Discussion Paper Series

The KENYA INSTITUTE for PUBLIC
POLICY RESEARCH and ANALYSIS

An Assessment of Kenya's Sustainable Smart Dairy Farming: Trends and Scenario Analysis

Dorah Momanyi and Faith Pepela

DP/328/2024

THE KENYA INSTITUTE FOR PUBLIC POLICY
RESEARCH AND ANALYSIS (KIPPRA)

YOUNG PROFESSIONALS (YPs) TRAINING
PROGRAMME

An Assessment of Kenya's Sustainable Smart Dairy Farming: Trends and Scenario Analysis

Dorah Momanyi and Faith Pepela

Kenya Institute for Public Policy
Research and Analysis

KIPPRA Discussion Paper No. 328
2024

KIPPRA in Brief

The Kenya Institute for Public Policy Research and Analysis (KIPPRA) is an autonomous institute whose primary mission is to conduct public policy research leading to policy advice. KIPPRA's mission is to produce consistently high-quality analysis of key issues of public policy and to contribute to the achievement of national long-term development objectives by positively influencing the decision-making process. These goals are met through effective dissemination of recommendations resulting from analysis and by training policy analysts in the public sector. KIPPRA therefore produces a body of well-researched and documented information on public policy, and in the process assists in formulating long-term strategic perspectives. KIPPRA serves as a centralized source from which the Government and the private sector may obtain information and advice on public policy issues.

Published 2024

Bishops Garden Towers, Bishops Road
PO Box 56445-00200 Nairobi, Kenya
tel: +254 20 2719933/4; fax: +254 20 2719951
email: admin@kippra.or.ke
website: http://www.kippra.org

ISBN 978 9914 738 67 4

The Discussion Paper Series disseminates results and reflections from ongoing research activities of the Institute's programmes. The papers are internally refereed and are disseminated to inform and invoke debate on policy issues. Opinions expressed in the papers are entirely those of the authors and do not necessarily reflect the views of the Institute.

This paper is produced under the KIPPRA Young Professionals (YPs) programme. The programme targets young scholars from the public and private sector, who undertake an intensive one-year course on public policy research and analysis, and during which they write a research paper on a selected public policy issue, with supervision from senior researchers at the Institute.

KIPPRA acknowledges generous training on futures foresight methodology by EDHEC Business School, France; and the UNESCO Futures Literacy Laboratory Chair at Dedan Kimathi University of Technology (DeKUT), Kenya. The course on "Building Strategic Foresight Capabilities" by EDHEC Business School was beneficial for building capacity of Young Professionals on futures foresight.

Abstract

Smart dairy farming uses advanced sensing and analyzing technologies to reduce environmental issues, raise animal health, and meet the demand for milk and milk products. The sustainable adoption and use of this system in developing countries is limited given the high initial capital-intensive technologies, inadequate capabilities, and infrastructure. As such, many developing economies like Kenya have experienced low yields, milk waste and losses, compromised animal welfare, and environmental degradation. This paper analyses trends and develops scenarios in the dairy sector using a qualitative foresight approach employing a literature review approach, intuitive data analysis, and the Delphi technique. The findings from this study first suggest that the adoption of emerging trends such as dairy intensification, dairy automation, and environmental sustainability could improve productivity and processes throughout the dairy value chain. Secondly, land intensification, animal welfare, technology, greenhouse emissions, research, and development, rising incomes, and resource scarcity are key drivers that stakeholders could look out for and find ways to mitigate their effects. Finally, the multiple futures in the dairy industry could require high investment in animal welfare to support changing consumer preferences, green purchasing, and efficient use of land resources to meet the projected increase in demand for milk particularly in developing countries. Kenya's dairy sector thus holds significant potential for growth and sustainability. The government could repurpose agricultural policies and financing mechanisms to support the adoption and scaling of smart dairy technologies by smallholder farmers. In addition, they could establish robust regular data collection and analysis systems on the key drivers to monitor how they evolve to support quick response and redesigning of the industry. Finally, stakeholders could capacity-build smallholder farmers and consumers on the nexus between dairy farming and environmental sustainability to enable consumers to purchase environmentally friendly animal products and smallholders to adopt sustainable and resilient smart dairy techniques.

Abbreviations and Acronyms

4IR	Fourth Industrial Revolution
AI	Artificial Intelligence
BETA	Bottom-Up Economic Transformation Agenda
FAOSTAT	Food and Agriculture Organization Corporate Statistical Database
GDP	Gross Domestic Product
GPI	Gross Product Index
GSM	Global Systems for Mobile
ILRI	International Livestock
IOT	Internet of Things
KNBS	Kenya Bureau of standards
LU	Livestock units
ML	Machine Learning
NDC	Nationally Determined Contribution
NZ	New Zealand
PDF	Precision Dairy Farming
PESTEL	Political, Environmental, Social, Technological, Environmental and Legal
CSA	Climate Smart Agriculture
SDF	Smart Dairy Farming
SDGs	Sustainable Development Goals
STS	Social Technical System Theory
SWOT	Strengths, Weaknesses, Opportunities and Threats
USA	United States of America
USDA	United States Department of Agriculture

Table of Contents

List of Tables

List of Figures

1. Introduction

The dairy sector is one of the fastest-growing agricultural sub-sectors in Eastern African countries, which has generated significant economic returns and employment opportunities. Kenya has one of the largest dairy sectors in East-Saharan Africa with an estimated 4.3 million dairy cattle and milk production of 754.3 million litres in 2022 (KNBS 2023). The annual per capita milk consumption estimates vary between 80 and 100 litres, which is the highest in Africa. The sector plays a significant role in food and nutrition security, rural development, and poverty reduction (Henchion et al., 2022). Dairy farming in Kenya contributes 3.5% of Kenya's national GDP and 12% of the agricultural Gross Domestic Product (GDP) (KNBS 2023). According to the KNBS Economic Survey 2024, the quantities of processed milk and cream increased by 17.3 percent to 555.4 million litres in 2023. Further, the quantities of processed butter and ghee increased by 34.7 per cent from 742.0 tonnes to 999.6 tonnes. In the fourth Medium Term plan, livestock value chains are identified as a priority area. Of the 2900 million allocated to dairy and leather, the government allocated Ksh. 2,130 million for the "Livestock Value Chain Support Project" Additionally the dairy sector has been highlighted as a key enabler to the Bottom-Up Transformation Agenda (BETA).

Despite the favorable trends described above, several issues constrain the development of the dairy sector in Kenya. First, Kenya has a low rate of processing capacity utilization with a 25% share of idle capacity. Low demand for processed dairy products and their limited diversification where more than 60% of the raw milk supply is processed as fresh, pasteurized whole milk often limit the use of available capacity. Secondly, the supply side is faced with high milk production and collection costs and the inadequate quality of raw milk. While the Government of Kenya's policy ambition for the sector, enshrined in the Kenya National Dairy Master Plan, is to increase the share of the formal processed chain in the milk market and to improve milk quality, little progress has been achieved. Poor milk quality limits the volumes of value-added products. The loss of milk due to spoilage is another major risk resulting in income loss and supply disruptions. Additionally, the dairy marketing system lacks sufficient incentives for quality assurance, with consumers often unaware of food safety risks and unwilling to pay more for higher quality (Muriuki et al 2003; Kembe et al 2008; Omunyin et al 2014; Kibiego et al 2015; Mutavi et al 2016).

The small-scale dairy farm's lack of broad-based use of modern farm technologies/ practices, inadequate access to feed due to expensive fodders, and improved breeds have resulted in low productivity with a 5.9 per cent decline to 754.3 million Liters recorded in 2022. Kenya thus imports dairy products to meet an expanding domestic demand. Low productivity is compounded by seasonal changes in pasture conditions and poor productivity during dry seasons. Furthermore, traditional, religious, and cultural practices affect both the supply and demand for dairy products (CDI, 2014). Despite the period of privatization in the late 1980s and early 1990s and the devolved government in Kenya, governments have maintained some public structures providing services including animal breeding, inspection and certification, and training and extension failing to reach the last mile small-holder farmer. The absence of county-specific and clear dairy policies remains a key constraint to the comprehensive development of the industry in the region. The main policy frameworks are the 2010 Kenya Dairy Master Plan and the Dairy Industry Act which is considered outdated and non-adapted to current dynamics. The synergies and trade-offs of other sectorial policies in the areas of land, cooperatives, industry, trade, health, and environment are often not incorporated in the Dairy master plan. This lack of a unique and clearly defined policy framework has often left the door open for changing regulations. These factors have resulted in the potential of the dairy sector remaining underexploited hence the need for a rapid transition to sustainable smart dairy farming in Kenya.

With the advent of the fourth industrial revolution (4IR) characterized by AI, Blockchain, Internet of Things, Big Data, and 3D printing. The adoption of smart technology in dairy farming aids in the visualization of the entire production chain and the automation of decision-making (SomaDetect, 2020). Smart dairy farming is a transformative and innovative farming approach that employs a combination of techniques and technology to sustainably satisfy the increasing demand for quality dairy products. This approach to dairy farming can reduce environmental issues, decrease the use of resources, and raise animal health by using advanced sensing and data analyzing technologies (Muhammad Osama et.al, 2020). Smart Dairy farming offers the promise of improved efficiency of business processes through improved management strategies and enhanced farm efficiency.

At the product level, robotic milking systems analyze and preserve the milk simultaneously. At the process level, these technologies monitor cow movement, feed, and health parameters. At the consumption level, innovations promote the development of novel dairy feeds that meet rapidly changing consumer demands. Moreover, the adoption of technologies has the potential to promote environmental sustainability (Herrmann, n.d.). Despite its potential, many smallholder farmers in Kenya have not adopted smart dairy farming hence experiencing low milk yields, degradation of the environment, and poor animal welfare (Smallholder Dairy Production in Kenya; a Review, n.d.).

With the growing population, dairy farming needs to evolve to sustainably cater to the increasing demand for safe and sustainable livestock products. Stakeholders in the dairy industry need to keep tabs on more dynamic changes such as consumer tastes, government regulations, or new technologies that have the potential to disrupt current assumptions and trends and know the future to avoid big surprises. This study anchored on the foresight methodology is thus critical in bringing to the forefront, predetermined signals such as demographic shifts, key drivers and alternative possible future scenarios and events unfolding as we move into the future.

This discussion paper considers smart farming across the value chain including production, processing, consumption and environmental sustainability. The objectives of the study will be to: assess the status of Smart Dairy farming in Kenya using a comparative analysis, identify emerging trends in Smart Dairy farming in Kenya, identify key drivers of the Smart Dairy Farming and develop scenario identifying their impacts, implications, and intervention pathways, that stakeholders can use to monitor disruptive trends in the Smarty Dairy Farming.

This study is important in Kenya due to its potential to revolutionize the country's agricultural sector, enhance food security, and boost economic growth. With Kenya's dairy industry being a significant contributor to its GDP and a critical source of livelihood for millions of smallholder farmers, integrating smart farming technologies can address challenges such as low productivity, poor animal health, and inefficiencies in supply chains. This research is crucial for developing scalable and sustainable agricultural practices that can be replicated across other regions in sub-Saharan Africa, thereby contributing to global efforts in sustainable development and food security. The paper may inform policy action and formulation in the dairy sector as studies on smart dairy farming have been conducted internationally but not in an in-depth manner under scenario building in the foresight methodology. The study will encourage foresight and identification of signals of change and encourage proactive steps by shareholders in the dairy sector.

The paper, in section 2 will discuss trends in dairy milk production, consumption, export and imports, and environmental emissions. Chapter 3 discusses the literature review and highlights the major indicators as well as technological and environmental innovations in Sustainable smart dairy farming. Chapter 4 explains the methodology for trend analysis and scenario development. Chapter 5 explores emerging trends, scenarios, implications, and policy interventions. Finally, chapter 6 provides some conclusions and recommendations derived from the study.

2. Trend in Smart Dairy Farming

This section uses data between 1961 to 2021 to give an overview of the dairy sector comparing Kenya and New Zealand (NZ) and the United States of America (USA) as aspirators and India and Ethiopia as comparator countries.

2.1 The total livestock per unit area

Figure 2.1: Total Livestock Units (Source: Data were from FAOSTAT. Results calculated by authors)

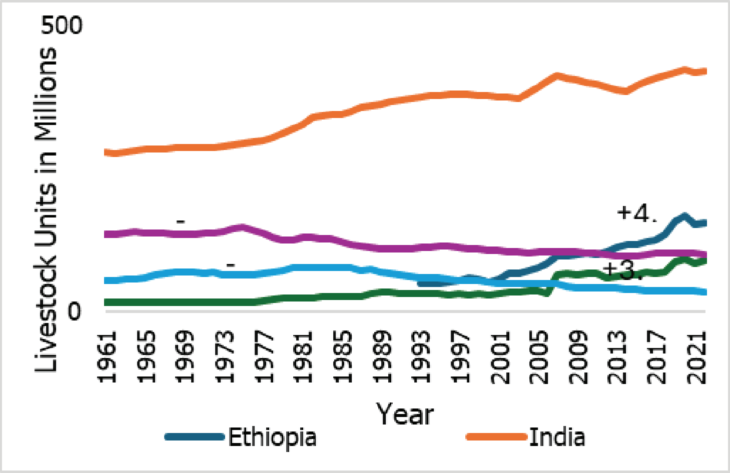


Figure 2.2: Total livestock units per unit area (Source: Data were from FAOSTAT. Results calculated by authors).

