., Dangal, S.R., Qin, X., Wang, S., Tubiello, F.N., Canadell, J.G., & Jackson, R.B. 2022. A 130-year global inventory of methane emissions from livestock: Trends, patterns, and drivers.

Scaling up Climate Ambition on Land Use and Agriculture through Nationally Determined Contributions and National Adaptation Plans (SCALA), is an initiative led by FAO and UNDP, implemented from 2021 to 2028, with funding from the German Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection (BMUV) through the International Climate Initiative (IKI).

SCALA responds to the urgent need for increased action to cope with climate change impacts in the agriculture and land use sectors. The twenty-six million euro programme will support at least twelve countries in Africa, Asia and Latin America to build adaptive capacity and to implement low emission priorities.

Country support includes strengthening policies, adopting innovative approaches to climate change adaptation and removing barriers related to information gaps, governance, finance, gender mainstreaming and integrated monitoring and reporting. To achieve this shift, the programme engages the private sector and key national institutions.

SCALA supports countries to develop the capacity to own and lead the process to meet targets set out in their National Adaptation Plans and Nationally Determined Contributions under the Paris Agreement, and to achieve the Su ainable Development Goals. The SCALA initiative builds on another FAO-UNDP led programme, Integrating Agriculture in National Adaptation Plans (2015-2020). which has closed.

Food and Agriculture Organization of the United Nations
www.fao.org/in-action/scala/en

United Nations Development Programme
www.adaptation-undp.org/scala

International Climate Initiative (IKI)
www.international-climate-initiative.com

German Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection (BMUV) www.bmuv.de/en/

Supported by:

Federal Ministry
for the Environment, Nature Conservation,
Nuclear Safety and Consumer Protection

IKI INTERNATIONAL CLIMATE INITIATIVE

based on a decision of
the German Bundestag

ISBN 978-92-5-139717-6

9 789251 397176

CD4914EN/1/05.25