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# Modeling the transition towards lab-grown milk: future pathways for the Italian dairy-beef system

TESI DI LAUREA MAGISTRALE IN
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# Abstract


Milk has always been considered an essential food in people's diets. However, animal-based food production is raising increasing ethical and environmental concerns. As a result, new alternative protein sources are being developed. Among the most recent innovations is lab-grown milk, a product obtained through precision fermentation that aims to transform the dairy industry.

Through a literature review and a series of interviews conducted with industry experts, the key dynamics characterizing the Italian dairy sector and its related sectors were identified. The information gathered were used to develop a system dynamics model aimed at representing and quantifying the interconnections between milk production and meat production, as well as their effects on the feed and energy sectors. Subsequently, a scenario analysis was conducted to explore different possible future pathways for the dairy-beef system over the period 2025-2040.

The results show that a reduction in traditional milk production can generate effects that extend beyond the dairy sector. Indeed, a decline in the number of dairy cows affects the availability of meat from dairy farms and leads to changes in land occupation and energy consumption. Furthermore, the analysis demonstrates that different future trends in meat consumption can amplify or mitigate the effects generated by the decline in traditional milk production.

This thesis therefore emphasises the importance of adopting a systemic perspective when analysing emerging food innovations, highlighting the need to consider interactions between interconnected systems.

**Key-words:** Lab-grown milk; Protein transition; System dynamics; Scenario analysis; Dairy sector; Dairy-beef system.

# Abstract in italiano

Il latte è da sempre considerato un alimento essenziale nella dieta delle persone. Tuttavia, la produzione di alimenti di origine animale sta generando crescenti preoccupazioni su questioni etiche ed ambientali. Di conseguenza, si stanno sviluppando fonti proteiche alternative. Tra le innovazioni più recenti figura il latte coltivato in laboratorio, un prodotto ottenuto tramite fermentazione di precisione che si propone di trasformare il settore lattiero-caseario.

Attraverso una revisione della letteratura ed una serie di interviste condotte con esperti del settore, sono state individuate le principali dinamiche che caratterizzano il settore lattiero-caseario italiano e i settori ad esso collegati. Le informazioni raccolte sono state utilizzate per sviluppare un modello di system dynamics volto a rappresentare e quantificare le interconnessioni tra produzione di latte e produzione di carne bovina, e i loro effetti sui settori mangimistico ed energetico. Successivamente, attraverso una scenario analysis, sono stati esplorati diversi possibili percorsi di evoluzione del sistema latte-carne nel periodo 2025-2040.

I risultati mostrano come una riduzione della produzione di latte tradizionale possa generare effetti che si estendono oltre il settore lattiero-caseario. Infatti, una diminuzione di vacche da latte impatta sulla disponibilità di carne bovina proveniente dagli allevamenti da latte e determina cambiamenti nell'uso del suolo e nei fabbisogni energetici. Inoltre, l'analisi dimostra che tendenze future diverse

riguardo al consumo di carne bovina possono amplificare o attenuare gli effetti generati dalla riduzione della produzione di latte.

Questa tesi sottolinea pertanto l'importanza di adottare una prospettiva sistemica nell'analisi delle innovazioni alimentari emergenti, evidenziando la necessità di considerare le interazioni tra sistemi.

**Parole chiave:** Latte coltivato in laboratorio; Transizione proteica; System dynamics; Scenario analysis; Settore lattiero-caseario; Sistema latte-carne.

# Contents

# 1 Introduction

The dairy sector is a crucial component of global agri-food systems, significantly contributing to nutrition, food security, agricultural livelihoods, and economic development. According to the Food and Agriculture Organization of the United Nations (FAO), approximately 150 million households worldwide are engaged in milk production, highlighting the central role of dairy farming in both developed and developing countries. (FAO, 2024; Priyashantha, 2025)

Beyond milk production itself, the dairy sector is connected to a wide range of sectors, including feed, meat, and energy. Consequently, changes affecting the dairy sector can generate effects that extend throughout the entire agri-food system.

In recent years, the expansion of dairy farming and the growing demand for food products have intensified the pressure on agricultural systems and their environmental impact. Concerns regarding greenhouse gas emissions, resource use, and animal welfare have therefore led to a growing interest in alternative production methods. (Alrhmoun et al., 2025; Rovira-Alsina et al., 2025)

Within this context, several alternatives to dairy products have emerged. Currently, plant-based beverages represent the most established alternative. At the same time, recent technological advances have enabled the development of new alternatives, including products derived from cell-based agriculture.

Among these innovations, lab-grown milk has attracted increasing attention due to its potential to replicate traditional milk's characteristics while reducing dependence on livestock farming. However, despite its growing visibility, the future diffusion of lab-grown milk and its possible implications for existing production systems remains challenging. Understanding how lab-grown milk may affect the dairy sector and its interconnected sectors therefore represents an important research topic.

This thesis investigates how the diffusion of lab-grown milk could influence the traditional dairy sector and its interconnected sectors. By applying system dynamics and scenario analysis, the study aims to explore potential future developments and assess their implications for the wider agri-food system.

To achieve this objective, the study is structured around a central overarching research question: *How could the increasing diffusion of lab-grown dairy reshape the structure of the traditional Italian dairy sector and its interconnected sectors?*

Then, to support and better explore this question, two more specific research questions have been posed:

RQ1: *What are the main interconnections between the traditional dairy sector and related sectors and how can they be quantified?*
RQ2: *How the introduction of lab-grown dairy could affect the configuration of livestock sectors, and what impacts might this have on related sectors?*

## 1.1 Research context and importance

The diffusion of alternatives to dairy products, especially of lab-grown milk, is generating increasing debate regarding the future of livestock-based food systems.

Since it is a highly innovative product, current research often focus on isolated aspects of the transition, overlooking the interconnections and balancing mechanisms that characterize food systems. Hurst & Pant (2025) note that literature on alternatives to dairy mainly focuses on consumer acceptance and market dynamics, while the implications for producers or for other actors within the food system are not explored in depth. However, according to Duluins et al. (2025), protein transition involves numerous interactions between environmental, economic, social and political dimensions. Therefore, analysing these dimensions separately can lead to fragmented understanding. (Duluins et al., 2025; Hurst & Pant, 2025)

To address this gap, it is necessary to better understand the relationships between interconnected sectors and how changes in one part of the food system can have repercussions elsewhere. It is within this context that this research is situated, aiming to analyse how the adoption of lab-grown milk might reshape the dairy sector and its related systems.

## 1.2 Structure of the thesis

This thesis is structured into seven chapters, which are briefly described below.

In this 1st chapter, the context of the research and the overall structure of the paper are described.

Chapter 2 provides the theoretical background of the research. Firstly, the structure of the Italian dairy supply chain and its interconnections with related sectors are described. Then, the chapter examines emerging alternatives to traditional dairy, with a specific focus on lab-grown dairy. Finally, it introduces the concept of protein transition and briefly discusses its main drivers and challenges.

Chapter 3 presents the research questions guiding the study.

Chapter 4 describes the methodological approach adopted in the research, including literature review, interviews, system dynamics approach, and scenario analysis.

Chapter 5 focuses on the development of the system dynamics model. It first illustrates the causal loop diagram used to represent the main feedback mechanisms within the system. The chapter then presents the stock and flow models where the interconnections between sectors are quantified.

Chapter 6 presents the scenario analysis. Different scenarios are simulated to assess how changes in market conditions could influence the evolution the dairy sector. The chapter evaluates the resulting effects on a range of indicators, providing insights into the potential consequences of a transition to lab-grown milk.

Finally, Chapter 7 summarizes the main research findings, discusses their implications, and outlines the limitations of the study. The chapter concludes by identifying directions for future research.

Together, these chapters provide a comprehensive and holistic understanding of the dairy sector and its interconnected sectors, highlighting how the adoption of lab-grown milk may influence their future evolution over time.

# 2 Theoretical background

## 2.1 The Italian dairy supply chain

The Italian dairy sector is one of the most important in the national agri-food industry in terms of economic value, geographical distribution, and cultural significance.

According to ISMEA (Institute for Agricultural and Food Market Services), in 2024 the Italian dairy sector recorded a total turnover of over € 21 billion in the production phase. At the same time, the value of agricultural production attributable to the same sector reached € 7.9 billion, an increase of 50% compared to the same period of the previous year. (ISMEA, 2025)

The dairy supply chain is long and complex, characterized by significant heterogeneity, high enterprises fragmentation, and high level of specialization. It includes a variety of actors (farmers, cooperatives, processing industries, distributors, and consortia) interconnected by material, economic, and information flows. All these elements determine the structure of the supply chain influencing its efficiency, continuity, transparency, and ability to generate added value.

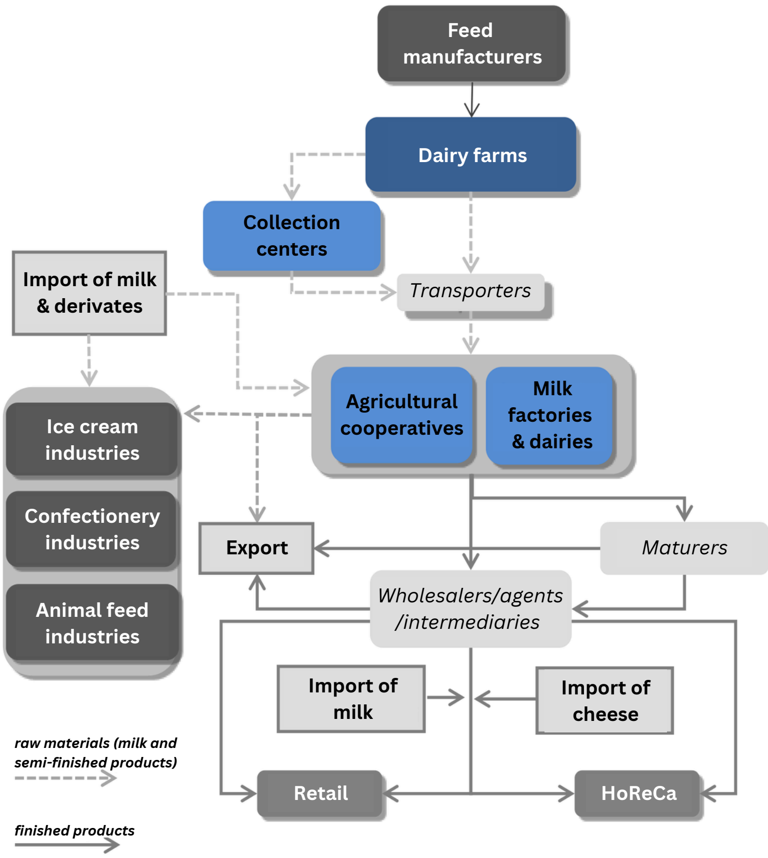


*Figure 2.1 Italian dairy supply chain - (Ronga, 2025)*

The typical Italian dairy supply chain, represented in Figure 2.1, can be broadly divided into four main sections:

1. Primary production
2. Collection and delivery
3. Dairy processing
4. Distribution

### 2.1.1 Primary production

Primary production represents the starting point of the dairy supply chain and includes all the activities related to livestock farming. As shown in Figure 2.1, this stage occupies an intermediate position between upstream suppliers, mainly feed manufacturers with a predominantly industrial nature, and downstream operators, consisting of milk processing and transformation companies.

Within farms, dairy cattle are managed. They are selected, fed according to their nutritional needs, and monitored mainly for health and performance. During this phase also milking is carried out daily. Today, this operation is almost entirely mechanized thanks to the use of automatic milking machines capable of simulating the natural suckling process. This has largely replaced manual milking, now limited to small-scale or traditional farms. (Condoleo et al., 2011)

From a territorial perspective, livestock farming is widespread throughout the country. However, it is characterized by high heterogeneity, both regarding the structural size of farms and the destination of the produced milk. Particularly, it is mainly concentrated in four regions: Lombardy, Emilia-Romagna, Veneto, and Piedmont, where the largest and more productive farms are located. (Ronga, 2025)

According to ISMEA (2024), the sector counts 22,972 specialized dairy farms with a total of 2.6 million head of cattle. About half of these farms are small-scale (< 49 head of cattle) but represent only 7% of the total dairy cattle, while large-scale farms, despite representing less than 5% of the total, own over a third of the cattle population. (Ronga, 2025)

Over the past ten years, the number of farms has significantly decreased, while their average size has increased, highlighting a process of production concentration. This trend can be attributed to technological developments, such as automatic milking and feeding systems, which cause a decline in the average cost per unit of milk produced. This favors the survival of larger and more structured companies. (Ronga, 2025; Rosa et al., 2015)

Furthermore, a phenomenon of geographical localization has happened: the production has become more concentrated in certain regions which are characterized by favored agro-climatic conditions, lower land competition, high supply of forage and cereals, and higher labor productivity. (Rosa et al., 2015)

### 2.1.2 Collection and delivery

Once milked, milk is immediately conveyed into collection tanks where it is filtered to eliminate impurities and refrigerated to prevent the proliferation of germs. After cooling, milk is transported in specially equipped tankers that maintain it at refrigeration temperature and prevent any contamination, until it reaches the plants where it will undergo the required treatments. (Condoleo et al., 2011; Musella et al., 2009)

While awaiting transport to the final plants, milk may pass through an intermediate actor: collection centers. Typically located in areas with a high concentration of dairy farms, these are facilities where raw milk from multiple producers is collected and, if necessary, cooled and filtered. They therefore serve as “temporary storage” before milk arrives to standardization, treatment, and processing plants. (Redazione VeSA, 2006)

### 2.1.3 Dairy processing

At this time, milk is transported to dairy processing plants where it undergoes heat treatments and, depending on its intended use, it may be further processed. In Italy, there are approximately 1,800 companies operating in this sector which can be divided into three main categories: agricultural cooperatives, milk factories, and dairies. (Ronga, 2025)

The first ones are associations that collect and process milk supplied by member farmers, often using it for certified quality products. Milk factories mainly focus on heat treatments (e.g. pasteurization, UHT treatment, and sterilization) and packaging of milk for consumption. Lastly, dairies are responsible for processing milk into its various derivative products. (Condoleo et al., 2011; FIliera Latte del Lazio, n.d.)