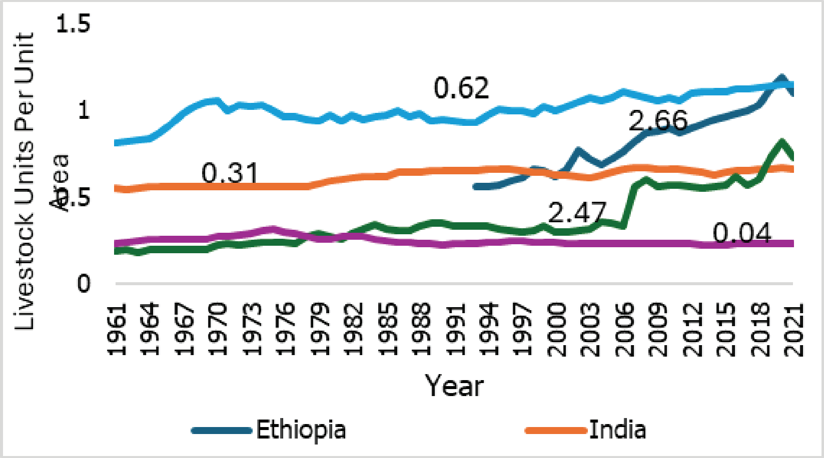


Table 1: Changes in livestock units per area and total number of livestock

	Ethiopia	India	Kenya	NZ	USA
Average Livestock per unit area	1.58	1.21	0.71	1.98	0.49
Change in Livestock Per Unit Area	2.66	0.31	2.74	0.62	0.04
Change in total livestock units	4.19	0.68	3.54	-0.67	-0.47

Source: Data were from FAOSTAT. Results calculated by authors

Over the past 60 years, the number of live animals and livestock per unit area in developing countries has increased whereas in developed countries it has decreased. The USA for instance 0.49 livestock units per with a low growth rate of 0.04per cent while Ethiopia has 1,58 livestock units per unit area with a 2.66 per cent growth rate. As opposed to the trends towards dairy intensification of milk production in developed countries, production in developing countries is largely due to the increasing number of dairy animals with only a small proportion attributed to productivity gains.

2.2 Total production for raw milk and value-added products

Figure 2.3: Total raw milk production (Source: Data were from FAOSTAT. Results calculated by authors)

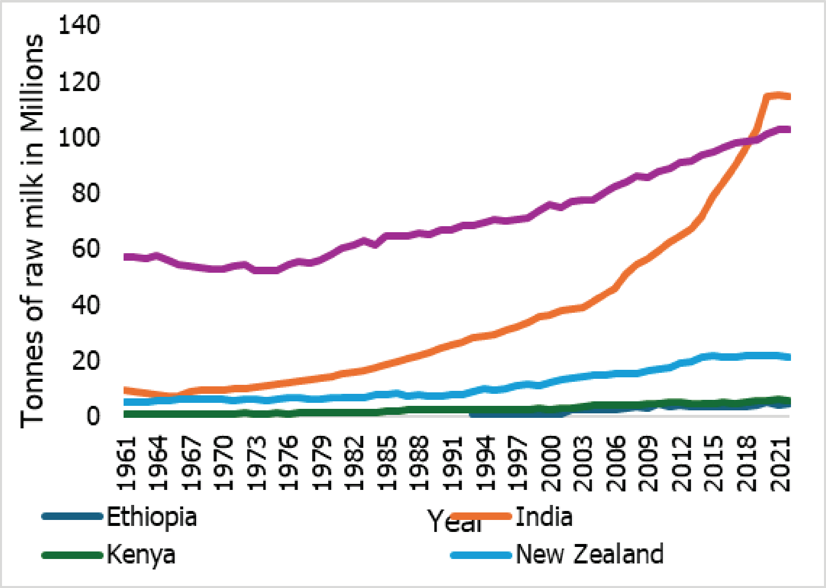


Figure 2.4: Total production for value-added products. (Source: Data were from FAOSTAT. Results calculated by authors)

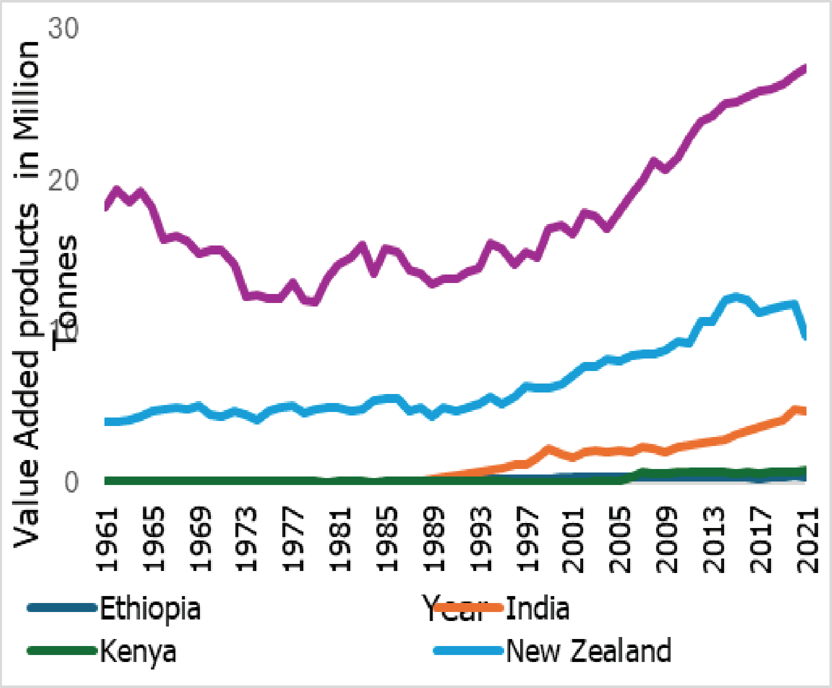


Table 2: Ratios showing yield per livestock and proportion of milk used in value addition.

	Ethiopia	India	Kenya	New Zealand	USA
Proportion of milk used in value addition	11.2	3.2	9.4	58.3	24.2
Yield per livestock	3.0	10.3	7.2	19.5	60.6

Source: Data were from FAOSTAT. Results calculated by authors

Total milk production over the past 60 years has remained high in developing countries despite decreasing numbers of livestock animals. The high milk yields per livestock in the USA of 60.6 Liters per LU and 19.5 Liters per LU in New Zealand and lower yields in India, Kenya, and Ethiopia of 10.3 Liters per LU, 7.2 Liters per LU and 3.0 Liters per LU could be attributed to dairy intensification and automation. To meet changing consumer preferences and with the evolution of new dairy technologies, New Zealand and the USA use 58.3per cent and 24.2per cent of their raw milk for value addition whereas India, Kenya, and Ethiopia use only 3.2per cent, 9,4per cent, and 11.2per cent respectively. Diversified dairy products play a critical role in improving smallholder farmers' income as well as increasing the shelf life of this highly perishable product.

2.3 Gross production index

The Gross Production Index (GPI) is a measure used to assess the overall production performance of a specific sector. Despite being less than 100per cent in the five countries the dairy sector significantly contributes to the overall economic growth of the USA, Kenya, and Ethiopia with a GPI of 96per cent, 92per cent, and 92per cent respectively making it a valuable tool for policymakers. 2.4 Import and Export of live dairy animals and value-added products.

Figure 2.5: Gross Production Index (Source: Data were from FAOSTAT. Results calculated by authors)

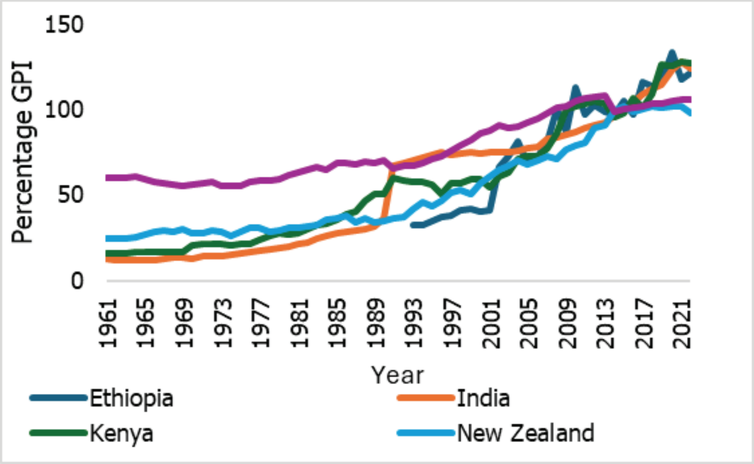


Figure 2.6: Gross Per Capita production (Source: Data were from FAOSTAT. Results calculated by authors)

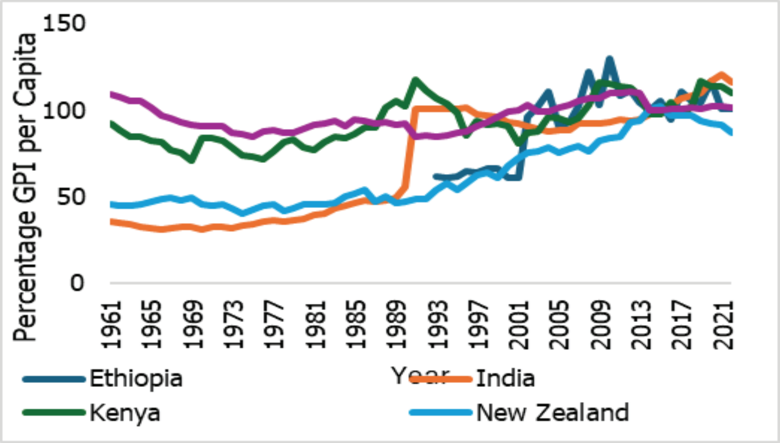


Table 3: Net export of live animals

Country	USA	New Zealand	India	Ethiopia	Kenya
Export Quantity (c)	25585275	12700290	9049388	7554461	1333989
Import Quantity (c)	96796905	42757	1854826	134608	1214856
Net Export	-71211630	12657533	7194562	7419853	119133
Percentage Net Export	-58.1879	99.32894	65.97965	96.49872	4.673999

Source: Data was from FAOSTAT. Results calculated by authors) (c-count)

Table 4: Net Export of dairy value-added products

Country	New Zealand	USA	India	Kenya	Ethiopia
Export Quantity (t)	74144528	30072305	1224477	471977.2	26952.21
Import Quantity(t)	660304.2	11867217	1364809	853144.2	84447.05
Net Export (t)	73484224	18205088	-140332	-381167	-57494.8
Percentage net export	98.23459	43.40795	-5.41971	-28.7647	-51.6115

Source: Data was from FAOSTAT. Results calculated by authors) (t-tonnes

The dairy sector is highly localized as milk is a heavy and highly perishable product with only a small proportion traded internationally. Developing countries thus have a positive net export for live dairy animals with a negative net export for value-added products and vice versa in developed countries. Most milk trade taking place in the international market has shifted from subsidizing countries such as the USA to non-subsidizing countries such as NZ. Despite technological advances such as portable refrigeration and cooling, the dairy global trade sector remains unexploited. With rising demand for dairy products in countries that are not self-sufficient in milk production, Volumes of demand are gradually increasing an opportunity for Kenya and other developing countries to tap into.

2.5 Changes in nutrient composition in raw milk

Figure 2.7: Changes in nutrient composition over the years (Source: Data were from FAOSTAT. Results calculated by authors)

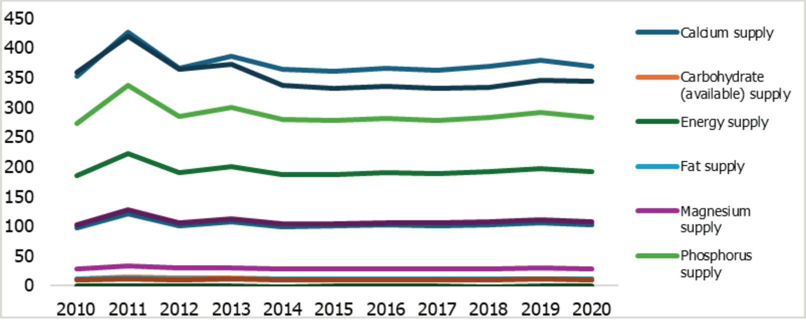
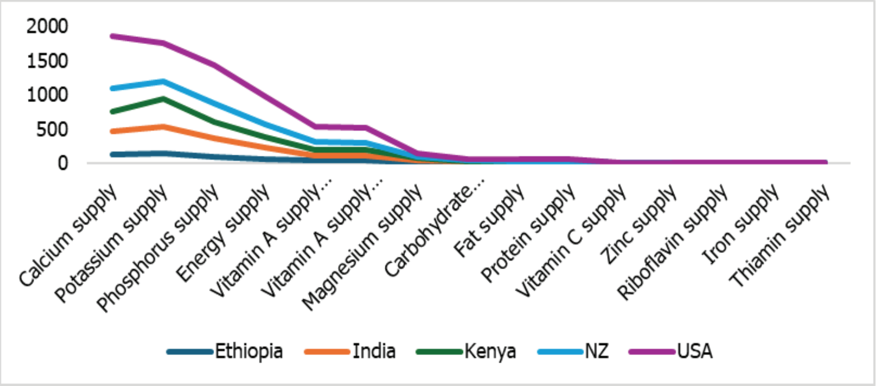


Figure 2.8: Nutrients supplied by raw milk in different countries



Source: Data were from FAOSTAT. Results calculated by authors

Milk composition changes when there are changes in the type of feed such as silage-based to pasture-based. The feed type from silage to pasture is often influenced by climatic variability throughout the year and through different years. The Milk fat and protein content vary significantly due to seasonal variability in the feed. A study in the UK showed that the fat content in bovine milk collected between 2009–2013 decreased from January to July, followed by a sharp increase in August and September, remaining constant after that, while protein content declined steadily from November to April (3.35per cent to 3.23per cent), remained constant (April to July), and increased marginally after that (changes in milk composition paper). Higher nutrient composition in developed countries could be attributed to novel feed formulations.