With regard to processing, milk is transformed into dairy products such as cheese, butter, and yogurt, each of which is obtained through specific technological processes. This sector represents one of the pillars of the national food industry, with a total turnover of € 21.8 billion and an incidence of over 11% on the value of the entire food sector. (Ronga, 2025)

The main derivative product is cheese. Notably, Italy stands out for the significant role of Geographical Indication (GI) productions, which reflect the strong territorial and cultural identity of the Italian dairy supply chain. At present, there are 39 registered designations (36 PDO, 2 PGI, and 1 TSG)[1] which collectively account for almost half of the national production of cow's milk. The main ones are Grana Padano, Parmigiano Reggiano and Gorgonzola. (Ronga, 2025)

Finally, once the final product has been obtained, it is packaged and labeled.

### 2.1.4 Distribution

After that, milk and its derivatives can follow three major destinations:

- some are destined for the ice cream, confectionery, and animal feed industries to be used as raw materials for further processing.
- some are placed on the foreign market through export.
- some are transferred to wholesalers, agents, or other intermediaries who market them. (Ronga, 2025)

As regards to distribution on the internal market, this mainly takes place through two channels: Retail, that comprises all the direct sales to the end consumer and includes both large-scale retail trade (GDO) and normal trade, and Ho.Re.Ca., i.e., Hotellerie-Restaurant-Café/Catering. (Ronga, 2025)

Large-scale retail trade, which accounts for about 70% of the market, is a retail system operating through a network of supermarkets and other chains of

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[1] PDO = Protected Designation of Origin. PGI = Protected Geographical Indication. TSG = Traditional Speciality Guaranteed.

intermediaries of various kinds. It is characterized by centralized management, extensive territorial coverage, recognizable and heavily advertised commercial brands, and standardization in terms of assortment, prices, and logistics. (Giuliano et al., 2021; Gruppo VéGé, n.d.)

Based on size, breadth and depth of assortment, price positioning, display characteristics, presence of fresh produce counters, availability of parking, and additional services offered to consumers, large-scale retail outlets can be grouped into four types: supermarkets (e.g. Esselunga), hypermarkets, minimarket, and discount stores (e.g. Lidl). (Gruppo VéGé, n.d.)

Normal trade, conversely, is characterized by a network of small retailers and mainly includes independent stores, local stores, and direct sales outlets at farms. Although this channel covers a minority share of the market, it continues to play a significant role within the dairy supply chain. In fact, it guarantees a wide presence throughout the territory, maintaining points of sale even in rural or peripheral areas where the presence of large-scale retail trade is more limited. It contributes to the promotion of local products and short supply chains, allowing for a reduction in the number of intermediaries and favoring links with the production territory.

Ho.Re.Ca. includes all supplies for the hotel sector, commercial and collective catering, as well as bars, cafes, and catering services. This channel is characterized by a high focus on quality and supply diversity, and by a more fragmented demand than the retail sector, with smaller quantities supplied but with greater frequency.

Lastly, a niche distribution channel, distinct from the others, is the direct sale of raw milk to consumers. In fact, Italian legislation, in compliance with strict hygienic, structural, and traceability requirements, allows the sale of freshly milked milk directly at farms or through vending machines installed on site. (Musella et al., 2009)

As regards to distribution on the foreign market, Italy is the world's $2^{nd}$ largest exporter of cheese and dairy products, behind Germany, generating a record value of over € 5.4 billion and constantly growing. The main export products are fresh and hard cheeses (e.g., Grana Padano, Parmigiano Reggiano, and Gorgonzola), which alone represent 75% of total volumes. The main destinations are Germany and France, which together accounted for 36% of export volumes in 2024. Whereas, among non-EU countries, the United States and the United Kingdom remain the main markets. (Ronga, 2025)

## 2.2 Interconnections within the dairy system

The dairy system cannot be analyzed and understood as an isolated system, as it is integrated with other systems.

In fact, the dairy system, which is defined as a multifunctional process, relies on multiple inputs, such as feed and land, and generates multiple outputs, such as milk, meat, and manure. (Romano et al., 2021) Furthermore, these outputs are not independent from one another but are linked through a common element: dairy cows. Therefore, depending on how dairy herds are managed (lactation, feeding, etc.) and on the economic decisions that are taken (adoption of new technologies, insemination strategies, etc.), the outputs vary and affect each other.

The strongest and most direct interconnection is between milk and meat production. In fact, dairy cows, not only produce milk, but also give birth to calves that can be reared for meat. Furthermore, at the end of their productive lives, dairy cows are slaughtered and enter the meat system. This imply that any change in the size of dairy herds has a direct impact on the availability of meat on the market.

The dairy system is also linked to agricultural production and land use. Indeed, feed is the main input in livestock farming. This means that fluctuations in crop yields or in feed prices may have a significant impact on production costs, thereby influencing farmers decisions.

Another output is manure, which directly connects the dairy and energy sectors. It is often considered as a waste, but if correctly treated it becomes a valuable resource. In fact, it can be used to produce renewable energy and for agricultural production, promoting circular economy and a more efficient use of available resources.

Lastly, the dairy sector is linked with other sectors, generally considered as secondary: the leather sector, that uses the hides of slaughtered cattle, and the veterinary and pharmaceutical sector, which deals with animal health and the supply of hygiene and sanitary products.

The main interconnections are further deepened in the following sub-chapters.

### 2.2.1 Linkages between dairy and meat production

Dairy and beef sectors are closely interconnected, to the extent that they can be regarded as part of a single, large sector: the cattle sector. In fact, dairy farms not only produce milk but also generate animals (calves and cull cows) that are destined for the beef sector. (Vinci, 2022)

The first connection between the two sectors regards calves. Dairy cows must give birth to them to produce milk. Sexed semen is generally used on heifers (first-calf dairy cows) to ensure that only females are born. This technique is used both to increase animal fertility and longevity and to increase the rate of replacement cows, thereby allowing a greater number of calves for the meat industry. On the other cows, conventional beef semen is used, which results in both male and female calves. Female calves are kept on farms and grown to replace the actual herd, while male calves, after around 15 days of life, are sold to specialist fattening farms thus entering the meat supply chain. (Bittante et al., 2023; Romano et al., 2021)

Another alternative is the use of beef bull semen for the insemination of dairy cows to obtain crossbred calves, also referred to as beef-on-dairy calves. In Italy, the preferred bred for beef bulls is Belgian Blue, as the calves born from this bred provide meat that is well suited to market demand. Crossbred calves also have a higher economic value compared to purebred dairy calves, thereby improving dairy farms profitability. Furthermore, crossbreeding is proved to increase fertility of dairy cows, having thus a positive effect on the herd. For these reasons, in Italy the proportion of Holstein cows[2] inseminated with beef bull semen has risen from 6% in 2012 to 23% in 2023. (Bittante et al., 2023; Caccin et al., 2024)

It is therefore evident that the supply of meat from calves coming from dairy farms depends both on the size of dairy herd and on how it is managed. In fact, the combined use of sexed semen, conventional semen, and beef bull semen enables dairy farms to modify the number of calves entering the meat supply chain.

Another connection regards cull cows: female cows that have given birth on average two or three times, up to a maximum of seven times, that are no longer productive or economically convenient to maintain. These are slaughtered, thereby contributing to the overall supply of meat. Particularly, the obtained meat is used in the production of processed beef products and burgers for major fast-food chains. (Fondazione ITS Agroalimentare Puglia, 2018)

The link between the dairy and beef sectors is therefore both biological and economic. From a biological perspective, through breeding the dairy sector contributes to the beef sector, not as a separate activity, but as a natural consequence of the way livestock farming operates. From an economic perspective

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[2] Holstein-Friesian is the most common dairy cow breed. (Ronga, 2025)

the sale of calves or cull cows provides an additional source of income for farms. Although milk remains the main product and the primary source of income, these secondary revenues nevertheless contribute to the farm's profitability.

The importance of this interconnection is also confirmed by market data. In fact, the European Parliament has declared that in 2022 meat produced by dairy cows accounted for around two-thirds of meat supply in Europe, with percentages varying among countries. This value further highlights the extent to which potential changes in the dairy sector can affect the beef sector. (Vinci, 2022)

### 2.2.2 Feed production and land use

Another system closely linked to the dairy sector is animal feed, as it affects a wide range of factors: animal productivity, milk quality, land use, methane emissions, manure composition, and farm costs. (Herrero et al., 2013)

Dairy cows' feed is mainly composed of two parts: forages and concentrates. Forages, such as grass, hay, and silage, are the main part of the diet. The most common one is corn silage which can account for more than 80% of the total forage in the diet of dairy cows. Concentrates, on the other hand, are mixtures of protein sources, such as soybean and rapeseed meals, which supplement the diet of dairy cows. (Bellingeri et al., 2020; Borreani et al., 2013)

The ratio between forages and concentrates can significantly vary among farms, mainly depending on farm structure, cows' lactating stage, production intensity, and nutritional properties of milk. For example, as regards to production intensity, intensive livestock farms with high-production cows, which require a high protein intake, often use feed rich in concentrates. Conversely, farms with low-production cows tend to rely more heavily on forages. (Fantini, 2022; Herrero et al., 2013; Musco et al., 2020)

Feed creates an important connection between dairy farming and land-use. Therefore, it is important to distinguish between self-produced feed (*on-farm feed*) and purchased feed (*off-farm feed*). By analyzing these, it is possible to assess the level of self-sufficiency of dairy farms and the extent to which they are exposed to economic and productive fluctuations of external markets. (Herrero et al., 2013)

On-farm feed mainly consists of forages and a small portion of concentrates. Dairy farms tend to increase on-farm production, as a higher self-sufficiency allows them to have greater control over feed quality and production costs. For example, a study conducted by Borreani et al. (2013) on dairy farms in the Po Valley shows that the use of on-farm forages can reduce feed costs per liter of milk, with estimated reductions of between 9% and 22% compared to systems that rely more on purchased feed. (Borreani et al., 2013)

However, it is not possible to produce all necessary feed internally, as there are structural limitations. An example is the availability of sufficient arable land, which might be particularly problematic for intensive livestock farming, as it involves a large number of animals on a limited land area. Another example is that agricultural production is impacted by climatic conditions, water availability, soil fertility and other factors specific to the area in which farms are located. Therefore, not all farms can produce the same quantity and type of feed internally. (Bellingeri et al., 2020; Borreani et al., 2013)

On the other hand, off-farm feed, which is purchased on the market, mainly consists of concentrates. Dairy farms, tend to reduce off-farm supply, primarily for economic reasons. In fact, feed cost is the main expense for a farm, accounting for between 50% and 70% of the operating costs. Consequently, fluctuations in off-farm feed production or transportation costs have a direct impact on the farm's profitability. (Bellingeri et al., 2020)

The ratio between on-farm and off-farm production is also relevant from an environmental perspective. In fact, farming has a direct impact on land-use, water resources, fertilizers, and emissions. Purchased feed shifts part of the environmental impacts outside the farm. Therefore, to obtain a complete overview of the dairy system, it is necessary to consider not only the impacts of on-farm production but also the indirect impacts resulting from off-farm production.

It is therefore evident that the dairy sector is interconnected with the feed sector. For example, a reduction in the number of dairy cows would lead to lower demand for feed, resulting in less land use both on and off the farm. Conversely, an increase in the herd would increase the pressure on dairy farm resources, forcing them to purchase more feed off-farm.

### 2.2.3 Biogas production in dairy farms

Livestock farms generate large amounts of effluents, such as solid manure and slurry. These, if not properly treated, may contribute to environmental issues such as water eutrophication, acidification, and global warming. They also may contain pathogens that can cause zoonotic diseases, and antibiotics or heavy metals that can accumulate in soil and threaten food security and human health. (Wang et al., 2025)

However, if properly treated, livestock effluents can be transformed into a useful resource for the agricultural system. In fact, they host microorganisms and contain nutrients, such as nitrogen, phosphorus, and potassium that can enrich the soil and favor crop growth. Furthermore, since they are high in carbohydrates, fats, and proteins, they can also be processed to produce renewable energy. (Kadam et al., 2024; Mekunye & Makinde, 2024; Wang et al., 2025)

The most spread technology is anaerobic digestion: a microbial process in which bacteria break down organic matter, such as animal manure, in the absence of oxygen. The process takes place in reactors designed and constructed in various shapes and sizes depending on the livestock system and on the intended purpose. (Murphy & Thamsiriroj, 2013)

The flow chart of an anaerobic digestion system is depicted in *Figure 2.2.*

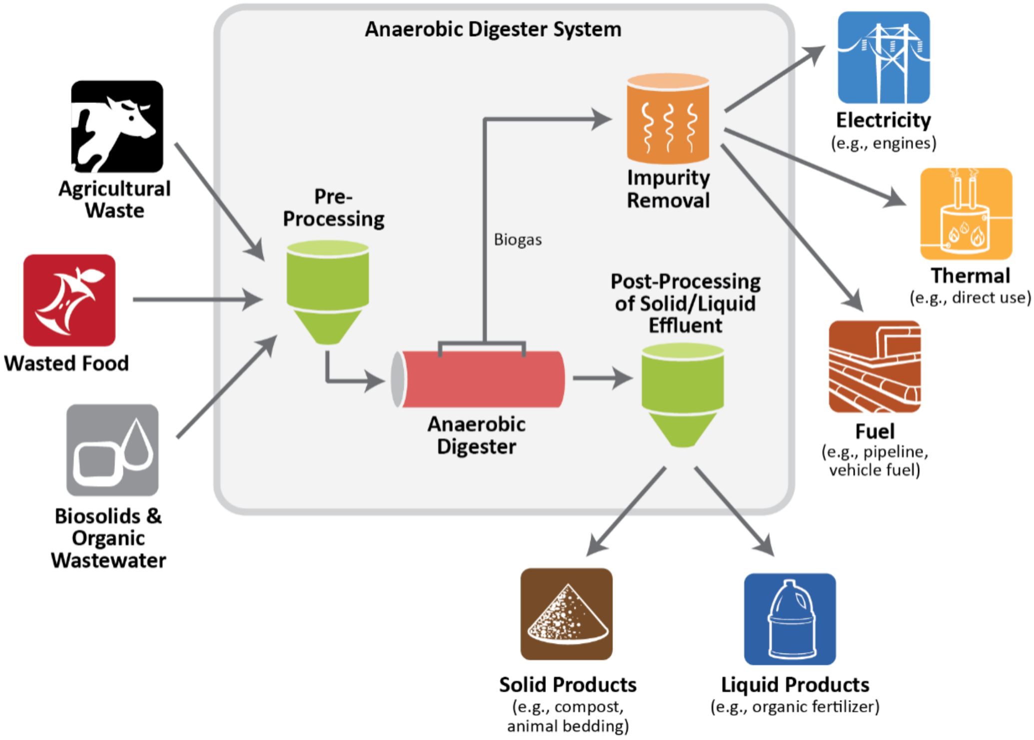


*Figure 2.2 Anaerobic digestion - (Mekunye & Makinde, 2024)*

As it can be seen, the inputs that can be processed by the reactor are various: agricultural waste, wasted food, biosolids and organic wastewater etc. Livestock farms generally tend to mix different inputs, e.g. manure and wasted crops, though performing an anaerobic co-digestion. In fact, by combining them, the nutrients entering the process are more balanced, thereby making the reaction more stable. Furthermore, agricultural or food wastes are generally richer in nutrients and therefore allow for greater energy production. (Kadam et al., 2024; Mekunye & Makinde, 2024)

The inputs are pre-processed to be prepared for the anaerobic digestion process and then enter the reactor where the main microbial reactions occur. From this process two main products are obtained: biogas and digestate.

Biogas is a mixture of various gases, mainly methane (CH4) and carbon dioxide (CO2), that after a purification treatment can be easily converted for various purposes. (Scarlat et al., 2018)

Through a cogeneration plant, biogas can be converted into electricity and heat. Electricity is used both for the farm's own consumption or fed into the grid, while heat is used to power the plant and maintain digesters temperature. Alternatively, through an upgrading process, biogas can be converted into biomethane, a renewable biofuel. It can be both fed to the grid and sold as natural gas or used as a fuel for transport. Generally, the first option is preferred because the plant is easier to manage, the process is faster, and the incentives are higher. (Bacenetti et al., 2013; Lijó et al., 2017; Mekunye & Makinde, 2024)

The second obtained product is digestate, which undergoes a post-processing that separates it into solid and liquid fractions. The liquid part is used as an organic fertilizer for the farm's crops. The solid part, on the other hand, which can be further processed to obtain a compost, acts as a soil improver, adding nutrients and organic matter to the soil, though improving its structure and overall fertility. Overall, digestate recovery represents a perfect example of circular economy, as a potential waste is transformed into a valuable resource, closing the nutrient cycle and reducing the company's dependence on fossil fertilizers. (Al Seadi et al., 2013; Lijó et al., 2017)

In summary, anaerobic digestion represents a strategic way to recover manure by converting it into renewable energy, biofuels, and organic fertilizers. In dairy farms this process is particularly valuable because the herd ensures a continuous flow of supply to the digestion plant. This imply that any change in the size of the dairy herd has a direct impact on the availability of manure and, consequently, on the farm's biogas and digestate production. Therefore, biogas production should not be seen as a marginal activity but as an integral part of the dairy system, capable of generating economic, energy and environmental benefits.

Today, there are over 2,200 biogas plants in operation in Italy, 80% of which are employed in the agricultural sector. This makes Italy the world's fourth-largest producer of biogas, after Germany, China, and the United States. (Paparo, 2024)

## 2.3 Plant-based beverages

Plant-based beverages, also referred to as dairy-free or alternative beverages, are drinks obtained by breaking down plant materials, such as cereals or legumes, in water. As they have the same consistency, appearance, and density of traditional milk, they are considered substitutes. (Rachtan-Janicka et al., 2025)

The main types of plant-based beverages include drinks made from oat, soy, almond and rice, which are the most widely consumed. In addition to these, there are drinks made from other plant materials, such as coconut or hemp, and mixtures of them. The growing variety of ingredients that can be used, represents an advantage for this sector, broadening consumers choices and creating greater opportunities for innovation. (Ashraf et al., 2026; Asif et al., 2026)

The market share expressed in terms % of sales volume in Italy in 2025 is depicted in *Figure 2.3*.

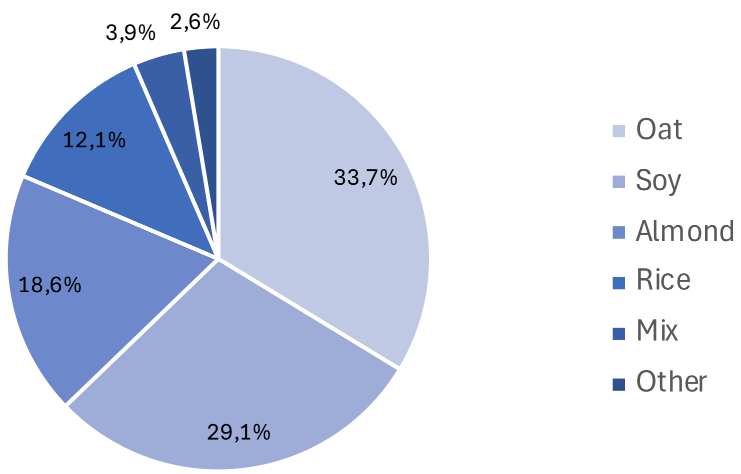


*Figure 2.3 Italy plant-based drinks sales by base ingredient in 2025 - (Breewood, 2026)*

These beverages have become increasingly popular in recent years, reaching in Italy a sales value of € 341,7 million in 2025. The main reasons are related to health, particularly to the increase in lactose intolerances, which according to Ashraf et al. (2026) affects «*almost 65% of the population worldwide*», and to allergies to milk proteins. Other factors include higher concern for animal welfare and environmental issues, as well as the spread of vegetarian and vegan diets. Furthermore, plant-based products are often perceived as healthier than animal-based products, enhancing consumer interest and contributing to the market's rapid growth. (Ashraf et al., 2026; Breewood, 2026; Pérez-Rodríguez et al., 2023)

Plant-based beverages, therefore, appear as valid alternatives to traditional milk and are often perceived as functional substitutes. However, their nutritional composition differs from that of cow's milk and significantly varies based on the type of plant source used, on the technological process employed, and on whether additives or fortifying agents are added. For example, soy-based drinks generally provide a higher protein content compared to other plant-based beverages, while almond-based drinks are rich in fatty acids, which have been linked to potential health benefits. However, plant-based beverages generally contain lower amounts of essential micronutrients, such as calcium and vitamin D, which are naturally present in traditional milk. While some products are fortified with these ingredients, their nutritional composition remains different compared to cow's milk. (Ashraf et al., 2026; Rachtan-Janicka et al., 2025)

Another difference regards functional properties. When plant-based beverages are further processed into derivates, like cheese alternatives, reproducing the same texture, flavor and meltability of traditional cheeses remains challenging. These limitations are mainly related to the different composition of plant-based ingredients compared to cow's milk. (Alehosseini et al., 2025)

For all these reasons, although plant-based alternatives serve similar purposes as traditional milk, they do not fully replicate its taste, nutritional composition, and functional properties. For this reason, new technological processes, with the aim of producing dairy products that are biologically similar to traditional milk and that reduce environmental and ethical concerns associated with animal farming, are emerging. Among these innovations, lab-grown milk is gaining increasing interest.

# 2.4 Lab-grown milk

## 2.4.1 Definition of lab-grown milk

Lab-grown milk is an innovative product designed to be a substitute for traditional milk, standing out from the already widely available plant-based beverages. In fact, compared to them, lab-grown milk is not only a functional alternative but aims to precisely replicate the biochemical composition, flavor, and texture of the original product. The main objective is to provide consumers with the same sensory experience as traditional milk, whilst mitigating the environmental impact and ethical concerns associated with conventional livestock farming. (Liu et al., 2024)

Compared to traditional milk, which is dependent on livestock and on the availability of feed, water, and land, lab-grown milk production relies on industrial bioreactors and new technologies. This results in a shorter and more centralized production system, that guarantees less variability and higher production predictability. (Ranjbar, 2025)

Moreover, the environmental impact radically changes. In fact, life cycle assessments suggest that in comparison to traditional milk, there may be reductions up to 90% in greenhouse gas emissions, 99% in land usage, and 90% in water consumption per liter of milk produced. (George, 2023)

Practically, the adopted technology is cellular agriculture, which may both imply the use of fermentation-based or cell culture-based technologies. In *Figure 2.4* the main steps of both are represented. In the following two paragraphs, these technologies will be further explored and detailed.

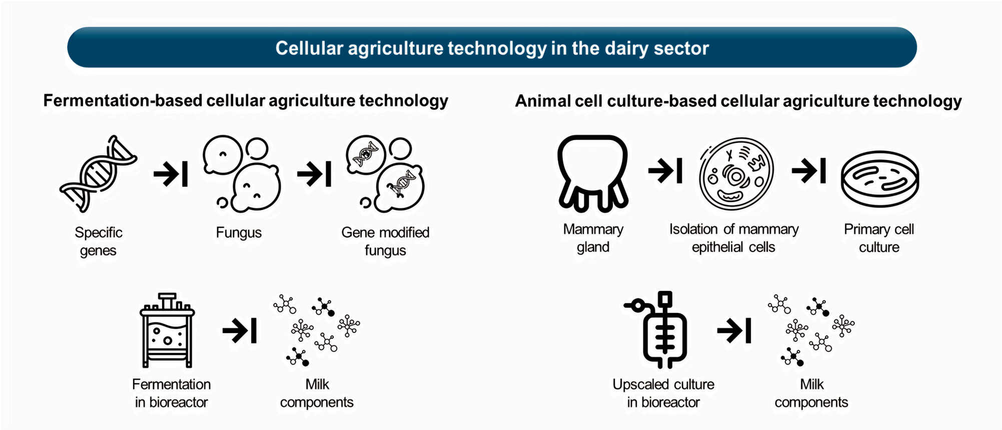


*Figure 2.4 Cellular agriculture technology in the dairy sector - (Kwon et al., 2024)*

## 2.4.2 Fermentation-based cellular agriculture

Fermentation-based cellular agriculture exploits precision fermentation. It is an innovative biotechnological process that «*combines the process of traditional fermentation with the latest advances in biotechnology to efficiently produce a compound of interest, such as a protein, flavor molecule, vitamin, pigment, or fat*». (Ranjbar, 2025) Unlike traditional fermentation, where microorganisms are mainly used to alter or enhance aromas in food products, in precision fermentation they are used as biological "cell factories", programmed to synthesize a precise target molecule. (Eastham & Leman, 2024)

Precision fermentation has its roots in the 1980s, when it was used to produce hormones and pharmaceutical proteins, such as human insulin. Subsequently, with developments in synthetic biology and improvements in DNA engineering techniques, the potential of this technology has gradually expanded, enabling both the production of more complex molecules and the entry into new fields, such as the food sector analyzed here. In this regard, one of the earliest examples is chymosin, which has been widely used in cheese production since 1990 as an alternative to rennet. Today, in the food industry, precision fermentation allows the synthesis of animal-identical proteins that mimic those found in dairy, meat, and other animal-based products, without the use of animals. (Eastham & Leman, 2024; Liu et al., 2024; Ranjbar, 2025)

The process begins with the choice of a suitable microorganism. There are three main types that can be used, each with its own advantages and disadvantages: bacteria, yeast, and filamentous fungi.