2.6 The emissions from livestock productions

Figure 2.9: Livestock Emissions in nitrous oxide (NO4)

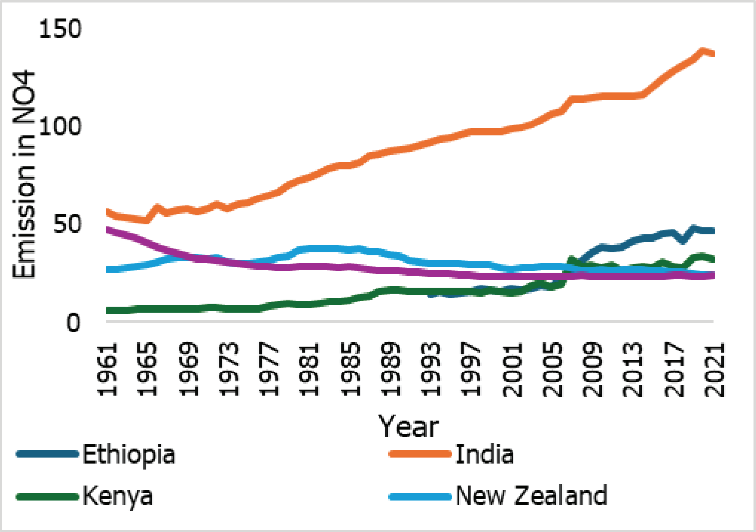
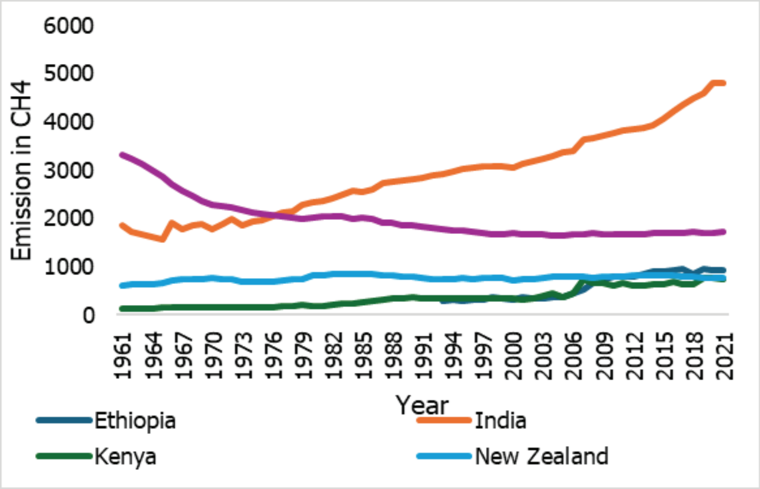


Figure 2.10: Livestock Emission in Methane (CH4)



Methane emissions (CH4) come from livestock production at the farm level while nitrous oxide emissions (NO4) are from industrial activities. New Zealand is famous for its clean air and green ecology; all its cows are free-range and enjoy natural fodder. The production of milk powder is based on the advanced wet process, which preserves its nutritional value and reduces the risk of secondary pollution. Emissions of NO4 in New Zealand despite being high up to the 1970s have been decreasing. Similarly, NO4 emissions in the USA have decreased to a low of 23.8 kg CO2e. Among developing countries however NO4 emissions have been increasing to a high of 32.17 kg CO2e in Kenya and 46.72 kg CO2e in Ethiopia.

3. Literature Review

This section outlines the theoretical and empirical literature reviewed to inform the study. The Innovation Diffusion Theory and the Sociotechnical System theory form the basis of the study. The available empirical literature is reviewed, and gaps are identified.

3.1. Theoretical framework

This paper will rely on 2 theories in its development and research. The paper adopts the innovation diffusion theory and the sociotechnical systems theory.

3.1.1 Innovation Diffusion Theory

This theory explores how innovations spread within a social system. It identifies stages of innovation adoption, from early adopters to laggards, and factors influencing adoption. In smart dairy farming research, this theory can help analyze the diffusion process of smart technologies among farmers and identify factors affecting the rate of adoption.

Innovators are the first individuals or farms to adopt modern technology. They are risk-takers and often have higher social status or financial resources. In dairy farming, innovators might be the early adopters of smart technologies such as automated milking systems, precision farming, or data analytics tools. Early adopters are opinion leaders in the farming community and have a significant influence on their peers. In the context of dairy farming, early adopters may implement new practices after seeing success in innovators' farms. They might share their experiences, influencing other farmers to adopt similar technologies.

The early majority represents the average farmer who adopts innovations before the average member of the social system. They rely on feedback from early adopters before making decisions. The early majority might adopt smart technologies once they observe positive outcomes in early adopters' farms and become convinced of the benefits. The late majority adopts innovations after the average member of the social system has adopted them. They tend to be sceptical and adopt innovations out of necessity. The late majority may adopt smart technologies when they become more commonplace, or when economic pressures or market demands necessitate their adoption. Laggards are the last to adopt innovations. They are often traditionalists who are resistant to change and may only adopt new practices when forced to do so. In dairy farming, laggards might resist adopting smart technologies until it becomes essential for competitiveness or compliance with industry standards.

In conclusion, the Innovation Diffusion Theory provides a valuable framework for understanding how smart technologies are adopted within the dairy farming community. Recognizing the different stages of adoption and the factors influencing each stage is crucial for designing effective strategies to promote the adoption of innovative practices in the dairy sector. Technologies, or management strategies within the dairy farming community.

3.1.2 Sociotechnical systems theory (STS).

This theory emphasizes the interaction between social and technical elements within a system. It recognizes that the successful implementation of technology depends not only on technical aspects but also on the interaction and interdependence between social and organizational factors. In dairy farming, the integration of smart technologies involves changes in farm management practices, roles of farmworkers, and communication patterns. It further incorporates the social dynamics within the farm, relationships among stakeholders, and the overall organizational structure.

STS suggests that the introduction of new technologies may require a redesign of work systems to ensure a better fit between the technical and social components. When adopting smart dairy technologies there may be a need to redesign work systems, redefine job roles, and establish new communication channels to maximize the benefits of the technologies while minimizing disruptions. It encourages participatory design approaches, involving end-users in the design and implementation of technologies to ensure that they align with social and organizational needs. In dairy farming, particularly among smallholder farmers, this could lead to more successful adoption and use of technology.

STS highlights the importance of considering ethical implications such as data privacy, animal welfare, and the equitable distribution of benefits among stakeholders in the design and implementation of technologies in a system. It recognizes the influence of organizational culture on the successful implementation of technologies. This calls for strategies to foster a culture that values innovation, continuous learning, and collaboration among stakeholders. It recognizes the need for systems to be adaptable and flexible to accommodate changes in technology and social dynamics over time. Dairy farming systems for instance could allow for upgrades, modifications, and adjustments as needed.

In conclusion, Sociotechnical Systems Theory offers a valuable framework for understanding the complex interactions between smart technologies and the social and organizational aspects of dairy farming. Applying STS principles can contribute to the successful adoption and integration of smart farming technologies, ensuring that these technologies align with the broader sociotechnical context of the dairy farming system.

3.2 Empirical literature

Daniel Berckmansiii defines Precision Livestock Farming as “Management of livestock farming by automatic real-time monitoring/ controlling of production, reproduction, health and welfare of livestock" (Berckmans, D. (2008). The EIP-focus group 'Mainstreaming Precision Farming' uses the definition: "Precision Farming refers to a management concept focusing on (near-real time) observation, measurement and responses to inter- and intra-variability in crops, fields and animals" (EIP AGRI Focus Group Precision Farming 2015).

A few critical elements can be derived from the aforementioned definitions when discussing smart dairy farming including, dairy farming, management, Inter- and intra-variability, (Near) real time, automatic observation/monitoring/controlling, (Re)production, welfare and health of animals, crops, and fields. This paper explores dairy farming across milk producing farm animals particularly cows, goats and camels. It covers milk and milk products on all types of farms, organic or non-organic, small, big family owned or otherwise funded farms. Dairy animals are the key production factor and as such the management of cows, goats, sheep and camels.

Smart dairy farming is an emerging field that integrates advanced technologies to enhance the efficiency, productivity, and environmental sustainability of dairy operations. This literature review aims to provide a comprehensive overview of the key developments, challenges, and opportunities in sustainable smart dairy farming. The use of Artificial Intelligence (AI), Machine Learning (ML), Internet of Things (IoT), Global System for Mobile (GSM) Communications, photovoltaic thermal solar systems, cloud data storage, and radio frequency identification (RFID) technologies that are utilized in drone farming, livestock monitoring, and farm warehouse systems are discussed. These advances can result in significant increases in production, efficiency, and profits, as well as better monitoring, surveillance, and tracking of the farm.

Smart dairy farming has revolutionized the traditional methods of dairy production. By utilizing cutting-edge technology, smart farming has improved efficiency and animal welfare in the industry. Automated milking systems, precision nutrition, and health monitoring sensors are just a few examples of how AI is transforming the dairy sector (Liu, Weihua, Shangsong Long, 2021). This not only benefits farmers by reducing costs and increasing productivity, but it also produces higher-quality products for consumers.

Smart dairy farming utilizes technology such as sensor applications, data analysis, and cloud-based data centres Arago et al. (2022). By integrating smart farming technology, farmers can increase milk productivity and cattle production while improving the management of livestock (Amin, R., and Rahman, M. (2018). This not only benefits the industry by meeting the growing demand for quality dairy products but also ensures the overall well-being of animals through early detection of standing-heat activities. With smart dairy farming, cows can receive individualized care and attention, leading to better health and higher milk quality (Liu, Weihua, Shangsong Long, Siyu Wang, Ou Tang). Additionally, this technology allows for more precise record-keeping and monitoring of herd health, reducing labour costs and potential human error. As we continue to rely on advancements in technology, smart dairy farming presents a promising future for sustainable agriculture practices that prioritize both productivity and animal welfare.

Smart farming is a modern approach to agriculture that utilizes technology for more efficient and sustainable practices (Muhammad Osama Akbar, Muhammad Saad Shahbaz Khan et al. 2020). One of the key components of smart farming is the use of automated systems, such as robotic milking machines, which allow for around-the-clock milking and increased milk production. Precision nutrition is another crucial aspect of smart dairy farming, where data from sensors and software are used to optimize feed rations for each cow based on their specific needs. This not only maximizes milk production but also reduces waste and promotes animal health.

Health monitoring sensors can track vital signs and detect early signs of illness in cows, allowing for timely treatment and preventing potential outbreaks. Smart dairy farming is also, "the practice of intelligent agricultural management based upon technological data gathering farm practice has proven to increase quality and yield while protecting the environment. Smart dairy farming encompasses various technologies that work together to improve efficiency and sustainability in the industry"(Vate-U-Lan, Quigley, and Masouras 2017).

The dairy farming industry has seen a significant shift towards the implementation of Artificial Intelligence (AI) in recent years. This technological advancement offers immense potential for sustainable practices that not only benefit farmers but also consumers. By leveraging IoT and different AI techniques, farmers can overcome traditional farming challenges and increase milk production (Amin,2018). With AI, farmers can analyze data on milk production, feed intake, and animal health to make informed decisions. This leads to reduced costs and improved efficiency, resulting in higher-quality products for consumers. Additionally, AI can assist in identifying potential health issues in cows before they become critical, leading to better animal welfare. The use of AI in dairy farming not only benefits individual farmers but also contributes to the overall sustainability of the industry by reducing water usage and greenhouse gas emissions.

As we continue to develop and innovate in this field, it is important to prioritize ethical considerations to ensure responsible usage of AI technology. By doing so, we can foster a more efficient and humane approach to dairy production that benefits animals, humans, and the environment alike.

The adoption of smart technologies in dairy farming is crucial for achieving sustainability goals and optimizing productivity. The impact of these technologies on agriculture about sustainable food security is explored in this research, where it is demonstrated that mechatronic farm automation integrated with mobile applications can offer better farm monitoring, increase yields as well as contribute towards better land utilization (Sindiso M, 2024).

The implementation of IoT in dairy farming enables real-time monitoring of various parameters such as milk production, animal health, and environmental conditions. Smart sensors, RFID tags, and wearable devices contribute to improved data collection and management. PLF involves the use of advanced technologies like sensors, robotics, and automation to monitor and manage individual animals and optimize their production. The integration of PLF in dairy farming enhances resource efficiency and animal welfare.

The adoption of renewable energy sources, such as solar and wind power, in dairy farming contributes to a more sustainable energy footprint. This research also explores studies evaluating the feasibility and benefits of renewable energy integration. Sustainable dairy farming involves efficient nutrient management to minimize environmental impact. This paper reviews practices such as manure recycling, precision fertilization, and the circular economy approach in dairy farming.