Bacteria, such as *Escherichia coli*, are characterized by rapid growth, high productivity, and low cultivation costs; however, they are less suitable for the synthesis of complex proteins.
Yeasts, such as *Saccharomyces cerevisiae*, are better suited for complex proteins and offer rapid growth and high scalability but are more expensive than bacteria.
Filamentous fungi, such as *Trichoderma reesei*, may achieve very high titers[3] and exhibit strong secretory capabilities, making them effective for complex proteins production. However, they involve greater operational complexity and higher costs. (Eastham & Leman, 2024)

Once selected, these microorganisms are genetically engineered to synthesize precise target molecules, such as dairy proteins, which are identical to those found in traditional milk. Their growth requires a culture medium: a substance that contains the ideal quantities of carbon, nitrogen, vitamins, and minerals to allow microorganisms to grow and proliferate under controlled conditions and to

[3] : "Titer" refers to the concentration of the target protein in the fermentation broth (aqueous mixture that results after the fermentation process has taken place). (Cambridge Dictionary, 2026b)

maximize production efficiency. (Cambridge Dictionary, 2026a; Eastham & Leman, 2024)

In industrial production, microorganisms are cultivated in sterile bioreactors under monitored conditions of pH, temperature, oxygen, light, and nutrient level. Under optimal conditions, microorganisms grow, multiply, and produce the desired protein.  (Liu et al., 2024)

During precision fermentation, based on the protein's characteristics, microorganisms can either excrete it into the culture medium (extracellular production) or accumulate it within the cells (intracellular production).

Once precision fermentation is completed, the target protein must be separated from the microbial culture and subsequently purified. This phase allows to produce proteins with high purity and free from microbial residues or other impurities. Once completed, the final product can be commercialized as a GMO-free product. (Nielsen et al., 2024)

Recovery and purification systems depend on whether the protein is produced extracellularly or intracellularly.
Regarding extracellular production, preferred for their ease of recovery and low operational costs, the first phase consists in the separation of biomass carried out via centrifugation or microfiltration. After this, the protein is concentrated and further purified using techniques such as ultrafiltration, tangential flow filtration, or precipitation, selected according to purity requirements and operating costs.
On the other hand, in intracellular production, a preliminary step of cell lysis is required to release the target protein into solution. Whilst this method allows high

concentrations to be achieved, it increases the cost and complexity of the process. (Liu et al., 2024; Nielsen et al., 2024; Ranjbar, 2025)

This phase is one of the most expensive of the entire process, both in terms of energy intensity and facility complexity. At the same time, it is also the moment when the protein's purity, functionality, and quality can be precisely defined, ensuring its compliance with food safety standards. (Eastham & Leman, 2024; Nielsen et al., 2024)

Once recovery and purification operations have been completed, the product can be formulated either in powder or liquid form, ready to be used as an ingredient in cultured milk-based foods. At this point, the proteins obtained are mixed with water and any other ingredient needed to achieve the desired sensory, functional, and nutritional properties of lab-grown milk. (Nielsen et al., 2024; TurtleTree, 2023)

Currently, fermentation-based cellular agriculture is in a more advanced state of development compared to cell culture-based cellular agriculture. Since this technology is already consolidated in other sectors, significant advances have already been made to improve cell growth and milk protein yields. In fact, precision fermentation has already reached the market in producing dairy products. (George, 2023)

### 2.4.3 Cell culture-based cellular agriculture

Cell culture-based cellular agriculture is an emerging technology that «*relies on tissue engineering to produce functional tissues using minimal cells or cell lines obtained from living animals*». (Kwon et al., 2024)

In practice, inside dairy cows, milk is produced and secreted by the mammary gland. Its primary functional cells, known as mammary epithelial cells (MECs), act as factories that absorb nutrients from the blood and convert them into proteins, such as casein and whey. The objective of cell culture-based cellular agriculture technology is to mimic this physiological process in a laboratory. (Finot et al., 2021; Kwon et al., 2024)

To do this, the first step of the entire process is to obtain mammary epithelial cells (ECs) from mammary gland tissues or milk of dairy cows. This step is very challenging, and indeed much research specifically focus on its optimization. In fact, at present it is uneconomical, time-consuming, and the ECs are difficult to isolate. (Kwon et al., 2024)

Subsequently, mammary ECs are cultured in vitro to secrete milk components. These cells are placed in bioreactors and brought into contact with a culture medium, which is rich in nutrients, serum (source of growth factors and hormones), and supplements. This specifically formulated environment induces cell proliferation and differentiation of ECs, thereby enabling the synthesis and subsequent secretion of the milk constituents. (Kwon et al., 2024)

To this end, both two-dimensional (2D) and three-dimensional (3D) culture methods are currently being tested.
In two-dimensional cultures, mammary epithelial cells are cultured on flat plastic supports, where they proliferate as monolayers. However, once removed from their native microenvironment, these cells tend to lose their polarity and change their morphology. This results in non-functional differentiation: cells become disoriented and unable to work together. Consequently, this method allows to produce only individual components, and in low quantities.
On the other hand, in three-dimensional cultures, mammary epithelial cells are immersed in 3D matrices or hydrogels that accurately replicate the structure and functioning of the mammary gland tissue. This ensures a higher production yield and enables the production not just individual components, but milk in its entirety. As present, 3D culture represents the most promising option, however, its costs are extremely high and its functioning is still under development. (Finot et al., 2021; Kwon et al., 2024)

At present, in food industry, cell culture-based cellular agriculture is mainly used to produce lab-grown meat. However, due to its structural complexity, further technological and process improvements are still necessary. As for the dairy sector, this technology is in its early stages. The optimization of bioreactor configurations, three-dimensional cell culture technologies, and culture medium formulations are key areas that require deepen investigation. In fact, overcoming these challenges is essential for achieving industrial scale-up and reducing production costs. Consequently, such advances are essential for cell-cultured milk to successfully enter the commercial market as an affordable and competitive alternative for consumers. (George, 2023; Kwon et al., 2024; Liu et al., 2024)

### 2.4.4 Current status of cellular agriculture in dairy production

Various companies are currently trying to produce milk components using cellular agriculture technology, most of them relying on precision fermentation. The main ones operating in this field, grouped by country, are shown in *Figure 2.5.*

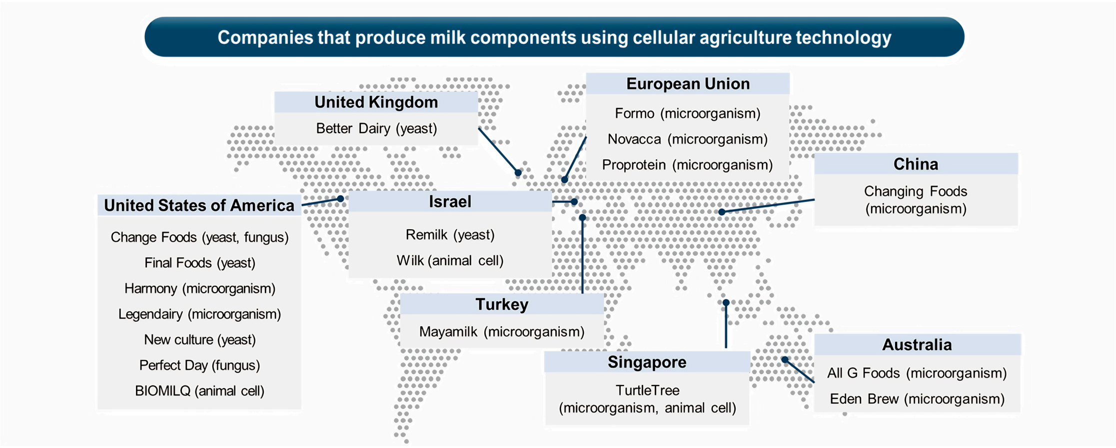


*Figure 2.5 Global start-up companies that produce milk components - (Kwon et al., 2024)*

In 2025, the global precision fermentation dairy protein market was worth $ 139,4 million. Five companies are currently leading the market: Perfect day (USA), Remilk (Israel), Imaginedairy (Israel), New culture (USA), and Formo (Germany), listed here in descending order of market share. (Pulidindi & Ahuja, 2025)

The pioneer and current market leader is Perfect day, which in 2024 held a 32% market share. The company was funded in California, United States, in 2014 by Ryan Pandya and Perumal Gandhi, originally under the name of “Muufri”. (*Perfect Day*, n.d.; Pulidindi & Ahuja, 2025)

Perfect day was the first company in this field to receive GRAS (Generally Recognized As Safe) approval from the FDA in the United States in 2019 for ProFerm™: a β-lactoglobulin (whey protein) produced through precision fermentation using the filamentous fungus *Trichoderma reesei*. This protein contains no lactose, cholesterol, hormones, or pesticides. (*Perfect Day*, n.d.; Ranjbar, 2025; Watson, 2021)

In 2020, Perfect day launched its first product, an animal-free ice cream developed in collaboration with the company Brave Robot. Since then, the company has increased its products also thanks to partnerships with several food companies. One relevant example is its collaboration with Breyers, a brand owned by Unilever. In 2024 they launched a lactose-free chocolate ice cream formulated with Perfect day's protein. The product is currently available in the major retail stores of the United States. (*Perfect Day*, n.d.)

The United States has pioneered this market becoming the first country to distribute dairy alternatives derived from cellular agriculture. Following this development, other countries have also begun to explore the sector, with notable examples including Remilk in Israel and TurtleTree in Singapore. More recently, several companies across Europe have also approached the sector. (Ranjbar, 2025)

One of the most relevant European examples, is Formo, a German start-up founded in 2019, which was the first European company developing cultivated dairy products through cellular agriculture. Formo produces a bioidentical and animal-free casein through precision fermentation, which can be used as an ingredient for cheese, yogurt, milk foam, and beyond. (Askew, 2022; *Formo*, n.d.)

However, unlike the United States, where some precision-fermented dairy proteins have already reached the market, the European market is still far behind. In fact, several barriers still need to be overcome.

The first and main limitation is regulatory. In the European Union, ingredients produced through cellular agriculture must be evaluated by the European Food Safety Authority (EFSA) as "novel foods" under the novel Foods Regulation (EU) 2015/2283. However, this process is strict, long and requires several stages. It is also more complex than in countries such as the United States. As a result, even if European companies are technologically advanced, their products cannot reach the market until regulatory approval has been granted. (Eastham & Leman, 2024; Ranjbar, 2025)

Another major challenge is production scale-up. Companies face significant difficulties when transitioning from small-scale laboratory production to large-scale industrial production. The main challenge lies in increasing scalability, protein yield, titer, and overall productivity, while simultaneously reducing production costs. Achieving this, will allow lab-grown milk to become economically competitive with traditional milk and successfully reach the market. (Ranjbar, 2025)

Lastly, consumer acceptance also represents a key limitation. In fact, lab-grown milk may face consumer skepticism, mainly due to its complex technological production process and to its taste and texture. Therefore, transparency and consumer education are essential to improve its acceptance. Nevertheless, surveys conducted in the United States and in the United Kingdom found that 71-79% of consumers would be likely to purchase lab-grown milk, yogurt, or cheese if these products were priced equivalently to traditional dairy products. (George, 2023)

In Italy, these barriers are particularly relevant. In fact, the Italian food system is strongly linked to tradition, territorial identity, and protected dairy products. This contributes to further slowdown the uptake of lab-grown milk. Moreover, Italy has recently passed a law banning the production and marketing of lab-grown meat. Although lab-grown milk is not the same as lab-grown meat, this position may negatively influence the perception and future market development of this product. Therefore, in the Italian context, the main barriers are not only regulatory and technological, but also cultural and political. (GFI Europe, 2023)

## 2.5 Transition pathways in the dairy sector

The growing interest in alternative protein sources has led to increased focus on the concept of the *protein transition*, defined by Duluins et al. (2025) as the «*shift from diets rich in animal protein to diets richer in plant protein and new alternative protein sources*». Recently, this concept has gained increasing prominence within the European Union (EU), where industries, non-profit organisations, researchers, and public health agencies promote it as a pathway towards more sustainable food systems. Therefore, protein transition is not simply intended as a dietary change, but as a broad transformation of food systems. (Duluins et al., 2025)

The rising interest in protein transition is largely driven by environmental and ethical concerns. In fact, animal-based foods, which currently play a central role especially in diets of high-income countries, are associated with excessive land and water use, animal cruelty, eutrophication and greenhouse gas emissions. Consequently, alternative proteins are increasingly being promoted as more sustainable alternatives. (Hurst & Pant, 2025)

However, the future course of this transition remains highly uncertain, as different actors have different views on its pace, direction, and outcomes. Furthermore, several food system actors and policy institutions continue to support the current livestock-based regime. (Duluins et al., 2025)

To investigate this uncertain transition, previous studies have employed modelling approaches such as scenario analysis, life-cycle assessment (LCA) or agent-based modelling (ABM), each of which focuses on different aspects of the food system transition.

As regards LCA approaches, these are generally used to assess the environmental impacts of a product or a service during its lifecycle. For example, Sinke et al. (2023) perrformed an LCA on cultivated meat  using data collected from over 15 companies. Their results show that cultivated meat brings several advntages in terms of carbon footprind or land use, and that strong climate goals can be realized. (Sinke et al., 2023)

Instead, among scenario-based approaches are used to explore alternative transition pathways and assess how different technological, market and policy developments might influence the evolution of food systems. For example, Gibson et al. (2022) combine ABM and scenario analysis to examine how milk and plant-based beverages consumption might evolve up to 2050 in the UK. Their findings showed that changes in prices and environmental awareness can lead to substantially different consumption trajectories and levels of adoption of plant-based alternatives. (Gibson et al., 2022)

# 3 Research questions

Based on the above theoretical background, this thesis analyzes how the adoption of lab-grown milk could impact the traditional Italian dairy sector and its interconnected sectors. In fact, changes in traditional milk demand could have an impact on the multiple systems.

The research is therefore guided by a central Research Question (RQ): *How could the increasing diffusion of lab-grown dairy reshape the structure of the traditional Italian dairy sector and its interconnected sectors?*

This main research question is addressed through two sub-questions:

Research Question 1 (RQ1): *What are the main interconnections between the traditional dairy sector and related sectors and how can they be quantified?*
The first research question focuses on identifying the key relationships linking the dairy sector with other agri-food sectors. These include, for example, the links between milk production, herd size, meat production from dairy animals, land and feed requirements, and biogas production. Quantifying these interconnections is necessary to understand how changes in one part of the system can generate effects in other systems.

Research Question 2 (RQ2): *How the introduction of lab-grown dairy could affect the configuration of livestock sectors, and what impacts might this have on related sectors?*

The second research question specifically focuses on the structural changes that the introduction of lab-grown dairy products could cause in the livestock sector. The rise of cellular agriculture represents a potential disruption to traditional dairy farming, which could necessitate a significant transformation of the entire livestock sector. The question therefore aims to assess how supply chains and market dynamics could evolve in the future, identifying the impacts and operational changes among all the analyzed sectors.

# 4 Methodology

This chapter, divided into five main sections, outlines the methodological approach adopted to answer to research questions. Firstly, a first exploratory phase through literature review was conducted to form the basis for the subsequent stages of the research. Secondly, semi-structured interviews were carried out. Here, the methodology used for the interviews and a list of interviewees are provided. Thirdly, the Systems Dynamics approach is introduced, as it provided the conceptual framework used to represent the main causal relationships between sectors. Fourthly, the scenario analysis methodology is described. Lastly, a joint interview was carried out to validate and optimize the constructed scenarios.

## 4.1 First exploratory phase

The first exploratory phase was structured in multiple phases, explained in the following sub-chapters.

### 4.1.1 Articles

The process began with an extensive literature review, which involved reading and analyzing the content of academic papers found on various academic databases, including Scopus/Elsevier, Google Scholar, ResearchGate and PubMed.

The aim of this phase was to build a comprehensive understanding of mainly three key thematic areas:

1. actors and flows of the traditional dairy supply chain and its interactions with other interconnected and/or impacted supply chains
2. alternatives to traditional dairy and definition and conceptualization of lab-grown dairy
3. simulation methods applicable to this case

As for the first thematic area, the search strategy combined keywords such as *"Italian dairy supply chain"*, *"dairy-beef system interactions"*, *"dairy sector feed need"*, and *"circular economy dairy sector"*. Then, for the second area, keywords such as *"lab-grown dairy"*, *"precision fermentation"* and *"novel food"* were used. Lastly, for the third area, *"simulation analysis"*, *"system dynamics"* and *"dynamic modelling agri-food sector"* were mainly used as keywords.

Boolean operators and wildcard characters were used, whether possible, to capture a broad range of relevant sources. No restrictions were applied regarding the publication year, as the objective was ensuring the most comprehensive analysis possible. Conversely, as regards the country, papers with Italian or European focus were preferred.

### 4.1.2 Snowball & Grey literature

Then, to expand the analyzed literature and deepen relevant topics, the so-called 'snowball search' method was used on a few papers. It consists of «*a way of tracking down related works by using the bibliography or reference list at the end of an article as starting point*». (Ghent University, 2025)

To supplement academic literature, a further research step was dedicated to the analysis of grey literature and secondary sources. This included institutional reports, company websites, market analyses and newspaper articles. The objective of this phase was to fill knowledge gaps and to find up-to-date information.
Regarding traditional milk, institutional websites such as ISMEA (Institute of Services for the Agricultural and Food Market) and IZS (Experimental Zooprophylactic Institute) were consulted to better understand the structure and internal dynamics of its Italian supply chain. Meanwhile, as regards lab-grown milk, reports from innovation platform, such as GFI (Good Food Institute), were examined to gather further information on regulatory frameworks and approval procedures for novel foods.

At the same time, journalistic sources from the last five years were consulted to identify the main and most recent developments and controversies related to lab-grown dairy products, as well as the main start-up operating in this field.

## 4.2 Explorative interviews

Although the selected academic, institutional, and journalistic sources provided a comprehensive overview of the above-mentioned thematic areas, they offered limited insight into how traditional dairy farms operate in practice. Particularly regarding decision-making processes, adjustment mechanisms to demand changes, and causal relationships. For this reason, explorative interviews were conducted.

The purpose of the interviews was to support both the development of a system dynamics model and of the subsequent scenario analysis. To this end, the interviews were designed to gather insights that could help in identifying causal links and potential time delays, while also supporting the definition of plausible scenario assumptions regarding future changes in the demand for traditional milk and lab-grown milk.

This approach is consistent with the system dynamics method, in which empirical data are often used in the first phases to map the system in analysis. (Sterman, 2000)

### 4.2.1 Identification and recruitment of participants

Potential participants were identified through a purposive sampling strategy, aimed at selecting individuals with direct practical experience in the traditional dairy sector. The final group of interviewees included seven dairy farmers, one beef farmer, and one sales agent who is specialized in feed for dairy cattle, for a total of nine experts. Although the size of the sample is limited, the selected participants provided complementary perspectives on the livestock sector.

Dairy farmers were selected as they are the primary actors within the analyzed system. During the interviews they were able to provide direct information on farm management practices, decision-making processes, and the adaptation strategies adopted in response to changes in demand.
The beef farmer was included to complement the perspective of dairy farmers with a specific insight into the beef sector. In this way, the interconnections between dairy and beef sectors were further investigated.
The sales agent was interviewed to gain a broader overview of the dairy sector. His professional relationships with numerous dairy farms have, in fact, enabled him to provide information on market dynamics, emerging trends, and price fluctuations.

Participants were contacted through personal and professional networks. In some cases, further contacts were identified through the interviewees who had already been contacted. In particular, the sales agent provided the contact details of three dairy farmers, all different from each other, among his clients. This helped to broaden the range of participants in the study.

The farms were all located in Lombardy and Piedmont, two regions characterized by a high concentration of livestock farming activities.

To ensure the anonymity of the participants whilst maintaining a clear narrative, the participants are identified by codes. The seven dairy farmers are identified by the codes FARM1 to FARM7, based on the order in which the interviews were conducted. The beef farmer is identified as FARM8, whilst the sales agent is referred to as AGENT. The interviewees are briefly introduced in the *Table 4.1*.

*Table 4.1 Interviews information*

| Interview code | Company size (head) | Farm location | Role of the interviewee | Interview duration | Rec? |
|---|---|---|---|---|---|
| **FARM1** | 850 | (PV) | Farmer | 1h 10 min | yes |
| **FARM2** | 800 | (MI) | Farmer | 30 min | yes |
| **FARM3** | 100 | (MI) | Farmer | 30 min | no |
| **FARM4** | 120 | (MI) | Farmer | 30 min | no |
| **FARM5** | 300 | (PV) | Farmer | 20 min | yes |
| **FARM6** | 600 | (LO) | Farmer | 30 min | yes |
| **FARM7** | 400 | (AL) | Farmer | 45 min | yes |
| **FARM8** | 1000 | (PV) | Farmer | 25 min | yes |
| **AGENT** | - | - | Sales agent | 45 min | yes |

### 4.2.2 Data collection

After recruiting participants, data were collected through semi-structured interviews. This method allowed the interviews to be structured differently according to the type of interviewee. In this way, each participant was able to provide different information based on their role within the system and their area of expertise.

As regards to dairy farms, the interviews were structured into three main sections. The first included general questions to outline the characteristics of the farm, such as herd size, production system and milk destination. This provided the necessary information to contextualize the answers and compare all farms. Then, the second section focused on the interconnections between the dairy sector and other sectors. This was divided into three parts: meat production, with a particular focus on calves and cull cows, feed, and biogas. Lastly, the interviews included a section dedicated to possible future scenarios. More precisely, farmers were asked how they would react to a steady decline in milk demand and how the beef sector would respond.

As regards to the beef farmer, the interview was structured to explore the interconnections between the dairy and beef sectors and how changes in the dairy farms could impact on meat supply. As in the interviews with dairy farmers, an initial set of general questions, aimed at outlining the main characteristics of the farm were asked. Then, the focus shifted to the functioning of the meat production cycle, with particular attention to the origin of calves and the role of animals from dairy farms. Finally, the interview ended with exploring how the beef sector might evolve in the next years.

As regards to the sales agent, the interview started with a few questions aimed at defining the interviewee’s role, his experience, and how he interacts with its clients. After that, questions were asked about recent structural changes in the dairy sector and how farmers are responding to shifts in market conditions, such as milk prices and production costs. Lastly, the current relationship between the dairy and beef sector was investigated, along with how it might change under possible future scenarios.

Interviews to dairy farmers were conducted directly on farm, where the interviewees could show their facilities and working conditions. This made it possible to move beyond a purely theoretical understanding of how farms operate and to better interpret the information gathered during the interviews. Instead, the others were conducted remotely or in person.

This data collection process thus served a dual purpose. First, it provided practical insights into the actual operations of dairy companies and related sectors. Second, it helped identify causal relationships, time lags, behavioral responses, and scenario assumptions that could not have been fully deduced from secondary sources alone.

### 4.2.3 Data analysis

At the end of each interview, the collected data was prepared for analysis. The recorded interviews were transcribed, while for the unrecorded ones, the notes taken during the conversation were integrated and organized. The purpose of this phase was to organize all the information provided by the participants into a single format, thereby reducing the risk of omitting relevant data and facilitating the subsequent analysis.

The notes were then reviewed and compared among the various participants. The responses were grouped according to the main topics covered during the interviews: farm management, interconnections with other sectors, and possible responses to changes in milk demand.

The objective was to identify both common patterns and differences among participants. Shared views were used to support the definition of the model's structure, while divergent perspectives were useful for highlighting uncertainties and for better understanding how the sector might change in the future. Thus, the analysis of the interviews contributed not only to the validation of the model but also to the construction of plausible future scenarios.

## 4.3 System Dynamics

System dynamics (SD) is a field of study originally developed at the Massachusetts Institute of Technology in the 1950s by Jay Forrester, to analyze and comprehend the behavior of complex non-linear dynamical systems through formal mathematical modeling and computer simulations. (Sterman, 2002)

Underneath this approach is the idea that many real-world problems do not arise from isolated events, but rather emerge from the dynamic complexity of the systems in which decision-makers operate. In such systems, as stated by J. D. Sterman (2000), «*everything is connected to everything else*», meaning that actions taken in one part of the system may generate consequences elsewhere, often with significant delays. (Sterman, 2000, 2002)

When trying to manage these problems, people are often misled by their limited mental models, which lead them to draw incorrect inferences about causal relationships and temporal dynamics within the system. As a result, the actions they take, even if they might appear effective in the short term, are often counterproductive in the long term and tend to generate new problems. For this reason, especially in a world characterized by increasing complexity and rapid changes, system dynamics appears valuable to overcome these limitations and to improve the understanding and managing of complex problems. (Sterman, 2002)

Dynamic complexity, defined as the «*counterintuitive behavior of complex systems that emerges from the interactions of the agents over time*», is what makes many real-world systems difficult to understand and manage. (Sterman, 2002) This complexity arises, for instance, when cause and effect are separated in time and space, when interventions generate delayed feedback, or when current decisions are restricted by past decisions. In such contexts, traditional analytical approaches and static models are often insufficient to capture the evolving behavior of the system. system dynamics addresses this limitation by modeling systems as sets of interacting stocks and flows, governed by feedback loops, often characterized by delays and non-linearities. (Monasterolo et al., n.d.; Sterman, 2002)

### 4.3.1 Key elements of System Dynamics

#### 4.3.1.1 Stock and flows

The first major concepts of system dynamics are stock and flows.
Stocks are accumulations that represent the state or condition of the system at a given point in time. They accumulate the effects of past events and therefore provide systems with inertia and memory. Their content can only change through inflows and outflows. For this reason, stocks determine the conditions under which decisions are made, informing decision-makers about the current state of the system and limiting the range of actions they can take. Stocks are also a source of time delays. Whenever the effects of an action are not immediate, the difference between input and output accumulates in the stock, generating a delay. (Sterman, 2000)
Flows, on the other hand, represent rates of change in stocks. Specifically, inflows increase the level of a stock, while outflows reduce it. Their accumulation determines the rate at which the state of the system evolves. Since inflows and outflows are often regulated by different decision-making processes or external conditions, they may diverge, leading to changes in stock levels. (Sterman, 2000)

In dynamic systems, a diagramming notation is used to represent stock and flows. Stocks are represented as rectangles, while inflows and outflows as arrows respectively pointing to and out of the stock. The other two main elements are valves, added to control the flows, and clouds, representing the sources and sinks of the flows. (Sterman, 2000) The set of all stocks and flows that describe the system constitutes the stock-flow diagram.

An example, as shown in Figure 4.1, are dairy cows, which can be modeled as a stock. Heifers aging and culled cows are inflows and outflows, respectively. The clouds, in this case, represent the stock of heifers and the stock dairy cows sent to slaughter.

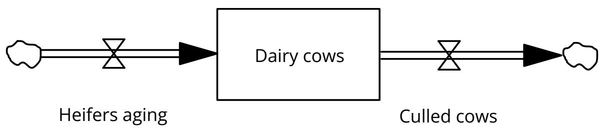


*Figure 4.1 Example of stock and flow diagram*

#### 4.3.1.2 Feedback loops

Along with stock and flows, the other major concepts in systems dynamics are feedback loops: causal chains through which the variables of a system influence each other over time.

Feedback loops can be classified as positive (or self-reinforcing loops) and negative (or self-balancing loops).