The innovative solutions are aimed at not only improving milk yields but also enhancing the efficiency of the dairy process. At the product level, the innovative systems strive to increase milk production by deploying robotic milking systems that milk the cow, analyse the milk, process the milk, and preserve it. At the process level, the systems are concerned with the health and welfare of the very cow producing the milk as they can monitor cow movement, feed, and health. At the consumption level, innovations strive to promote the development of novel dairy foods that meet rapidly changing consumer demands. Technologies should promote environmental sustainability.

It is therefore imperative that stakeholders in the dairy industry keep tabs on more dynamic changes such as consumer tastes, government regulations, or new technologies that have the potential to disrupt current assumptions and trends and know the future to avoid big surprises. We can count on predetermined signals such as demographic shifts and events unfolding as we move into the future.

3.2.1 Technological Innovations in Smart Dairy Farming

Dairy farming has been a cornerstone of agriculture for centuries, providing essential products like milk, cheese, and butter to consumers worldwide. However, with the growing global population and increasing demand for dairy products, traditional farming methods face challenges in meeting these demands efficiently while ensuring sustainability and animal welfare. In response to these challenges, smart dairy farming emerges as a transformative solution, integrating cutting-edge technologies to optimize productivity, enhance animal health, and minimize environmental impact.

This paper highlights the incorporation of technology in pursuit of sustainable smart dairy farming across six stages of the dairy value chain: Production, processing, distribution, retailing, consumption and waste disposal.

A. Breeding

IoT Sensors and Monitoring Systems:

Implementing IoT sensors allows for real-time monitoring of various parameters crucial for dairy farming, such as milk production, animal health, and environmental conditions. These sensors can track factors like temperature, humidity, milk quality, and even cow activity levels. By continuously collecting and analyzing data, farmers gain valuable insights into their herd's health and behaviour, enabling proactive management strategies.

Data Analytics and Predictive Analytics:

Leveraging advanced analytics tools, smart dairy farmers can transform raw data into actionable insights for informed decision-making. By employing techniques like predictive analytics, farmers can forecast trends in milk production, detect potential health issues before they escalate, and optimize breeding strategies for herd improvement. These data-driven approaches empower farmers to enhance efficiency, reduce costs, and maximize profitability.

Precision farming

Berckmans, (Berckmans D (2003) explains PLF as: monitoring, collecting and evaluating data from on-going processes. Collection of data from animals and their environment, by innovative, simple and low-cost techniques, is followed by evaluation of the data by using knowledge-based computer models. Currently, considerable PLF research is directed toward development and validation of various techniques for data measuring and registration on livestock farms. PDF is a subset of precision livestock farming. Precision Dairy Farming (PDF) is also defined Precision Dairy Farming as “the use of information technologies for assessment of fine-scale animal and physical resource variability aimed at improved management strategies for optimizing economic, social and environmental farm performance” (Eastwood CD, et.al (2004). A PDF system is constructed of the following components: a sensor that generates data, a model that gives a physiological interpretation of the data, a management decision making process and finally decision execution (Schuzel et al, 2007). The PDF systems can be divided into two categories: those used for diagnostic and those used for management and the same sensor can serve both categories.

Adoption of technology maximizes individual animal potential. Through adoption of technology geared towards sustainable smart dairy farming farmers can detect diseases earlier. Consequently, early detection of disease reduces the cost of disease to the farm and increases the length of animals’ lives. This technology also minimizes the use of medication through preventive health measures (Schuzel et al, 2007). Technologies for physiological monitoring of dairy cows have great potential to supplement the observations of skilled herd’s persons, which is especially critical as more cows are managed by fewer skilled workers. Technology ultimately optimizes economic, social and environmental farm performance allowing dairy producers to make more timely and informed decisions, resulting in better productivity and profitability. Components of PDF include Computers, Global Positioning System (GPS), Geographic Information System (GIS), Remote Sensing (RS) and Application control.

Electronic (radio frequency) identification systems

Electronic identification (EID) systems have provided a technological approach to the previously intuitive process of individual cow management. In 2000 the National Livestock Identification Scheme (NLIS) made the use of radio-frequency identification (RFID) tags, these tags contain a microchip that can be read electronically in a fraction of a second by producers who have a suitable reader. Electronic identification systems provide accurate identification of cows and linked to pedigree, management events, treatment records, electronic milk meters, computer-controlled feeding, automatic sorting and weighing, etc. Radiofrequency tags can be used to record animal events such as heat detection, treatments, calving interval, sire selection, etc. This can result in increased production and profitability by allowing better management of an individual cow's performance through the analysis of the collected data.

Automatic body condition scoring

Body condition scoring (BCS) is a method to evaluate fatness or thinness in cows that can be utilized to adjust dairy herd nutrition and improve the health of the cow. It is usually determined visually and manually by experienced experts to calculate body reserves and conducting body condition scoring and evaluate each animal. Roche et al stressed out the significance of body condition score for animal (Roche et al, 2005). Automated Body Condition Scoring (BCS) through extraction of information from digital images has been demonstrated to be feasible; and commercial technologies are under development. Ferguson et al. assessed the ability to assign a BCS to a dairy cow directly from digital photographs (Ferguson et al, 2006).

Pedometer for estrus detection

Estrus behaviour in dairy cattle is accompanied by an increase in physical activity. Kiddy was the first to use leg mounted pedometers to determine whether physical activity related to estrus varied enough compared with non-estrual animal which will be a useful method for estrous detection in dairy farming (Kiddy CA (1977). Comparison among various statistical procedures that use pedeometry data in lactating dairy cows indicate that 70% of estrous period and 99% of non-estrual periods can be accurately predicted using currently available pedeometry systems (Senger PL (1994).

B. Feeding

Smart dairy farming utilizes precision feeding technologies to optimize nutrition plans tailored to each cow's specific needs. By analysing factors like body condition, milk production, and dietary requirements, farmers can formulate precise feeding regimens using automated feeders or robotic feeding systems. This approach minimizes feed wastage, enhances milk quality, and promotes overall herd health.

Robotic calf feeding

Robotic calf feeding is another technology that consists of a calf feeder unit that mixes milk replacer with water, the processor for controlling the feeder and data processing, the transponder being placed around the neck of the calf for identification and a milk feeding stall where the calf drinks the milk. Automatic calf feeders consist of a self-contained unit that heats the water, dispenses a programmed amount of milk replacer, and mixes the milk replacer and water in a container from which the calf can suck it out via a nipple feeding station. Calves start robotic feeding on day and are weaned at approximately 45 days. having gained double their weight.

C. Milking

Automated Milking Systems

Automated milking systems streamline the milking process by employing robotics and sensors to clean, milk, and monitor cows autonomously. These systems not only reduce labour costs but also ensure consistency in milking procedures, leading to higher milk yields and improved udder health. Moreover, automated milking systems allow for individualized care, as data collected during milking sessions can identify health issues or irregularities in specific cows.

Milking robot is a part of automatic milking system, having a sensor system to locate the position of the teats and a manipulator to attach the milking unit to the teat. Sensor systems for milking robots, published by Artmann, identified several distinct sensing tasks such as animal identification, teat location and monitoring. The function of this systems is to ensure proper machine function, protect people and animals from injury, measuring milk quantity and composition as well as monitoring other aspects of Animal health.

Automatic recording devices (rumen temperature, pressure, pH)

Determination of ruminal pH, temperature and pressure in animals can be crucial to suppress the occurrence of health problems such as sub-acute rumen acidosis and bloat. Owen et al. reported that rumen acidosis is a serious problem in dairy and feed-lot sectors, resulting in animal deaths, morbidity, and diminished productivity (Owen et al, 2010).

Artificial intelligence or other advanced computational programs to evaluate the significance of ruminal acidosis in cattle performance as well as in defining the relations between intake and acidosis (Nagaraja TG,2007). For research monitoring of rumen pH, a permanent device in the rumen is required to continuously monitor rumen pH remotely without interfering with the normal behaviour of the animal (Owen et al, 2010).

3.2.2 Drivers of the Smart Dairy Farming using a SWOT Analysis.

Strengths

Dairy farming experiences strong demand growth for milk, presenting opportunities for new investments and inclusive value chain development. Also, entrepreneurial farm management can enhance productivity, while effective delivery of inputs and services can mitigate seasonality in feed and milk supply. Through smart dairy farming, production costs can be lowered while improving milk quality and enabling farmers to access domestic milk processing capacity and regional free trade markets.

Weaknesses

Unfortunately, reacting to market opportunities alone may not sustainably intensify dairy farming. Land appears to be the most limiting production factor in the Kenyan highlands, while climate effects on production are most limiting in the coastal lowlands (Kibiego et al 2015). The scarcity of land drives up land and feed costs and restricts purchasing of land. Currently, farming land scarcity drives intensification, necessitating increased production efficiency and enhanced efficiency along the Dairy Value Chain (DVC). Additionally high transaction costs and quality and safety issues in milk production hinder DVC integration (LR - Animal Breeding and Genomics et al., 2016).

Opportunities

The fourth industrial revolution has been accompanied by greater environmental awareness that has elevated social and environmental robustness considerations. This has created opportunities to address issues such as inclusive sector development, food safety, and environmental impacts. Innovation in the dairy sector also enhances farmer skills and training can improve product quality and safety, addressing public health risks. Government policy on dairy aims to increase the share of formal processed milk in the market and improve milk quality (LR - Animal Breeding and Genomics et al., 2016).

Threats

Limited progress has been made in increasing the formal sector's market share, as the strong demand for raw milk and insufficient price and quality advantages of processed milk inhibit growth. Challenges in the dairy sector include inadequate attention to certain social and environmental robustness indicators, such as smallholder livelihood viability, farm biosecurity, and environmental impacts like water pollution and greenhouse gas emissions. Scores for social robustness indicators are weak in product quality and safety, with high public health risks from zoonoses, antibiotics, aflatoxin, heavy metals and other hazardous substances in milking, feeding and health practices. This is strongly related to the low levels of farmer skills resulting from two decades of disinvestment in training and extension following the Structural Adjustment Programs in the early nineties (Makoni et al., 2014).

3.2.3 Environmental Monitoring and Sustainability Practices

Smart dairy farming emphasizes sustainable practices by integrating environmental monitoring technologies. Sensors can track factors like soil health, water quality, and greenhouse gas emissions, allowing farmers to minimize their environmental footprint. Additionally, implementing renewable energy sources such as solar panels or methane digesters reduces reliance on non-renewable resources and mitigates climate impact.

A. Environment conservation.

Waste Management Solutions

Dairy farming generates various types of waste, including manure and effluent, which can pose environmental risks if not managed properly. Sustainable dairy farms implement waste management solutions such as anaerobic digesters, composting, and nutrient management plans to minimize pollution and recycle organic matter. These practices not only reduce greenhouse gas emissions but also yield valuable by-products like biogas and nutrient-rich fertilizers.

Renewable Energy Integration

To reduce reliance on fossil fuels and mitigate carbon emissions, dairy farms are increasingly integrating renewable energy sources such as solar panels, wind turbines, and methane digesters into their operations. By harnessing renewable energy, farms can power their operations sustainably while lowering energy costs and reducing their carbon footprint.

Efficient Water Usage

Water scarcity is a growing concern globally, making efficient water usage a priority for sustainable dairy farming. Farms implement water-saving technologies such as drip irrigation, rainwater harvesting, and water recycling systems to minimize water consumption and protect local water resources. Efficient water management not only conserves a precious resource but also reduces operational costs and enhances farm resilience to drought conditions.

B. Animal Welfare Enhancements:

Comfortable Housing Systems

Providing comfortable and humane housing for dairy cows is essential for ensuring their well-being and productivity. Sustainable dairy farms invest in modern housing systems such as free-stall barns, pasture-based systems, and deep-bedded stalls that prioritize cow comfort, ventilation, and cleanliness. These housing systems reduce stress, prevent injuries, and promote natural behaviours, leading to healthier and happier cows.

Monitoring and Health Management

Monitoring and managing the health of dairy cows are critical aspects of animal welfare in sustainable farming practices. Farms utilize advanced technologies such as sensors, wearable devices, and automated monitoring systems to track key indicators of cow health, including body temperature, rumination, and activity levels. Early detection of health issues allows farmers to intervene promptly, administer appropriate treatments, and prevent disease outbreaks, thereby enhancing overall animal welfare and reducing veterinary costs.

C. Economic Viability

Cost-Effective Technologies

Sustainable dairy farming incorporates cost-effective technologies and management practices that optimize resource utilization and minimize operational expenses. Examples include precision feeding systems, automated milking parlors, and smart ventilation systems, which improve efficiency, reduce labour costs, and enhance profitability. By investing in innovative yet economical solutions, dairy farms can achieve long-term financial sustainability while minimizing environmental impact.