Positive loops tend to reinforce and amplify whatever is happening in the system, both in a positive or negative direction. In fact, an initial increase in a variable leads to further increases, while an initial decrease leads to further decreases. An example of self-reinforcing loop is related to calves' growth. As dairy cows increase, the number of calves born also increases. Consequently, the number of heifers increases, which further enlarges the overall number of dairy cows over time. This self-reinforcing mechanism can generate exponential growth as long as no limiting factors intervene. (Bala et al., 2017; Sterman, 2000)

Negative loops, on the other hand, oppose against change to stabilize the system around threshold values or a steady state. When a variable deviates from its reference value, the self-balancing loop activates and generates corrective actions that bring the system back to its equilibrium. An example of self-balancing loop is related to the law of demand. In fact, as milk price increases, milk demand decreases. At the same time, other things being equal, as milk demand increases, milk price increases. (Bala et al., 2017; Sterman, 2000)

Graphically, they can be represented as follow:


*Figure 4.2 Example of positive loop, on the left, and negative loop, on the right.*

As can be seen in Figure 4.2, the relationships between variables are indicated by directional arrows. Each arrow has a polarity, positive (+) or negative (–), which describes the type of causal relationship between the variables involved. The positive one indicates that a change in the first variable leads to a change in the same direction of the second variable, while the negative one indicates a change in the opposite direction. In addition, there is a circular arrow inside the loop that shows its type: R (reinforcing) in case of a positive loop and B (balancing) in case of a negative cycle.

All systems, regardless of sector or complexity, can be represented as a network, referred to as Causal loop diagram, of positive and negative loops, whose interactions determine its behavior.

System dynamics are therefore not driven by isolated cause-effect relationships, but rather emerge from the simultaneous functioning of multiple reinforcement and balancing mechanisms that influence each other in different parts of the system. The more interconnected these loops are, the more difficult it becomes to predict the behavior of the system.

The effects of a given action may only become visible after a certain period of time or manifest themselves in system's components that, at first glance, appear to have no relation to the initial decision. In fact, as also mentioned before, loops may be characterized by time delays and non-linearities.

#### 4.3.1.3 Delays

Time delays occur when there is a lag between the moment a decision is made and the moment its effects are visible in the system. They are widespread in real-world systems and create instability. In system dynamics, delays are commonly distinguished as material delays and information delays. The former arise from physical or biological processes that require time to complete, such as production processes or biological growth. The latter, instead, are due to limited availability of information or slowness in its collection and reporting. (Bala et al., 2017; Sterman, 2000)

The presence of time delays significantly affects feedback loops. In positive loops, delays can mask the early stages of growth or decline, causing changes in the system to be underestimated and thus more difficult to control. In negative loops, on the other hand, delays may cause decision-makers to continue with corrective actions even after sufficient adjustments have been made, causing oscillations to the system. (Sterman, 2000)

Graphically, as it can be seen in Figure 4.2, delays are represented as two lines on the arrow they are referred to. In the represented positive loop, delays are biological and associated to both animal growth and gestational period of dairy cows. On the other hand, in the represented negative loop, there is a delay on the arrow that goes from milk price to milk demand. This is usually associated to the reaction time of consumers to price increases.

#### 4.3.1.4 Non linearities

Another characteristic of loops is non-linearity, meaning that the effect is not proportional to the cause. In fact, small changes may produce large effects, while large interventions may have a limited impact. Furthermore, what happens locally in the system is rarely applicable to distant regions, and strategies that work well in one situation may fail in another. (Sterman, 2000)

### 4.3.2 Practical steps of System Dynamics modelling

From a practical point of view, to correctly apply the system dynamics approach, 6 main steps must be followed: (Bala et al., 2017)

1. Identify the problem.
2. Develop a dynamic hypothesis explaining the cause of the problem.
3. Create a basic structure of a causal graph.
4. Augment the causal graph with more information.
5. Convert the augmented causal graph to a system dynamics flow graph.
6. Translate a system dynamics flow graph into STELLA or VENSIM programs or equations.

The first step is to clearly identify the problem, set its boundary, and establish specific objectives. To do this, it is necessary to describe the system in detail, clarify which variables have the greatest impact on it, and define the time horizon and the level of aggregation chosen for the analysis. Identifying the problem also allows to delimit the scope of the analysis, distinguishing between those elements that actively contribute to the system dynamics and the ones that can be considered exogenous or negligible. (Bala et al., 2017)

Once the problem has been defined, the next step is to develop a dynamic hypothesis: a theory capable of explaining the causes and the behavior of the problem. It is “dynamic” because it is based on feedback, stock, and flows, and not on isolated causes; and it is an “hypothesis” because it is provisional and continuously subjected to revision. The dynamic hypothesis is used as a starting point to build the system model. (Sterman, 2000)

At this point, the dynamic hypothesis is formalized through the construction of a causal loop diagram. Initially, in step 3, a simplified diagram is constructed, which includes a limited number of key variables, to make the basic structure of the system explicit. Subsequently, in step 4, the diagram is progressively enriched by introducing additional variables, relationships, and time delays in order to increase its accuracy and reliability. (Bala et al., 2017)

Although the causal loop diagram is an effective tool for understanding the structure of the system, it is not sufficient for quantitative analysis and simulation of behavior over time. For this reason, in step 5, it is translated into a stock-flow diagram, in which stocks, flows, and the functional relationships between them are explicitly represented. (Bala et al., 2017; Sterman, 2000)

Lastly, in step 6, the stock-flow diagram is translated into a set of mathematical equations and simulated with software like VENSIM ®, specific for the system dynamics approach. Simulations allow to explore the behavior of the system over time, to analyze how it may react to alternative scenarios and to evaluate the sensitivity of the model. (Bala et al., 2017)

In this research, all the steps were conducted based on both a literature review and interviews. Since both highlighted the interconnection between dairy and beef sectors as the most relevant one, in step three and four, the causal loop diagram was developed with a specific focus on them. As regards step five and six, they have been adapted to the scope of the thesis. Instead of translating the causal loop diagram into VENSIM ®, the main production relationships of a traditional Italian dairy farm were modeled through equations in Excel, following a stock and flow logic. Therefore, the model should be interpreted as a statical annual representation of the system. This choice was consistent with the thesis's objective, as the model was not intended to simulate the system's entire dynamic behavior over time, but rather to quantify and compare the effects of alternative demand scenarios on selected indicators. The same indicators were also calculated for beef cattle farms. These were included as well in the scenario analysis in order to assess the impacts on the overall livestock sector.

### 4.3.3 Relevance of System Dynamics for the dairy sector

System dynamics was used as a methodological framework to represent the structure and interdependencies of the system under analysis. This approach is particularly suitable for agri-food systems. In fact, they can be seen as complex systems composed of heterogeneous actors and characterized by biological, economic, social, and environmental interactions. Within this system, apparently limited decisions, such as changes in demand or in price, can generate indirect, cumulative, and delayed effects throughout the entire supply chain. (Muflikh et al., 2021)

Particularly, system dynamics has already been applied in several studies on the dairy sector. For example, Atzori et al. (2023) show that this approach can be effectively used for dairy farm management. Their study maps the animal stocks of a dairy farm to forecast milk deliveries over time. This demonstrates the suitability of System dynamics for representing herd dynamics and capturing how changes in herd structure can influence production outcomes at a farm level. (Atzori et al., 2023)

## 4.4 Scenario analysis

Scenario analysis is a methodology used to explore possible future developments under conditions of uncertainty. Rather than predicting a single expected future, scenarios describe alternative and plausible configurations based on different assumptions regarding key variables and external conditions. (Cavana, 2010)

As stated by Kunc (2024), system dynamics and scenario analysis can be methodologically integrated in multiple ways. For example, firstly, system dynamics can provide the model structure, representing the key relationships between the components of the system under analysis, and enable the quantification of their effects. Then, scenario analysis can be used to introduce alternative assumptions into the model and to evaluate their effects on the system. (Kunc, 2024)

In this thesis, scenario analysis appears particularly valuable because the future evolution of the dairy-beef system is still uncertain. For this reason, scenarios have been developed to explore how the dairy system might respond to alternative market conditions, which were derived from the causal loop diagram. These were then incorporated into the Excel model to quantify the effects of each scenario on a set of selected indicators.

Scenario analysis is also consistent with previous applications of system dynamics to novel foods. For example, Skinner et al. (2023) developed a system dynamics model to forecast consumer demand for foods produced using cellular agriculture as a case study and tested it under various quality and marketing scenarios. This supports the use of both the approaches to explore the uncertain trajectory of the market of lab-grown milk and its potential effects on the traditional dairy and meat systems. (Skinner & Blake, 2023)

## 4.5 Validation interview

After developing a preliminary set of scenarios based on a literature review, a joint interview was conducted. The purpose of the interview was to present the proposed scenarios to experts in the field of cellular agriculture to validate the underlying assumptions and gather feedback for their refinement. This process aimed to improve the plausibility and robustness of scenarios by incorporating experts' knowledge.

Potential participants were contacted via email and LinkedIn. Of those contacted, two experts agreed to participate in the study. Both participants are members of *Agricoltura Cellulare Italia*, a non-profit association that promotes the understanding and development of cellular agriculture. Their different professional roles and educational backgrounds guaranteed complementary perspectives of the potential evolution of the alternative protein sector.

The interview lasted about one hour and provided valuable insights for refining the scenarios. It was structured into two main sections. The first focused on discussing the assumptions used in developing the scenarios, while the second examined the plausibility of the various scenarios and their potential implications for the future evolution of the dairy sector.

The interview was recorded and then transcribed. The obtained insights were incorporated into the definitive scenario analysis and were also used to support the conclusion of the study. To maintain a coherent narrative with the exploratory interviews, the participants of this interview are identified by the codes CELL1 and CELL2.

# 5 System Dynamics

This chapter outlines the development of the system dynamics model across three main sub-chapters.

The first presents the causal loop diagram, highlighting the main feedback mechanisms between lab-grown milk, traditional milk, and meat. The second describes the stock and flow model developed in Excel for a dairy farm. The final section develops a stock and flow model, preparatory to subsequent analyses, for a farm specialized in beef cattle.

Together, these sections provide the quantitative basis necessary for the scenario analysis presented in the following chapter.

## 5.1 Causal loop diagram

A causal loop diagram (CLD) has been developed based on information collected both through theoretical background and interviews. The objective was to better understand the underlying dynamics of the dairy system, how it is interconnected with the meat system, and the potential evolution of both following the introduction of lab-grown milk.

The resulting CLD is represented in Figure 5.1. As it can be seen, the diagram focuses on the main market mechanisms. In particular, it shows how changes in demand can affect prices and production decisions, and how these changes can influence both dairy and beef cattle farms. In this way, the CLD provides a simplified representation of the key mechanisms through which changes in one part of a system can generate effects on the whole.

The resulting CLD was structured around three main subsystems: lab-grown milk system, traditional milk system, and meat production system.

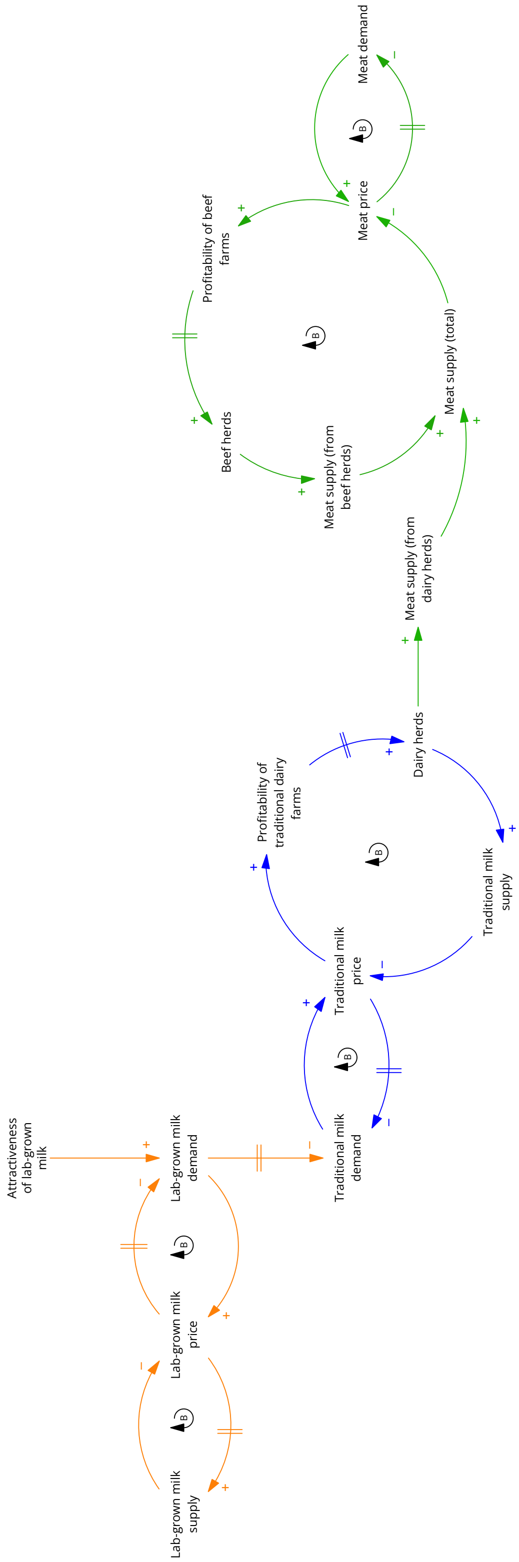


*Figure 5.1 Causal loop diagram*

### 5.1.1 Lab-grown milk system

The first subsystem, illustrated in *Figure 5.2*, models the dynamics of lab-grown milk market penetration. This part of CLD was developed starting from one key variable: demand of lab-grown milk.