Improved Productivity and Efficiency

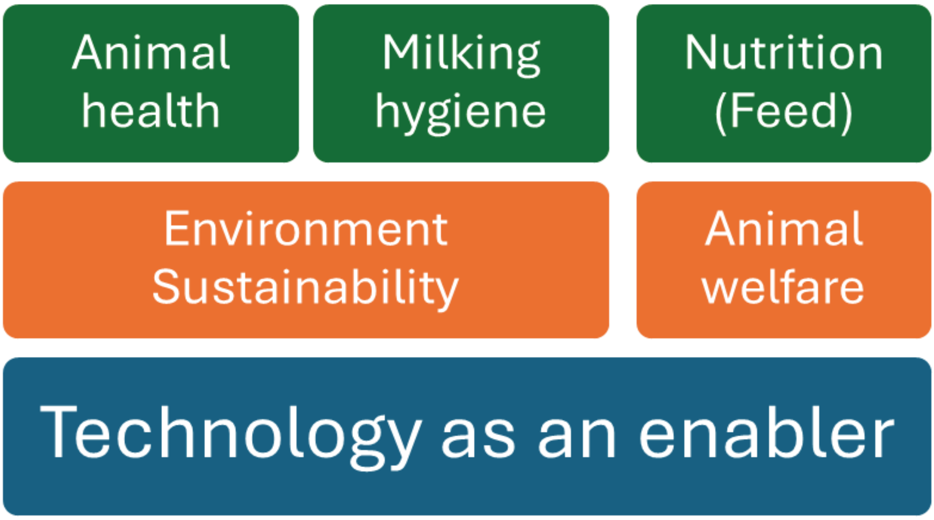
Sustainable dairy farming emphasizes improving productivity and efficiency through strategic management practices and technological innovations. Farms focus on maximizing milk production per cow, optimizing feed conversion efficiency, and minimizing waste generation. Enhanced productivity not only increases revenue but also reduces per-unit production costs, improving the farm's economic viability and competitiveness in the market.

4. Methodology

4.1 Conceptual framework

Smart dairy farming (SDF) is a key concept that can satisfy the increasing demand for quality dairy products, reduce environmental issues, decrease the use of resources, and raise animal health by using advanced sensing and data analyzing technologies. Technologies such as artificial intelligence, robotics, machine learning, the Internet of things, and data analytics enhance efficiency, and productivity, increase production, improve animal feeding regimes, promote better monitoring, surveillance, and tracking of the farm, and contribute to the achievement of sustainability goals (Kozina and Semkiv, 2020).

Figure 4.1: Smart Dairy Farming Conceptual Framework



4.2 Assessing the status of smart dairy farming a comparative analysis

In answering objective one, this study assessed the status of Kenya's dairy industry by analyzing quantitative data on production, consumption, and environmental sustainability variables (table 3.1). The comparative analysis uses the comparator and aspirator countries to benchmark Kenya's smart dairy trajectory. Ethiopia represents underdeveloped countries; India represents developing countries while New Zealand and the United States of America were used as aspirator countries (table 6). Data between 1961 and 2021 was obtained from FAOSTAT, 2018 and analyzed using advanced excel. The results of this analysis were used to identify emerging trends in dairy farming.

Table 5: Description of variables

Key Result Area	**Variable**	**Description**
Milk Production	Total milk yield in tonnes per annum	The total tonnage of milk produced by camels, cattle, goats and sheep
	Value added product	Codex Alimentarius defines a milk value-added product as a "product obtained by any processing of milk, which may contain food additives, and other ingredients functionally necessary for the processing
	Livestock per capita area	The number of dairy animals, such as cows, sheep, goats, and camels that are kept or raised per Hectare
	Total livestock stock (LSU)	The number of dairy animals, such as cows, sheep, goats, and camels
	Producer prices	Prices received by dairy producers for raw milk and value-added products in USD per ton
Milk Consumption	Domestic consumption	The total tonnage of milk consumed annually
	Nutrient supply	Essential nutrients supplied by milk per day
	Export quantities	Amount of raw milk and value-added products in tonnes exported into a country
	Imports quantities	Amount of raw milk and value-added products in tonnes imported into a country
	Consumer prices	Prices paid by consumers for raw milk and value-added products in USD per ton
Environmental Impact	Emission from livestock	Primarily consist of methane (CH_4) and nitrous oxide (N_2O),

4.3 Identify Emerging Trends in the Smart Dairy Industry in Kenya

In responding to objective two, a systematic literature review and intuitive data analysis were used to identify four emerging trends. Emerging trends for future approaches are increasingly being used to investigate uncertainties about the complex interactions that underpin the evolution of the smart dairy industry. It is a critical method when uncertainty is high, the problem is complex, and a long-term perspective is required.

This study reviewed 32 pieces of literature that examined trends in production, consumption, distribution, and environmental sustainability that reflect different perspectives on the future of the smart dairy industry, including policies, economic growth, technological development, exports, and local markets. Each emerging trend represents a condensed and abstract version of a possible future predicted by the relationships between massive amounts of data and descriptive clauses across the dairy value chain. The trends are influenced by policy changes, global trends, economic development, and technological advancements and differ from one another due to the variety of drivers, modeling techniques, historical data, and assumptions. Smart dairy trends in the literature span from 20 to over 100 years. This paper focuses on investigating new intervention pathways to meet the rapidly evolving trends in smart dairy farming.

4.4 Identifying drivers of smart dairy farming.

In investigating objective three, horizon scanning where a systematic literature review and a Delphi questionnaire were used to identify 44 drivers was conducted. The indicators were categorized using the Political, Economic, Social, Technological, Environmental, and Legal (PESTEL) framework (Table 7). The framework helped to widen our horizons while scanning through the key drivers in dairy.

4.5 A scenario analysis approach to identifying multiple possible futures.

In investigating objective four, the study adopted a scenario analysis approach which is an effective tool to prepare for potential futures. Scenario development is critical for a variety of reasons, including analyzing potential future images and clarifying strategic options for decision-makers (Mietzner and Reger 2005).

The method starts by subjecting the 44 internal and external variables (Table 7) to expert analysis. The purposive sampling criteria was used to identify experts in the dairy value chain. The inclusion criteria for selecting experts included researchers with publications in smart dairy farming, dairy farm managers, big dairy processors, micro and small enterprises processing milk, farmers growing fodder using technologies such as vertical farming, and consumers who consumed milk in any form for seven days a week. About 31 experts responded to an online questionnaire where they identified 14 key variables that can be used in a collective reflection to build the vision of the future of the smart dairy system.

Table 6: Stakeholder Classification

Stakeholder	Sample size 31 (100per cent)
Policy researcher	9(29per cent)
Dairy farmers	7 (22.6per cent)
Other Farmers	4(12.9per cent)
Consumers	7 (22.6per cent)
Dairy processors	3(9.7per cent)
Advocacy and civil society	1(3.2per cent)

Source: Author compilation

The method proceeds to analyze the relationship between the variables weighing the relationship according to the degree of influence and dependence between variables.

To achieve this another online questionnaire with the 14 variables interacting with each other was administered among the 31 stakeholders. Stakeholders were asked to weigh the relationship according to the following qualification: if the degree of influence is non-existent, low, medium or high, a scale that can be 0, 1, 2, and 3 was used.

The output of the second round of questionnaires was subjected to a mathematical model called MICMAC. The MICMAC software has been developed by the Institut d'Innovation Informatique pour l'Entreprise, under the supervision of their creators, Laboratory for Investigation in Prospective Strategy and Organization, LIPSOR (Godet, 1999).

Analysis of influence and dependence is obtained by the location of the indicator of the variable in the quadrant, resulting in a variable that can be a power variable, autonomous, of conflict, or output variable, according to their degree of influence and dependence. Two top key drivers in the power quadrant interacted to develop four scenarios within the dairy system.

4.6 Impact, implications, and intervention pathways

Finally, the method developed intervention pathways, innovation strategies, and alternative policies, tailoring them for a resilient variety of futures (Vervoort et al., 2014) based on literature and stakeholder input. This is aimed at creating a viable smart dairy value chain in Kenya over time while balancing the various sustainability dimensions. Understanding the various implicit and explicit trade-offs associated with potential intervention options is an important consideration in the analysis.

5. Futures of Smart Dairy Farming in the Country

A comparison between two aspirator countries (United States of America) and two aspirator countries (Ethiopia and India) and Kenya (The World Dairy Situation, 2021) based on variables of milk production and consumption, exports and imports, and environmental sustainability is shown in Table 4.1.

Table 7: Comparison between aspirator and comparator countries

Characteristics of aspirator and comparator countries			
Indicator	Kenya	Comparator Country (Ethiopia and India)	Aspirator Country (United States of America and New Zealand-NZ)
Milk production	The sector is characterized by low productivity and profitability with most dairy farmers being subsistent-oriented.	Ethiopia holds the largest livestock population of 59.5 million heads of cattle with a relatively undeveloped sector. India has a well-developed smallholder dairy sector.	The USA processes the largest quantities of milk after EU-28 while New Zealand ranks sixth.
Export and Import	The sector has a low formal marketing force with only small volumes being exported.	India imports limited quantities of milk and milk products. Ethiopia is the continent's top livestock producer and exporter.	New Zealand is the second largest dairy exporter with a share of 25per cent. The USA is the third with a share of 16per cent of the world dairy trade.
Milk consumption	The largest proportion of milk is for home consumption.		
	India's per capita local consumption of milk is 427g/day exceeding the world average of 305g/day.	New Zealand has the highest per capita liquid milk consumption of over 100kg.	

Environmental sustainability	The expansion of smallholder farmers is one of the main drivers of deforestation in resulting increasing greenhouse gas (GHG) emissions.		New Zealand is famous for its clean air and green ecology; all its cows are free-range and enjoy natural fodder.

Source: World Dairy Situation 2021

5.1 Emerging Trends in Smart Dairy Farming

This section reviews from literature as outlined in section 4.3 four emerging trends in Kenya's smart dairy farming discussing the status of the emerging trends in the aspirator and comparator countries and in Kenya. The section also discusses intervention pathways that stakeholders in the evolving dairy industry could consider.

5.1.1 Dairy Intensification

Dairy intensification is designed to alleviate poverty by increasing smallholder dairy income through improved dairy production(Clay et al., 2020). It combines multiple technologies, including but not limited to investment in higher-yielding and non-indigenous breeds of cows; improved cattle management and feeding systems such as the use of stall-feeding systems and supplementary feeding; and animal health practices that include regular deworming and vaccinations (Staal et al, 2008). Dairy intensification has been pursued vigorously to date and continues to feature prominently in global environment and development strategies.

Land-use intensification is a key strategy toward doubling the productivity of smallholders by 2030, achieving the UN Sustainable Development Goals of ending hunger (SDG2), and achieving sustainable use of terrestrial ecosystems (SDG15) (Thompson et al). In some developed countries, fewer dairy farms and larger herd sizes per farm have increasingly been seen. In the USA, for example, there were around 640,000 dairy farms in the 1970s (Blayney, 2002). By 2017 only about 40,000 remained (USDA 2018). Kenya has 1.8 million smallholder milk-producing households who own between one to three cows. This constitutes over 80 per cent of the national dairy herd with an estimated 4.2–6.7 million cattle (KDB, 2015); ILRI, 2008). The other 20 per cent are held by medium- and large-scale farms with 5,000 intensive and semi-intensive farms and 45,000 extensive medium- and large-scale dairy farms. In Kiambu, where small-size holdings are declining, the county sources replacement heifers from the Rift Valley, where there is a comparatively better-developed dairy supportive infrastructure and larger herds producing surplus marketed milk, heifers, and bulls. The county is also shifting from free- to semi-zero and zero-grazing.

Smart feeds: Increased knowledge of the impact of feeding on the quality and quantity of milk production has led to more sophisticated diet formulations for cattle. Smart feeds have been modified to induce changes in fat percentage, saturation, protein, and lactose content, and to increase the amount of unsaturated fatty acids for both health and manufacturing reasons (Jenkins and McGuire, 2006). The composition of the forage-to-concentrate ratio has been shown to alter the final protein composition (Schönfeldt et al., 2012)

In recent years, cassava products and by-products used as a grain substitute have been a good alternative source of carbohydrates and protein in animal diets in developing countries (Chagunda et al, 2018). In Kenya dairy farmers in the coastal regions, use grass species adaptable to soil moisture scarcity. In Western Kenya, on the other hand, farmers practice cut-and-carry stall feeding under a zero-grazing system which attracts favorable prices. While in Murang'a 66 per cent of dairy farmers adopted the use of improved fodder as a Climate Smart Agriculture Strategy (CSA) in dairy intensification.

However, maize stover is the principal feed during the peak of the long dry season. Between 88 per cent and 92 per cent of farmers provided supplements in the form of dairy meal concentrates to the lactating cows but the quantity was low and amount fixed (usually about 2 kg/day) throughout the lactation period and not commensurate with milk production. Fodder scarcity in Kenya has resulted in non-dairy households finding fodder growing for sale an attractive enterprise, which has led to feeding innovations in fodder, pastures, and non-conventional feeds (Wambua and Nguluu, 2011).

Genetic intensification to increase milk production per animal

The relative increase in average annual milk yield per cow despite a decreasing herd size between 1986 and 2016 in developed countries increased at an average rate of 1.5per cent per annum to 37 per cent in the United States, 39 per cent in New Zealand, 48 per cent in Ireland, and 56 per cent in the United Kingdom. The increase could be attributed to among other reasons, genetic gain. In Brazil, zebu and taurine cattle were crossed to produce Girolando (Gir 9 Holstein), which have both high tolerances to heat and humidity, and high productivity from temperate cattle.

In Kenya, the current dairy per capita consumption of 110 litres is projected to increase to 220 litres per capita by 2030 due to better incomes and better marketing. This will translate into an increase from the current annual demand of 5.2 billion litres to 12.76 billion litres of milk. The demand for milk by 2030 cannot be achieved at the current national average productivity levels of 5–8 litres per cow per day among small-scale farmers and 17–19 litres per cow per day among large-scale farmers (ACET, 2015). Smallholder farmers in Kenyan highlands prefer imported Bos taurus dairy breeds (78 per cent) and the Holstein–Friesian (HF) over Bos indicus breeds (22 per cent). Such genetic intensification strategies could be used to improve milk yield among smallholder farmers in Kenya.

Intervention pathways

Intervention pathways to dairy intensification could aim to increase productivity while promoting animal welfare and environmental sustainability. Dairy farmers could prioritize the use of data-driven technologies such as artificial insemination, animal genetics, heifers, and crossbreeds adapted to climatic and disease conditions and with high productivity. Providing training and extension services to facilitate the uptake of new technologies and sustainable practices among smallholder farmers could be prioritized. Stakeholders in the dairy value chain could implement pilot projects and integrate them at the grassroots to support scaling up and sustainability. Further, they could prioritize efforts to use high nutrient-dense drought-tolerant fodder crops, legume fodder crops, and cover crops to ensure a continuous supply of feed.

5.1.2. Dairy Automation

The 4IR implications in the smart dairy industry will be spurred by the greater use of automation, data exchange, robotics, 3D printing, blockchain, and artificial intelligence (AI). The automated workflows, improved tracking and scheduling, and optimized energy consumption inherent in the smart dairy farms could increase yield, uptime, and quality, as well as reduce costs and waste. This could further meet demands for promoting food safety, better managing supply chains, ensuring the greatest profitability in a complex, competitive world, or being able to respond flexibly to changing consumer demands now and in the future.

Some technologies that have been adopted in smart dairy farms include biosensors and wearable technologies used to monitor in real-time, the physical health of animals (Shu et al., 2021) such as sweat constituents (Tabasum et al., 2022), stress levels (Neethirajan, 2023) and observe behaviour and movement (Alonso et al., 2020). Artificial Intelligence (AL), and Machine Learning (ML) are used to monitor real-time important animal health aspects such as movement, air quality, and food and fluid consumption. (Gehlot et al., 2022). Technologies such as facial action coding systems (FACS) have been developed, to monitor facial emotions in an animal (Waller et al., 2020). Automatic Milking Systems (AMS) are gaining popularity on medium-sized or family-based dairy farms, replacing conventional Milking Systems (CMS) (Hansen and Stræte, 2020). In New Zealand, the number of cows per robot ranged from 50 to 80 with annual milk solids production ranging from 30,000 to 42,900 kg per robot (Woodford et al). This type of system allows fewer farmers to care for more animals, lessening production costs, and alerting farmers to the possibility of a disease, even if it is still in the pre-clinical stage avoiding catastrophic losses (Akbar et al., 2020).

Kenya is a Silicon Savannah, given its large amounts of ICT start-ups (Reference). However, to date, most tools are "simple digital tools", followed by "smart digital tools" using manual data. Such tools only requiring smartphone ownership are the "sweet spot" for supporting digital livestock development in Kenya. Most digital tools focus on dairy production, suggesting neglect of other types of livestock, with only a few tools for pastoralists. An example is the iCow, an e-extension tool that sends livestock farmers free SMS alerts and advice on topics such as feeding and disease control (Daum et al., 2022). Many sophisticated tools have been piloted but not implemented because of cost, lack of user-friendliness, and data insecurity. For instance, the Animal Bio Surveillance System (KABS) application built on the Java® platform, developed in 2019 had only 72per cent reported using the application within the first 3 months of downloading (Njenga et al., 2021).

Intervention pathways

The adoption of new technologies by smallholder farmers in Kenya to attain sustainable food and nutrition security is in line with the Africa Union's recent focus (Fadeyi et al., 2022). The rate of adoption is however influenced by dynamic factors such as finance, age, gender, access to extension services, education, access to technology, membership to dairy cooperatives, access to contracts, access to credit, type of service providers, and farm size (Fadeyi et al., 2022). These dynamics are, often addressed in silos calling for a strategic comprehensive policy speaking to all these factors. Further, the push towards the adoption of technology by smallholder farmers could be supported by strategically improving financial access to the last-mile smallholder farmer.

The technology adoption process is usually nonlinear, involving backward and forward loops (Akzar et al., 2023). There is the possibility that it can be challenging for the farmers to adapt to the digital farming technology, interpret the computerized results, and may also present operational difficulties due to the various technical systems that are integrated. Investing in practical training and demonstrations and even learning basic computing concepts to effectively operate, implement, and utilize farming systems is crucial (Geoffrey K. Ontiri and Lilian L. Amuhaya, 2022). This can be achieved through digital dairy schools at the grassroots.

The use of highly mechanized, faster, and more extensive farm automation technology and machinery could result in reduced human labour needs. Besides leveraging on the advantages of technology to increase farm yields which in turn promotes food and nutrition security. Stakeholders could retrain workers on transferable skills that will support labour reallocation to newly demanded tasks. Stakeholders in the dairy industry could promote the formation of “dairy boarding schools” or “microdairies”. These are dairy centres aimed at reducing the number of small dairy farms and increasing the average herd size within the same area.

5.1.3 Disruption from plant-based milk substitutes

Plant-based proteins are amid a range of global trends such as climate change, overconsumption of resources, population growth, urbanization, and an increase in life expectancy (Silva et al., 2020). The dairy sector increasingly turning toward sustainability issues has prioritized plant-based milk as a growing trend set to contribute to this challenge. For instance, in Canada, between 2004 to 2015, the consumption of plain milk significantly decreased from 70.2per cent to 56.1per cent, whereas the percentage of plant-based protein consumers significantly increased from 1.8per cent to 3.0per cent. The market of milk analogs is currently dominated by soya bean milk, oat milk, coconut milk, hemp milk, cocoa milk, multigrain milk, etc. most of which are produced by controlled fermentation which owes to their functional bioactive composition which is often correlated to their health-promoting and disease-preventing properties. Given the growing demand for milk-free products and derivatives in the world market, the development of new products is of importance to dairy companies in Kenya, because these new products are directly related to the needs and consumption trends of the population in the future (Aschemann-Witzel et al., 2020).

Intervention pathways

Vegetarianism has been growing in recent years and this has led to a growth in the market niche for new products (Muñoz-Furlong, 2003). One way to innovate and meet the demands of this sector is through leveraging technology and technology transfer. Structuring of policies to promote the acquisition and merging of the big dairy industries with upcoming plant-based industries to facilitate their adoption of plant-based milk alternatives. This strategy is key in ensuring the continuity and survival of smallholder farmers who send their milk to small processors.

5.1.4 Environmental sustainability

Growing awareness of the ecological impacts of the dairy industry is well documented. In addition to belching, the livestock industry is associated with land degradation due to overgrazing, soil erosion and salinization, deforestation, biodiversity loss due to changes in land use, and the contamination of surface and groundwater (Saari et al. 2020). The ongoing expansion of the dairy industry will exasperate pollution issues from acidification to eutrophication on land and freshwater systems (Poore and Nemecek 2019; Rotz 2018; Fiel et al. 2020), as well as the displacement of natural carbon sinks (Harwatt et al. 2019) if current production and consumption trajectories persist. These and similar findings are placing pressure on dairy industries to lower emissions and develop more sustainable systems. Dairy industries need to develop much more sustainable production processes if they are to mitigate growing consumer concerns about the environmental impacts of the industry. Being a significant contributor to greenhouse gas emissions, the global dairy sector has been recognized as one of the sectors with an important role to play in the reduction of global emissions mostly through methane released (Bar-On et al. 2018).

The US Dairy industry, for instance, has seen substantial improvements over the years. It has seen a great increase in milk production primarily due to dramatic increases in milk production per cow, an increase in average cow numbers per farm, as well as an overall decrease in total animal numbers (Wolf, 2003; Barkema et al., 2015). Some other major changes over the last 50 years include a shift to a primarily Holstein dairy herd (90per cent), an increased heifer growth rate, decreased age at first calving, and an increase in the use of artificial insemination (Capper et al., 2009). Nutrition of dairy animals has also allowed for a substantial improvement in production via the use of total mixed rations balanced for nutrient and energy requirements accounting for each animal's age and stage of lactation (National Research Council, 2001). Genetic selection has also been a major driver in increased productivity, longevity, and efficiency of dairy cows, further reducing the environmental impact per unit of milk production (Pryce and Haile-Mariam, 2020). Research into enteric fermentation, the metabolic process that creates methane in cattle rumen, has targeted the digestive system of cattle to limit the production of methane.

The Nationally Determined Contribution (NDC) and the dairy master plan of Kenya define specific targets for climate change mitigation and for the development of the livestock sector. According to these national policies, the increase in total GHG emissions in Kenya has to be lowered by 30per cent relative to projected business-as-usual emissions between 2010 and 2030 (Government of Kenya, 2015b). Within the same period, milk yields per cow should increase by 150per cent to ensure that local dairy production meets the increased requirements for food and nutrition due to population growth (Government of Kenya, 2010). Forest degradation is the largest component (75per cent) of forest emissions in Kenya, where deforestation rates have been around 35,000 ha/year in the last three decades (Carter, Herold, et al., 2018; Pearson et al., 2017).

Intervention pathways

Climate-friendly dairy will rely on improvements in cattle breeds (Wankar et al. 2021) and improvements in animal health to minimize “wastage” (Mylan et al. 2019). Furthermore, a newly developed Nationally Appropriate Mitigation Action (NAMA) for the dairy sector in Kenya defines a low☐emission development pathway, which aims to increase on☐farm productivity by promoting the adoption of high☐quality feeds (Government of Kenya, 2017). Smallholder farmers who keep their livestock in dairy boarding schools could be encouraged to utilize their small farms in promoting the 15 billion tree initiatives by the government. Stakeholders can offer incentives such as carbon credits to key players in the dairy industry utilizing low-energy use technologies. Further, incentives can be given to the youth to practice smart dairy farming as their main source of livelihood. The youth can be supported with initial capital and model farms that can support their ventures and walk them through making their first profit. The study also recommends extension services that train farmers on the uptake of biogas plants for cooking, lighting, and heating and for manure fertilizing of pastures and crops at the household level. Strict regulations to prevent the importation of milk and support local consumption can be introduced to promote Kenya's journey to become a food-sovereign state and reduce carbon miles that accrue as milk travels to Kenya.

5.2 Future Developments of Smart dairy: A scenario Analysis

Scenarios were built on the premise that the future of dairy is still in the making and can be actively shaped by anticipating emerging opportunities, challenges, and threats and by taking strategic action today that supports the performance of smart dairy farming in the future. The 44 drivers identified from the literature and classified using the PESTEL framework are shown in Table 4.3

Table 8: A total of 44 Drivers of change were identified from the literature and classified using the PESTEL Framework

Political	Economic	Social	Technological	Environmental	Legal
Corporate governance Subsidy support shifts Tax policy	International trade and Foreign trade policy Trade restrictions Exchange rates Export market competition Unemployment rates	Population growth Rising Incomes Urbanization Fast-paced lifestyles Changing consumers preferences Food safety emphasis Animal welfare Health consciousness Lifestyle attitudes Cultural barriers Clean labelling Personalized nutrition using AI, big data, and predictive analytics Generational shift-Millennials/ Gen Z Green purchasing	Food Technological innovations Level of innovation Automation Research and Development activity Technological Awareness Technological changes Dairy milk snack-healthy snacking IP/Patents	Diseases Outbreaks GHGs Deforestation and biodiversity loss Climate change Water pollution Water and resource scarcity Poor animal welfare Carbon footprints Land conversion Eco anxiety Smart feeds Environmental fines Seasonality-Changing milk composition	Consumer protection laws Copyright and patent laws Food taxation

The 14 variables named V1 to V14 in Table 5.1 were identified from the 44 drivers subjected to round one and two Delphi processes.

Table 9: Interaction between drivers in Smart Dairy Farming

Variables	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10	V11	V12	V13	V14
V1-Land conversion	0	2	2	2	3	2	2	2	2	2	2	2	2	2
V2-Export market competition	1	0	2	2	2	2	2	2	2	2	2	2	2	2
V3-A shift in subsidy	2	2	0	2	2	2	1	2	2	2	2	2	2	2
V4-Research and Development	2	2	2	0	2	2	2	2	2	2	2	2	2	2
V5-Deforestation and biodiversity loss	2	2	1	2	0	2	2	2	2	2	2	2	2	2
V6-Water and resource scarcity	2	2	2	2	2	0	2	2	2	2	2	2	2	2
V7-Animal welfare	2	2	2	2	2	2	0	2	2	2	2	2	2	2
V8-Level of technology	2	2	2	3	2	2	2	0	2	2	2	2	2	2
V9-Rising incomes	2	2	2	2	2	2	2	2	0	2	2	2	2	2
V10-Changing consumer preferences	2	2	2	2	2	2	1	2	2	0	2	2	2	2
V11-Food safety	1	2	2	2	2	2	2	2	2	2	0	2	2	1
V12-Green Purchasing	2	2	2	2	2	2	1	2	2	2	2	0	2	2
V13-Greenhouse gas footprint	2	2	2	2	2	2	2	2	2	2	2	2	0	2
V14-Population growth	2	2	2	2	2	2	2	2	2	2	2	2	2	0

The responses of stakeholders on the 14 drivers (Table 10) were subjected to the MICMAC software to calculate the intensity of the influence and dependency between variables. The structural analysis using MICMAC aids the necessary understanding of the role of each variable in the construction of the future of the smart Dairy farming ecosystem in Kenya. Each variable holds a unique position in relation to all other variables as shown in the quadrants represented in Figure 12.