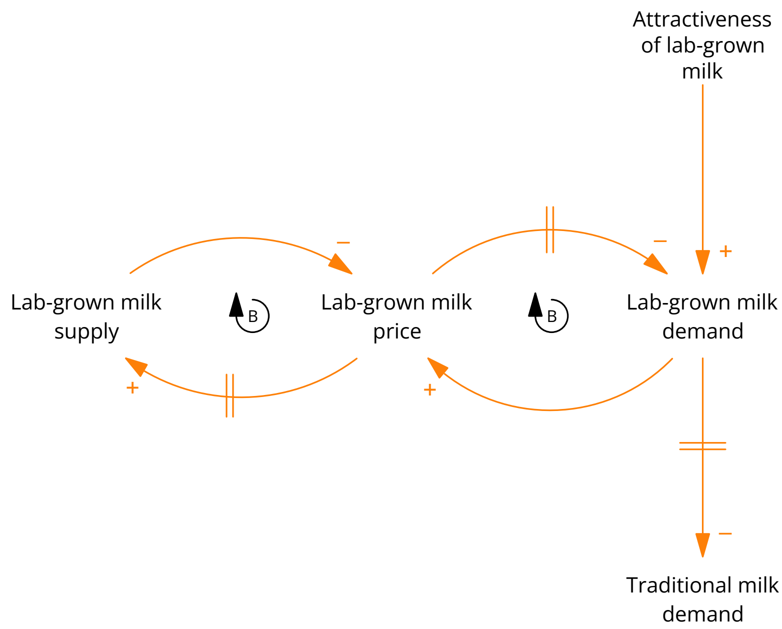


*Figure 5.2 Causal loop diagram – Lab-grown milk system*

Lab-grown milk demand is primarily influenced by the product attractiveness, which can be increased by various strategies, such as appropriate marketing initiatives, greater information, or a reduction in barriers perceived by customers. As the attractiveness increases, consumer interest is expected to grow, leading to an increase in lab-grown milk demand.

Demand is also directly linked to price and, indirectly, to supply. These relationships, which reflect standard market dynamics, are based on the law of demand and on the law of supply and generate two self-balancing loops. According to the law of demand, when the price of a good rises, consumer demand tends to fall, and vice versa. Conversely, according to the law of supply, when the price of a good rises, producers are encouraged to increase supply, and vice versa. Furthermore, all other things being equal, an increase in demand tends to push the price up, whilst an increase in supply tends to push it down. (Frank & Cartwright, 2017)

As can be seen, these self-balancing loops also include delays.
The first regards the link between price and supply. In fact, if the price rises today, lab-grown milk producers cannot instantly expand their production: it takes time to purchase raw materials, increase machinery capacity or install additional equipment and, if necessary, hire additional personnel.
The second delay regards the link between price and demand. Consumers do not immediately change their purchasing habits in response to price changes. Generally, it takes time for consumers to notice price increases or decreases, to compare alternatives and eventually decide to switch to a cheaper product or to try a new one.

This subsystem is directly linked to the traditional milk one. In particular, it is expected that an increase in lab-grown milk demand will reduce traditional milk demand, and vice versa. In fact, the two products are considered substitutes, meaning they can satisfy the same consumer need within the market. However, this substitution process does not happen instantly. Rather, it is characterized by a delay in adoption, as consumers do not easily or quickly change their eating habits. It therefore takes time for lab-grown milk to become part of consumers' daily consumption habits.

### 5.1.2 Traditional milk system

The second subsystem, shown in Figure 5.3, illustrates the internal dynamics of the traditional dairy sector.

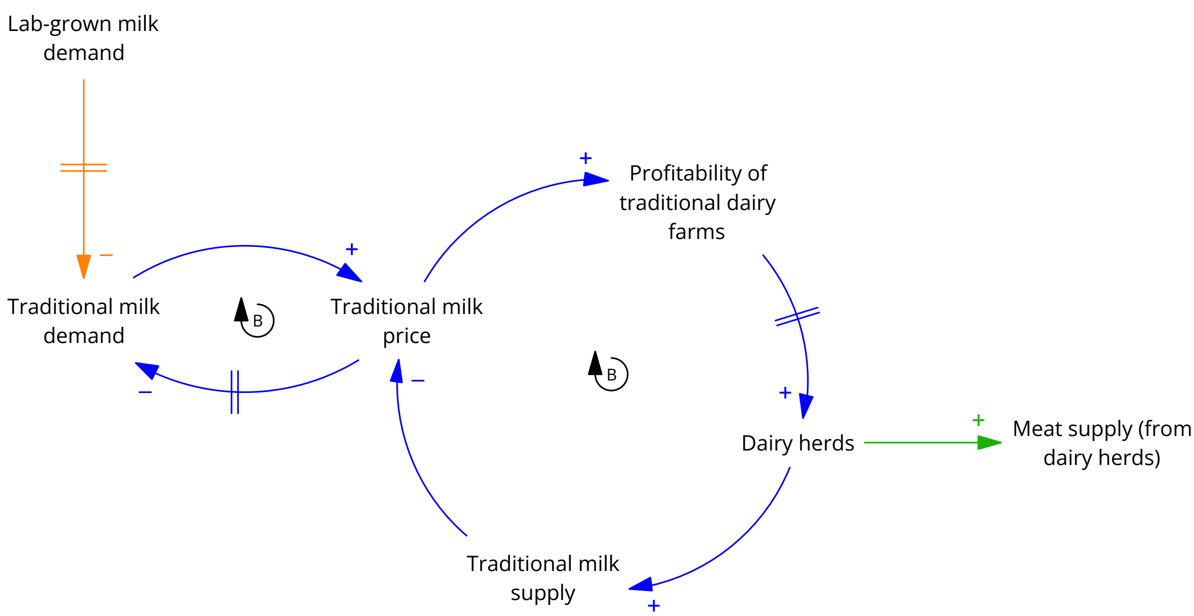


*Figure 5.3 Causal loop diagram – Traditional milk system*

Traditional milk demand is linked to its price in accordance with the same market dynamics described for lab-grown milk. Instead, the relationship between price and supply is depicted in greater detail, to better examine the internal mechanisms of dairy farms and to highlight the structural link between the dairy and beef sectors.

As it can be seen, as the traditional milk price increases, the profitability of traditional dairy farms increases, as the revenue is higher. Greater profitability allows farmers to have more financial resources that can be used to make investments, such as expanding the dairy herd. However, such investments do not produce immediate results. In fact, expanding the herd takes time, both for biological reasons linked to the gestational period and growth of the animals, and for managerial and economic reasons linked to investment planning. For this reason, a delay has been introduced in the diagram on the arrow that connects profitability to dairy herd.

Continuing along the self-balancing loop, an increase in the dairy herd size leads to an increase in the quantity of traditional milk produced. In turn, an increase of the traditional milk supply causes the price to decrease, in line with the market dynamics already illustrated in the case of lab-grown milk.

This subsystem is directly linked to the meat production subsystem. This interconnection emerged from both literature and interviews. For example, FARM8 stated that «*the two supply chains intersect and optimize each other*». In fact, dairy cows give birth to calves, some of which enter the meat supply chain; furthermore, at the end of their productive lives, dairy cows are also slaughtered. Consequently, a change in the size of dairy herds has a direct impact on meat supply.

More precisely, an increase in dairy herds leads, in the long term, to an increase in meat supply (coming from dairy farms) entering the market. Conversely, in the case of a reduction in the size of dairy herds, it is necessary to distinguish between short-term and long-term effects.

In the short term, a decrease in the size of dairy herds may lead to a temporary increase in meat supply, as more animals are slaughtered to reduce dairy herds. This creates a temporary peak in availability. This mechanism was also highlighted in the interviews, when AGENT affirmed that «*[…] in a "downsizing" phase: farms reduce their herds; so, in the short term, there will be plenty of meat*».

Instead, in the long term, a smaller dairy herd leads to a decrease in meat supply from the dairy sector. The same interviewee also emphasized this transition stating that «*Once the system stabilizes, there will be a reduction in supply and, consequently, a rise in prices [. . . ]*».

In the constructed CLD the long-term effects are represented, as they are the most relevant for describing the overall evolution of the system.

### 5.1.3 Meat production system

The last subsystem, depicted in Figure 5.4, is related to the meat production system.

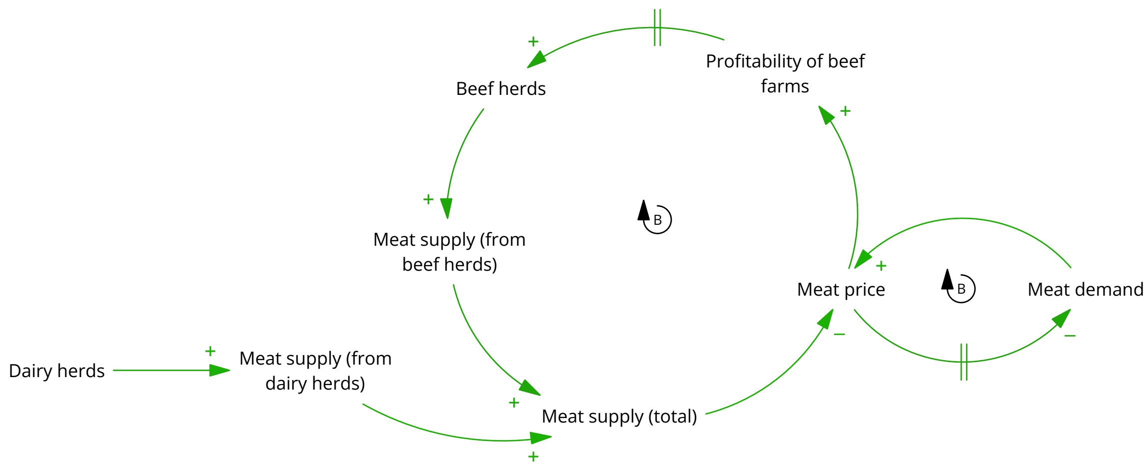


*Figure 5.4 Causal loop diagram – Meat production system*

Starting with the balancing loop on the left, it can be seen that the total meat supply derives from two main sources: dairy herds and beef herds. The total meat supply influences the meat price, which, in turn, interacts with meat demand according to standard market dynamics and delays already discussed in the previous subsystems.

The left self-balancing loop, which specific for beef cattle farms is similar to the one of dairy farms. Therefore, an increase in meat price leads to increased profitability, as the revenues from the sale of animals are higher. Greater profitability, in turn, increases farmers’ investment capacity, allowing, after a certain delay, for the expansion of beef herds. This delay reflects both the biological time required for the animals to grow and the time needed to plan and implement new investments. Finally, the increase in beef herds leads to an increase in meat supply (coming from beef herds), which tends to exert downward pressure on prices, thus closing the balancing loop.

To summarize, only looking to this loop and considering the long period, an increase in meat supply from dairy herds, evolves in a decrease in meat supply from beef herds. While, a decrease in meat supply from dairy herds, evolves in an increase in meat supply from beef herds.

However, this is not completely true. In fact, meat price is not only impacted by the total meet supply, but also by meat demand. This means that whether meat demand remains stable, increases, or decreases, the effects on beef herd can change.

For example, considering the case of a decline of dairy herds in the long period. This would theoretically lead to an increase in beef herds. However, this would only be the case if beef demand remains constant or, alternatively, increases; in that case, the increase would be proportionally greater. Conversely, if beef demand were to decrease, depending on its extent, this would reduce the incentive to increase beef herds, or could even lead to a structural decrease in their size.

### 5.1.4 Final considerations

Overall, the causal loop diagram illustrates that the three analyzed subsystems are not independent but rather closely interconnected. In fact, lab-grown milk, traditional milk, and meat influence one another through market dynamics that involve variables such as supply, demand, and price. Therefore, a change in one subsystem can have direct or indirect effects on the others, altering the overall stability of the agri-food system under examination.

In particular, the potential entry of lab-grown milk into the market could lead to a decline in demand for traditional milk and, consequently, to a reduction in the dairy herd in the long term. Such change could also affect the beef sector, reducing the contribution of meat supply from dairy farms. The response of specialized beef farms would depend, however, on trends in meat demand: if meat demand remains stable, it could lead to an increase in the size of beef herds; conversely, if meat demand also declines, there will be a contraction of this sector as well.

The diagram in *Figure 5.1*, therefore, shows that the adoption of lab-grown milk can lead to structural changes across the entire livestock sector. For this reason, the analysis cannot be limited to the direct effects on the dairy market but must also consider the interdependencies with meat production and the system's potential responses over time.

## 5.2 Dairy farm Excel model

Following the development of the causal loop diagram, a model has been constructed on Excel, following a stock and flow logic. The objective was to represent the functioning of a traditional dairy farm and to quantify the main dynamics regarding herd management, meat production, feed requirements, and biogas production.

The model has been developed considering a hypothetical dairy farm with 100 lactating dairy cows. This reference has been chosen to represent a medium-sized farm.

This section is structured in sub-chapters. First, the main assumptions are presented, as they define the boundaries and the logic behind the model. Then, there are four sub-chapters, each of which focuses on a specific part of the system. Lastly, the overall diagram is presented.

### 5.2.1 Assumptions

A few assumptions were introduced to make the representation of dairy farms more consistent and understandable. These are listed below:

- The model covers a one-year time horizon. Therefore, all the stocks and flows must be interpreted on an annual basis.