Figure 5.1: Plane of direct influences.

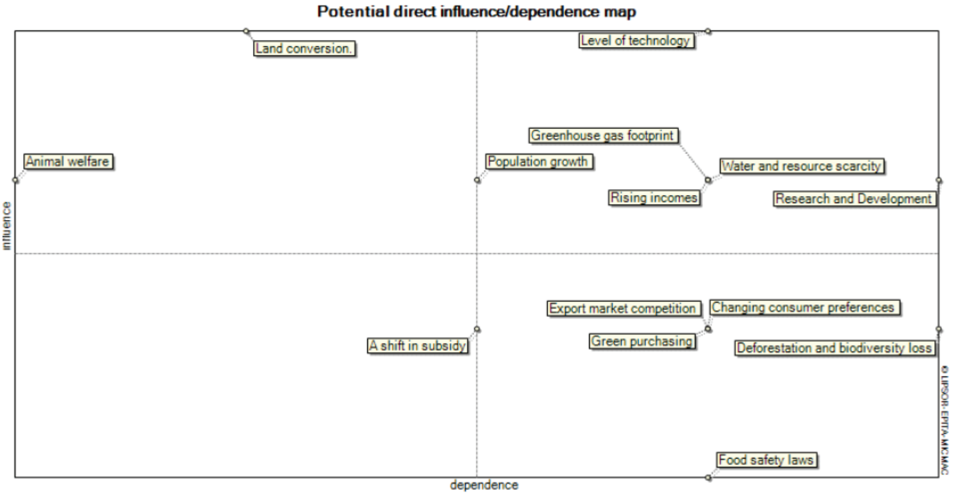


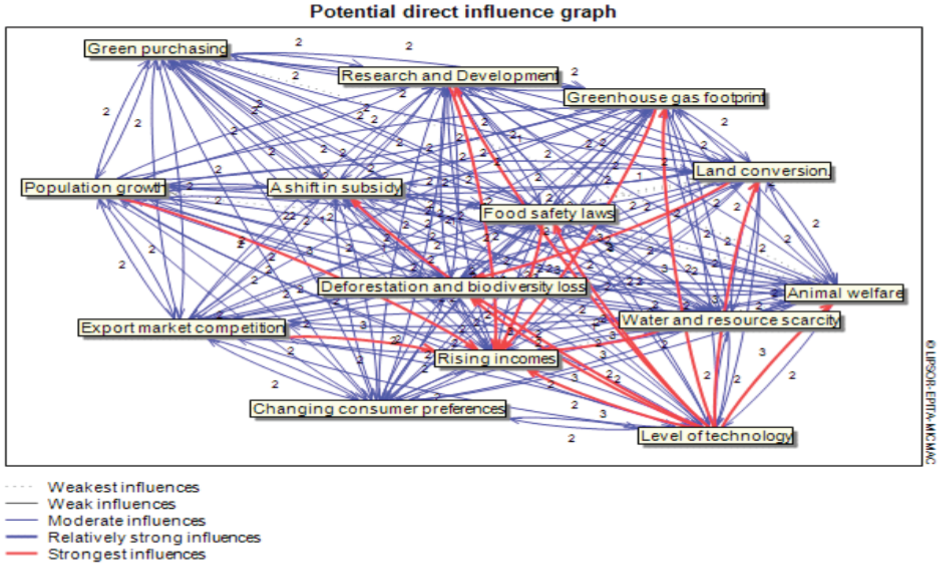
Table 10: Explanation of quadrants

Depending on the variable location on the matrix every factor was classified into influential, rely, dependent, and autonomous variables as described below:

Situation	Variables	Description
Autonomous	A shift in subsidy	This variable has no significant influence over the other or is not influenced by them, since they have little influence and dependence.
Power	Land conversion, Animal welfare	These two variables have the highest influence and lower dependence and will be used to construct scenarios. A slight change in any one of the two variables will influence variables in other quadrants as well as the whole smart dairy farming industry.

Conflict	Level of technology, greenhouse gas footprint, research and development, water and resource scarcity, rising income, population growth	These variables have high mobility and high dependency. These very influential variables are highly vulnerable, they influence the other variables and are also influenced. These are the most critical variables of the future. The strategic variables influence the whole dairy system and are dependent on the power variables. Given that they are highly variable, they represent unstable and emergent outcomes with smart dairy farming. These relay factors shift the outlook of the future of Smart Dairy Farming if the driving forces they depend on have a significant change.
Output	Export market competition, green purchasing, changing consumer preferences, deforestation and biodiversity loss, food safety laws	They are the result of interactions in the other quadrants. They have low mobility but high dependence.

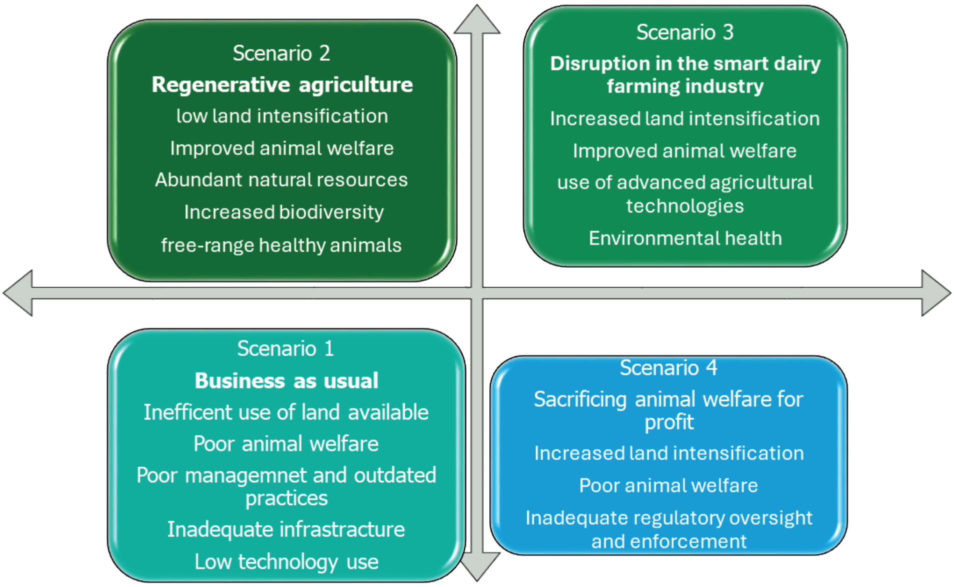
Figure 5.2: Potential direct influence graph.



5.2.1 Scenarios, implication, and intervention pathways

The section reflects on the impact, emerging challenges, implications, intervention pathways, and policy alternatives for the smart dairy industry in Kenya.

Figure 5.3: 2 by 2 scenario matrix



Scenario 1: Business as usual

The business-as-usual scenario is characterized by inefficient land use with poor animal welfare practices that fail to prioritize animal wellbeing. Here, farmers could own large tracts of land, but poor management and outdated practices lead to suboptimal production and poor animal welfare. With low intensification, animals are allowed to graze without rotational management leading to overgrazing in some areas and underutilization in other areas. Animals are neglected with inadequate care. Diseases and injuries go unnoticed and untreated, and the mortality of animals is high. This scenario can lead to environmental degradation, low productivity, and high animal mortality.

The common patterns in the business-as-usual scenario as deduced from the six critical uncertainties variables in the conflict quadrant could include inadequate data, manual processes, and inadequate infrastructure due to low investment in technology exacerbating poor animal welfare. In contrast, high technology use could advance automation, monitoring of animals, and data-driven decision-making processes. This scenario could significantly increase greenhouse gas emissions because of high energy and resource use, poor waste and manure management issues, and land degradation. Whilst the population is estimated to increase in the future, in this scenario they will be exposed to high food and nutrition insecurity, increased incidences of diseases, and a strain on water and resources that are already scares compromising environmental sustainability. The Smallholder farmers could experience low incomes because of poor-quality milk and milk products. Research and development through fostering innovations in sustainable dairy practices could improve environmental sustainability and animal welfare.

The challenges faced by this scenario include inadequate standards and enforcement allowing poor practices to go unchecked. Smallholder farmers in this scenario have inadequate education, resources, and financial incentives to improve their practices. Stakeholders could consider intervention pathways such as providing smallholder farmers with training on sustainable land management and animal welfare, offering financial incentives for improvement, and implementing stricter regulations on animal welfare and land management to ensure minimum standards are met.

Scenario 2: Regenerative agriculture

This scenario is characterized by low land intensification and improved animal welfare. In the best-case scenario, this could be a regenerative agriculture system implemented on a small family-owned farm in a rural area. The farm could be characterized by an abundant natural resource with increased biodiversity, fertile soils, and ample water supply. Low land intensification could be characterized by rotational grazing allowing the land to recover, agroforestry promoting biodiversity, allowing cultivation of crops, and reducing carbon emissions.

Improved animal welfare will be a result of free-range animals raised in almost a natural habitat with ample space to move around. In these scenarios, animals are bred for health and longevity unlike in intensified lands where they are bred rapidly for profit. This scenario could promote environmental sustainability, animal welfare, and high-quality and sustainably grown products that could be sold at premium prices. Advancements in technology such as automated feeding, health monitoring of animals, and sustainable manure and waste management enable farmers in this scenario to use land more efficiently and to improve animal welfare.

The challenges to this system could stem from finding a market and consumers who are willing to pay for the premium products that are produced sustainability. A transition to regenerative agriculture could require advanced knowledge and expertise that are limited currently in Kenya. The initial cost of setting up a regenerative farm even in rural requires high capital investment.

Scenario two exemplifies a balanced approach to smart dairy farming that prioritizes environmental health and animal welfare while maintaining economic viability. The intervention approaches to these scenarios could include providing grants and tax incentives to farmers practicing regenerative agriculture, increasing research and development and the transfer of technologies used in regenerative agriculture, and encouraging the formation of cooperatives and networks to support the development of premium markets to absorb goods produced sustainably.

Scenario 3: Disruption in the smart dairy farming industry

A scenario characterized by increased land intensification and improved animal welfare might involve the use of advanced agricultural technologies and innovative practices to maximize land use efficiency while ensuring high standards of animal welfare. Animals in this system are reared in enriched areas that have adequate lighting, a variety of novel diets that improve health and wellbeing, and physical infrastructures designed to meet animals' physical and mental welfare. This scenario will promote high productivity due to the use of advanced technologies in relatively small farms contributing to food and nutrition security and sustainability due to the adoption of renewable energy sources.

Greenhouse gases pose a significant challenge in this scenario. However, targeted research and development and adoption of innovations such as low-emission technologies, sustainable intensification practices, and innovations promoting animal welfare could contribute to a resilient and sustainable dairy value chain in the future. premium milk products from the scenario will be greatly appreciated by consumers whose incomes are increasing and who are becoming increasingly aware of eco-friendly purchasing.

Such a system is however challenged by large initial capital investment and limited market access to high-value products. Intervention pathways including branding and marketing strategies that emphasize the farm's sustainability and welfare standards, as well as establishing direct consumer sales channels will be important in promoting economic gains from these farms. Stakeholders in dairy could also implement and enforce regulations that ensure high standards of animal welfare in intensive farming systems. They can put in place a framework that promotes transparency and accountability through regular audits and reporting.

Scenario 4: Sacrificing animal welfare for profit

This scenario is characterized by increased land intensification and poor animal welfare. In the future, land will be extremely scarce and expensive. To meet the rising demand for dairy products, high-density animal production zones will emerge. Land intensification will need to optimize the use of technologies to utilize the small pieces of land optimally. Livestock will be kept in confined overcrowded facilities that compromise animal well-being exacerbating health problems including animal lameness. This system will also be vulnerable to environmental degradation contributing to deforestation, and loss of biodiversity since natural habitats are converted to dairy farms. An increase in the use of chemical inputs will have long-term effects such as soil degradation and water contamination.

The use of advanced technologies in this scenario could offer opportunities to increase productivity and efficiency. If not used appropriately, it could pose a risk to animal welfare. Stakeholders in the dairy value chain could promote responsible technology adoption that prioritizes animal welfare. Through fostering a culture of education and compliance, dairy farmers could achieve sustainable intensification while ensuring the well-being of their livestock. Stakeholders across the dairy industry could work together to strike a balance between productivity goals and ethical considerations in dairy farming.

Inadequate regulatory oversight and enforcement mechanisms may allow such farms to prioritize profit over animal welfare without facing significant consequences. In this scenario, strict implementation of such regulatory policies should thus be enforced. Advocacy and capacity building, particularly for stakeholders with a vested interest in profitability, could be educated on the need to promote long-term sustainability even as they endeavour to feed the future profitably. Public awareness campaigns to promote green purchasing and eco-friendly animal products can also be intensified to facilitate the death of such dairy farming systems.

6. Conclusion and Recommendations

6.1. Conclusion

This paper has provided an in-depth assessment of Kenya's sustainable smart dairy farming, examining emerging trends, key drivers, and potential future scenarios. In the past 60 years, the dairy sector has gradually evolved to adopt dairy intensification and automation at a small scale contributing to Kenya becoming an almost milk-sufficient country. With six years left to the attainment of the SDGs, the country's dairy sector is faced with a triple challenge of feeding the increasing population with the most available and cheaper source of protein, improving the livelihoods of smallholder farmers in dairy, promoting environmental sustainability, and improving animal welfare.

Kenya's dairy sector thus holds significant potential for growth and sustainability through the adoption and scaling of smart dairy technologies and sustainable farming practices. The future of Kenya's dairy farming lies in embracing innovation while maintaining a strong commitment to environmental stewardship and ethical farming practices. Further, the sector needs to evolve to meet the changing consumer preferences particularly a shift towards sustainable purchasing and consumption.

With the right policy interventions and collaborative efforts from all stakeholders towards market access and value addition, research innovation and financial support to accelerate the adoption of smart technologies. Kenya has the potential to build a resilient and thriving dairy sector that supports the livelihoods of smallholder farmers, contributing to national food security, and aligns with global sustainability goals. Stakeholders in the dairy sector could start implementing intervention pathways to adapt to the diverse futures as they unfold. Indeed, addressing the challenges of poor animal welfare and under-exploitation of land intensification which are the key driving forces in the dairy sector in the future is critical to achieving the full potential of smallholder dairy farmers in the future.

6.2. Policy recommendations

Establish data collection and analysis systems

To support smallholder dairy farmers in the business-as-usual scenario the Ministry of Agriculture, Livestock and Fisheries supported by the Ministry of ICT could establish regular data collection and analysis systems. This will help in quantifying productivity, animal welfare, and the extent of environmental issues. This can be followed by supporting local agricultural institutions to offer veterinary services and good animal husbandry practices. The government could also intensify education and capacity building for smallholder farmers through farmer field schools to support the adoption of sustainable dairy farming.

Community-based rangeland management systems

In the regenerative agriculture scenario, the Ministry of Agriculture, Livestock and Fisheries, and support ministries could consider promoting community-based rangeland management systems where the local community is involved in making decisions. This could promote diversification of agricultural activities to reduce pressure on grazing land and support smallholder farmers' resilience when dealing with the effects of climate change. To enable farmers in these scenarios to sell their premium products, the Ministry of Transport could invest in infrastructure including roads and market facilities to facilitate the movement of products to the end consumer.

Establish innovation labs and incubation centres

In the scenario of disruption in the smart dairy farming industry. The Ministry of Agriculture, Livestock and Fisheries could establish innovation labs and incubation centres that test technologies before scaling up to the farmers. Stakeholders in academia, the private sector, the government, and other research institutions could conduct collaborative research to drive the adoption of and channeling of funds to the dairy sector.

Develop a clear regulatory framework

To address the negative impacts in the scenario where farmers are sacrificing animal welfare for profit. The Ministry can develop a clear regulatory framework with guidelines on healthcare, housing, feeding, and handling of animals. The Ministry of ICT can establish hotlines where farmers can get prompt advice on animal welfare issues. The Kenya Bureau of Standards could develop certification schemes that recognize dairy products that uphold high standards of animal welfare.

References

Arcidiacono, C. et al. (2020). Smart Dairy Farming: Innovative Solutions to Improve Herd Productivity. In: Coppola, A., Di Renzo, G., Altieri, G., D'Antonio, P. (eds) Innovative Biosystems Engineering for Sustainable Agriculture, Forestry and Food production. MID-TERM AIIA 2019. Lecture Notes in Civil Engineering, vol 67. Springer, Cham. https://doi.org/10.1007/978-3-030-39299-4_30

Admin, A. (2023, September 3). 4IR impact on agriculture. Agribusiness Education and Research International. https://agribusinessedu.com/4ir-impact-on-agriculture/

Akbar, M. O., Shahbaz khan, M. S., Ali, M. J., Hussain, A., Qaiser, G., Pasha, M., Pasha, U., Missen, M. S., and Akhtar, N. (2020). IoT for Development of Smart Dairy Farming. Journal of Food Quality, 2020, e4242805. https://doi.org/10.1155/2020/4242805

Akbar, M. O., Shahbaz Khan, M. S., Ali, M. J., Hussain, A., Qaiser, G., Pasha, M., Pasha, U., Missen, M. S., and Akhtar, N. (2020). IoT for Development of Smart Dairy Farming. Journal of Food Quality, 2020, 1–8. https://doi.org/10.1155/2020/4242805

Body condition assessment using digital images—PubMed. (n.d.). Retrieved 3 April 2024, from https://pubmed.ncbi.nlm.nih.gov/16960058/

dr.ir. C (Kees) Lokhorst. (2012, September 4). WUR. https://www.wur.nl/en/persons/kees-lokhorst-1.html

Ferguson, J. D., Azzaro, G., and Licitra, G. (2006). Body condition assessment using digital images. Journal of Dairy Science, 89(10), 3833–3841. https://doi.org/10.3168/jds.S0022-0302(06)72425-0

Hassoun, A., Garcia-Garcia, G., Trollman, H., Jagtap, S., Parra-López, C., Cropotova, J., Bhat, Z., Centobelli, P., and Aït-Kaddour, A. (2023). Birth of dairy 4.0: Opportunities and challenges in adoption of fourth industrial revolution technologies in the production of milk and its derivatives. Current Research in Food Science, 7. https://doi.org/10.1016/j.crfs.2023.100535

Henchion, M. M., Regan, Á., Beecher, M., and MackenWalsh, Á. (2022a). Developing 'Smart' Dairy Farming Responsive to Farmers and Consumer-Citizens: A Review. Animals, 12(3), Article 3. https://doi.org/10.3390/ani12030360

Henchion, M. M., Regan, Á., Beecher, M., and MackenWalsh, Á. (2022b). Developing 'Smart' Dairy Farming Responsive to Farmers and Consumer-Citizens: A Review. Animals: An Open Access Journal from MDPI, 12(3), 360. https://doi.org/10.3390/ani12030360

Herrmann, S. N. and I. (n.d.). The fourth industrial revolution in agriculture. Strategy+business. Retrieved 21 February 2024, from https://www.

strategy-business.com/article/The-fourth-industrial-revolution-in-agriculture

IEEE Xplore Full-Text PDF: (n.d.). Retrieved 21 February 2024, from https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=andarnumber=9277547

Kamau, W. (2019, July 24). New Technology Set to Increase Milk Production in Kenya. Talk Africa. https://www.talkafrica.co.ke/new-technology-set-to-increase-milk-production-in-kenya/

Kaur, R., Garcia, S. C., Horadagoda, A., and Fulkerson, W. J. (2010). Evaluation of rumen probe for continuous monitoring of rumen pH, temperature and pressure. Animal Production Science, 50(2), 98–104. https://doi.org/10.1071/AN09048

Kiddy, C. A. (1977). Variation in physical activity as an indication of estrus in dairy cows. Journal of Dairy Science, 60(2), 235–243. https://doi.org/10.3168/jds.S0022-0302(77)83859-9

Lokhorst, K. (2018). An introduction to Smart Dairy Farming. Van Hall Larenstein. https://doi.org/10.31715/20181

LR - Animal Breeding and Genomics, Knowledge Technology and Innovation, Animal Production Systems, WIAS, Van Der Lee, J., Omedo Bebe, B., and Oosting, S. (2016a). Sustainable intensification pathways for dairy farming in Kenya: A case study for PROIntensAfrica WP2, Deliverable 2.3. Wageningen Livestock Research. https://doi.org/10.18174/401333

LR - Animal Breeding and Genomics, Knowledge Technology and Innovation, Animal Production Systems, WIAS, Van Der Lee, J., Omedo Bebe, B., and Oosting, S. (2016b). Sustainable intensification pathways for dairy farming in Kenya: A case study for PROIntensAfrica WP2, Deliverable 2.3. Wageningen Livestock Research. https://doi.org/10.18174/401333

Nagaraja, T. G., and Titgemeyer, E. C. (2007). Ruminal acidosis in beef cattle: The current microbiological and nutritional outlook. Journal of Dairy Science, 90 Suppl 1, E17-38. https://doi.org/10.3168/jds.2006-478

Nleya, S. M., and Ndlovu, S. (2021). Smart Dairy Farming Overview: Innovation, Algorithms and Challenges. 35–59. https://doi.org/10.1007/978-981-16-6124-2_3

Owens, F. N., Secrist, D. S., Hill, W. J., and Gill, D. R. (1998). Acidosis in cattle: A review. Journal of Animal Science, 76(1), 275–286. https://doi.org/10.2527/1998.761275x

Perin, L., and Enahoro, D. (2023). Foresight study on dairy farming systems in Central Kenya and north of Senegal. Frontiers in Sustainable Food Systems, 7. https://doi.org/10.3389/fsufs.2023.1061834

Pratap Singh, S. (2014). Precision Dairy Farming: The Next Dairy Marvel. Journal of Veterinary Science and Technology, 05(02). https://doi.org/10.4172/2157-7579.1000164

Roche, J. R., Friggens, N. C., Kay, J. K., Fisher, M. W., Stafford, K. J., and Berry, D. P. (2009). Invited review: Body condition score and its association with dairy cow productivity, health, and welfare. Journal of Dairy Science, 92(12), 5769–5801. https://doi.org/10.3168/jds.2009-2431

Schulze, C., Spilke, J., and Lehner, W. (2007). Data modeling for Precision Dairy Farming within the competitive field of operational and analytical tasks. Computers and Electronics in Agriculture, 59(1), 39–55. https://doi.org/10.1016/j.compag.2007.05.001

Smallholder dairy production in Kenya; a review. (n.d.). Retrieved 15 April 2024, from https://www.lrrd.org/lrrd29/7/atiw29139.html

Taneja, M., Jalodia, N., Byabazaire, J., Davy, A., and Olariu, C. (2019). SmartHerd management: A microservices-based fog computing–assisted IoT platform towards data-driven smart dairy farming. Software: Practice and Experience, 49(7), 1055–1078. https://doi.org/10.1002/spe.2704

Taneja, M., Jalodia, N., and Dezfouli, B. (2021). Towards Building a Data-Driven Framework for Climate Neutral Smart Dairy Farming Practices. 2021 IEEE Global Humanitarian Technology Conference (GHTC), 213–218. https://doi.org/10.1109/GHTC53159.2021.9612417

The Future of Dairy: SomaDetect and the 4th Industrial Revolution. (2020, August 19). SomaDetect. https://somadetect.com/somadetect-blog/future-of-dairy https://doi.org/10.31715/20181

Appendix

Appendix 1: References for dairy intensification emerging trend

Emerging trend	Themes	Reference							
Dairy intensification of production	Intensification of milk production per animal	(Clay et al., 2020)	(Duncan et al., 2013)	Click or tap here to enter text.	(Alvarez et al., 2008)	(Brandt et al., 2020)	Chagunda1	Wilkinson1 et al, 2020	(Larsen et al., 2010)
	Intensification of milk production per unit area	(Clay et al., 2020)	(Duncan et al., 2013)	(Salou et al., 2017)	(Alvarez et al., 2008)	(Brandt et al., 2018)	Chagunda1 et al, 2015	Thompson et al)	Wilkinson1 et al, 2020
	Indoor housing/ feeding, energy and protein-dense commercial feeds	(Njuki et al., 2016)	(Ma et al., 2019)	(Styles et al., 2018)	(Duncan et al., 2013)	(Salou et al., 2017)	(Schönfeldt et al., 2012)	(Brandt et al., 2018)	Chagunda1 et al, 2015

Annex 2: References for dairy intensification emerging trend

Scenario/ Key Trends/ megatrends	Themes	Reference								
Dairy Automation using precision livestock technologies	Animal Health Monitoring	Arcidiacono et al, 2020	(Ipema et al., n.d.)	(Neethirajan, 2023)	(Fuentes et al., 2020)	(Akbar et al., 2020a)	(Tabasum et al., 2022)	(Shu et al., 2021)	(Njenga et al., 2021)	(Daum et al., 2022)
	Animal Tracking safety	(Fuentes et al., 2020)	Hempstalk	(Zhuang et al., 2020).	(Wurtz et al., 2019).	(Casas et al., 2021)	(Alshehri, 2023)	(Ilyas and Ahmad, 2020)	(Isaac, 2021)	
	Milk monitoring and ssupply chain	(Alonso et al., 2020)	(Saravanan et al., 2021)	(Duncan et al., 2013)	(Fuentes et al., 2020)	(Patil et al., 2021)				
	Feed monitoring	Taneja et al	(Schönleben et al., 2020)	(Daum et al., 2022)	(Neethirajan, 2023)	(Wambua and Nguluu, 2011)				
	Robotic Automated milking	Hansena	(Woodford et al., 2015)	Lundstrom	(Fuentes et al., 2020)	(Ji et al., 2022)	Gargiulo et al	(Solano et al., 2022)	(Silva Boloña et al., 2022)	(Filho et al., 2020)

Annex 4: References for environmental sustainability emerging trend

Emerging trend	References								
Environmental sustainability	(Kozina and Semkiv, 2020)	(Chagunda et al., 2016)	(Brandt et al., 2018)	(Fuentes et al., 2020)	(Marañón et al., 2011)	(Salou et al., 2017)	(Poore and Nemecek, 2018)	(Ipema et al., n.d.)	(Notenbaert et al., n.d.)

ISBN 978 9914 738 67 4

Kenya Institute for Public Policy Research and Analysis
Bishops Garden Towers, Bishops Road
PO Box 56445, Nairobi, Kenya
tel: +254 20 2719933/4, 2714714/5, 2721654, 2721110
fax: +254 20 2719951
email: admin@kippra.or.ke
website: http://www.kippra.org