- It was assumed that each dairy cow calves once a year. In reality, based on the animal's age or characteristics, more than one insemination may be necessary before pregnancy occurs, thereby resulting in a longer period of time. However, for ease of calculation, the model assumes one calf per cow per year, representing the optimal situation that farmers generally aim for.

- The number of calvings a dairy cow has during its production live is highly variable. In fact, from the interviews emerged that the number could vary from one to six. For this reason, the model assumes an average of four calvings per cow. After the fourth calving, the cow remains on the farm for an additional year, until her productivity declines, and then she is removed from the herd and slaughtered.

- The model assumes a uniform distribution of cows across the different production stages. Specifically, it assumes that the number of cows in the first, second, third, and fourth calving groups is the same. This assumption allows for a simplified and stable representation of the herd structure.

- It was assumed that all animals are healthy and follow their normal production cycle. Premature deaths and unforeseen exits from the herd were not considered in the model.

- It was assumed that all the born purebred female calves, hereinafter referred to simply *female calves*, remain in the dairy production system. Therefore, they are all considered potential replacements for the existing dairy herd and none of them are destined to slaughter. On the contrary, all the other calves are sold to fatteners.

- Purebred dairy calves are generally destined for veal or beef production, depending on market demand. However, due to a lack of precise and consistent data, the model assumes that these calves are distributed according to the same fixed percentages used for crossbred calves.

- According to literature, biogas plants installed on farms can be used both to produce energy (electricity and heat) and to produce biofuels. However, all interviewees who own a biogas plant stated that they used it for energy production. For this reason, only this intended use was considered in the model.

### 5.2.2 Dairy

The overall excel model is based on a central stock: dairy cows (DC). These are all the dairy cows currently in lactation. Depending on the number of calves they have already had, these are classified as primiparous cows (PC) and multiparous cows (MC). Primiparous cows are those that are at their first calving, while multiparous cows are those at their second, third, or fourth calving.

Since a uniform distribution of dairy cows across different production stages was assumed and since there are four age groups, 25% ($S_{PC}$) of the total are considered primiparous cows, while 75% ($S_{MC}$) are considered multiparous cows (of which 1/3 are at their second calving, 1/3 at their third calving, and 1/3 at their fourth calving).

Therefore, the following equations were used to calculate the number of primiparous and multiparous cows:

$$PC\ [head] = DC[head] * S_{PC}\ [\%] \tag{5.1}$$

$$MC\ [head] = DC[head] * S_{MC}\ [\%] \tag{5.2}$$

The model is based on an annual time horizon, in line with the production and reproductive cycle of dairy cows. In fact, every year, dairy cows are inseminated, then they go through a gestational period of about nine months, and, after calving, a new lactation begins. After two or three months they are inseminated again. This process usually lasts about a year.

Immediately after calving, as stated by FARM2, «*milk production can reach a peak of around 60 kg of milk per day*», after which it gradually declines. For modelling purposes, daily production was estimated at 34 kg of milk ($M_{cow}$), representing the mean value observed from the interviews. To calculate annual milk production ($M_{tot}$), the following formula was applied:

$$M_{tot}\ \left[\frac{ton}{year}\right] = \left(DC\ [head] * M_{cow}\left[\frac{kg}{head * day}\right]\right) * \frac{305\ \left[\frac{days}{year}\right]}{1000\ \left[\frac{kg}{ton}\right]} \tag{5.3}$$

As can be seen, annual production was not calculated over 365 days, but over the 305 days of actual lactation. In fact, in the two months prior to calving (approximated at 60 days), the cow enters a "dry" period during which she does not produce milk.

As regards calves, it was assumed that dairy cows have 1 calf a year ($N_{unit}$), but a distinction is necessary based on whether it is a primiparous or multiparous cow.

- In the case of primiparous cows, sexed semen is used to ensure that only female calves are born. This approach ensures an adequate number of animals for internal replacement.
- In the case of multiparous cows, on the other hand, conventional semen is used, resulting in an approximately balanced distribution of calves. However, for 23% of the multiparous cows, semen from beef bulls is used, resulting in the birth of crossbred calves. (Caccin et al., 2024) Therefore, the percentages of calves born form multiparous cows used are 23% beef-on-dairy calves ($S_{BoD}$), 38,5% female calves ($S_{CF}$), and 38,5% male calves ($S_{CM}$).

For each type of calf, the stillbirth rate was considered. These are reported in *Table 5.1.*

*Table 5.1 Stillbirth rates - (Caccin et al., 2024)*

| Variable | Symbol | Value |
|---|---|---|
| **Stillbirth rate of female calves** | $SB_{CF}$ | 5,8% |
| **Stillbirth rate of male calves** | $SB_{CM}$ | 5,8% |
| **Stillbirth rate of beef-on-dairy calves** | $SB_{BoD}$ | 6,4% |

Based on these data, the number of female calves born ($CF$) in a year was calculated using the following formulas. As it can be seen, both the contributes of primiparous and multiparous cows were considered.

$$CF_{prim}\ [head] = \left(PC\ [head] * N_{unit}\left[\frac{calf}{head * year}\right]\right) * (1 - SB_{CF}[\%]) \qquad (5.4)$$

$$CF_{multi}\left[\frac{head}{year}\right] = \left(MC[head] * S_{CF}[\%] * N_{unit}\left[\frac{calf}{head * year}\right]\right) * (1 - SB_{CF}[\%]) \quad (5.5)$$

$$CF\ [head] = \left(CF_{prim}\left[\frac{head}{year}\right] + CF_{multi}\left[\frac{head}{year}\right]\right) * 1\ year \quad (5.6)$$

In equation 5.6, the number of female calves born in one year was multiplied by the one-year time horizon of the model. In fact, female calves are retained in the farm for the entire year, therefore, they can be expressed as heads.

Then, the number of male calves ($CM$) and beef-on-dairy calves ($BoD$) were calculated using the following formulas.

$$CM\left[\frac{head}{year}\right] = \left(MC[head] * S_{CM}[\%] * N_{unit}\left[\frac{calf}{head * year}\right]\right) * (1 - SB_{CM}[\%]) \quad (5.7)$$

$$BoD\left[\frac{head}{year}\right] = \left(MC\left[\frac{head}{year}\right] * S_{BoD}[\%] * N_{unit}\left[\frac{calf}{head * year}\right]\right) * (1 - SB_{BoD}[\%]) \quad (5.8)$$

Once born, calves follow different paths depending on their sex and intended use.

Male calves and beef-on-dairy calves, as affirmed by FARM1 and FARM4, are generally reared on the farm for 15-45 days, until they reach a certain live weight of approximately 50 kg and 60 kg respectively. Then, they are sold to specialist fattening farms, where they remain until slaughter.

Female calves, on the other hand, represent a strategic resource for the farm, as they are intended for herd replacement. For this reason, they generally remain on the farm and follow a specific growth program. During the various stages of development, they are fed according to dedicated nutritional plans and managed in separate groups based on age, so as to best meet their physiological needs. Over time, female calves develop into heifers. Once they have reached the appropriate age and weight, they are inseminated to have their first calving at around the age of two. After calving, they become primiparous cows and continue the production and reproductive cycle previously described.

In the diagram, heifers ($H$) were calculated as follows:

$$H\ [head] = PC\ [head] * 2 \tag{5.9}$$

The calculated value is based on the fact that heifers remain in the rearing phase for around two years before joining the dairy herd, meaning that at any given time the farm must have two annual groups of future replacement animals.

In some cases, the number of heifers reared may exceed the farm's replacement requirements or the available capacity. Under these circumstances, surplus heifers can be sold. Generally, to maximize their economic value, they are sold pregnant and on a live-weight basis. For this reason, an outflow from the heifer stock has been modelized. Assuming a stable herd among the year, sold heifers ($H_{sold}$) were calculated as follows:

$$H_{sold}\ [head] = CF[head] - PC\ [head] \tag{5.10}$$

At the end of the year, multiparous cows at their fourth calf are slaughtered. These are called culled dairy cows ($CC$) and are modeled as an outflow from the stock of multiparous cows. It was calculated as follows:

$$CC\ \left[\frac{head}{year}\right] = MC\ [head] * R_{culling} \left[\frac{\%}{year}\right] \tag{5.11}$$

Where $R_{culling} = 33\%/year$ indicates the percentage of multiparous cows slaughtered in one year, corresponding to the 1/3 multiparous cows at their fourth calving.

The resulting values for the reference farm of 100 dairy cows are shown in *Table 5.2.*

*Table 5.2 Stock and flow values summary – Dairy system*

| Stocks - dairy | Symbol | Value | U.o.M. |
|---|---|---|---|
| **Primiparous cows** | $PC$ | 25 | head |
| **Multiparous cows** | $MC$ | 75 | head |
| **Milk production** | $M_{tot}$ | 1.037 | tons/year |
| **Female calves** | $CF$ | 51 | head |
| **Male calves** | $CM$ | 27 | head/year |
| **Beef-on-dairy calves** | $BoD$ | 16 | head/year |
| **Heifers** | $H$ | 51 | head |
| **Sold heifers** | $H_{sold}$ | 26 | head |
| **Culled dairy cows** | $CC$ | 25 | head/year |

### 5.2.3 Meat

As regards meat, the model aims to quantify the amount of it supplied to the market by dairy farms. To this end, two main stocks have been defined: veal (V) and beef (B).

The veal stock represents the meat obtained from calves, both purebred and crossbred, that are sold to fatteners and slaughtered, according to the FARM8, within approximately 9 months.

The beef stock, on the other hand, comprises meat obtained both from calves, either purebred and crossbred, which are sold to fatteners and slaughtered at later stage of growth, and from culled dairy cows that are slaughtered at the end of their productive life.

As regards purebred calves and culled dairy cows, the inflows for these two stocks were calculated considering the animals' live weight at slaughter and the dressing percentage, which was used to convert live weight into carcass weight. Instead, as regards beef-on-dairy calves, carcass weight was already available from literature; therefore, it was directly used in the model without applying any conversion factors.

In *Table 5.3*, the numerical data are reported.

*Table 5.3 Meat data - (Bittante et al., 2023; Dati - Macellazioni Bovini, n.d.)*

| Typology | Variable | Symbol | Value | U.o.M. |
|---|---|---|---|---|
| **Pure calves x veal** | **Average weight before slaughtering** | $W_{pure_{calf}}$ | 227 | kg/head |
| | **Dressing percentage - veal** | $\alpha_{veal}^{pure}$ | 62% | |
| **Pure calves x beef** | **Average weight before slaughtering** | $W_{pure_{steer}}$ | 567 | kg/head |
| | **Dressing percentage - beef** | $\alpha_{beef}^{pure}$ | 60,5% | |

| | | | | |
|---|---|---|---|---|
| **Culled dairy cows** | **Average weight before slaughtering** | $W_{cull_{cow}}$ | 546 | kg/head |
| | **Dressing percentage** | $\alpha_{beef}^{cull}$ | 51,5% | |
| **Beef-on-dairy calves x veal** | **Average carcass weight** | $W_{BoD_{calf}}^{carcase}$ | 181 | kg/head |
| **Beef-on-dairy calves x beef** | **Average carcass weight** | $W_{BoD_{steer}}^{carcase}$ | 404 | kg/head |

An additional parameter required in the model is the proportion of calves, both purebred and crossbred, destined respectively for veal and beef production.

As regards beef-on-dairy calves, Bittante et al. (2023) report that, in Europe, around 16% of calves are kept on-farm for internal meat production, while the remaining share is sent to fatteners. Of these animals, 55% are destined for veal production and 28% for beef production. However, none of the interviewees reported keeping calves on-farm for meat production. For this reason, the percentages were normalized by assuming that all calves are sold to fatteners. The final percentages are therefore $s_{veal}^{BoD} =$ 66,3% for veal production and $s_{beef}^{BoD} =$ 33,7% for beef production. (Bittante et al., 2023)

As regards purebred calves, on the other hand, no precise quantitative data regarding their allocation were found in literature. However, Bittante et al. (2023) affirm that «*The purebred and crossbred calves from dairy farms in Europe are mainly destined for veal production*». For this reason, the same distribution adopted for beef-on-dairy calves was applied: $s_{veal}^{pure}$ = 66,3% e $s_{beef}^{pure}$ = 33,7%. (Bittante et al., 2023)

At this stage, based on collected data, the values of the two stocks were calculated by adding up all their respective inflows. The formulas used are set out below:

$$V_{pure}\left[\frac{kg}{year}\right] = \left(CM\left[\frac{head}{year}\right] * s_{veal}^{pure}\,[\%]\right) * W_{pure_{calf}}\left[\frac{kg}{head}\right] * \alpha_{veal}^{pure}\,[\%] \qquad (5.12)$$

$$V_{BoD}\left[\frac{kg}{year}\right] = \left(BoD\left[\frac{head}{year}\right] * s_{veal}^{BoD}\,[\%]\right) * W_{BoD_{calf}}^{Carcase}\left[\frac{kg}{head}\right] \qquad (5.13)$$

$$V\left[\frac{kg}{year}\right] = V_{pure}\left[\frac{kg}{year}\right] + V_{BoD}\left[\frac{kg}{year}\right] \qquad (5.14)$$

$$B_{pure}\left[\frac{kg}{year}\right] = \left(CM\left[\frac{head}{year}\right] * s_{beef}^{pure}\,[\%]\right) * W_{pure_{steer}}\left[\frac{kg}{head}\right] * \alpha_{beef}^{pure}\,[\%] \qquad (5.15)$$

$$B_{BoD}\left[\frac{kg}{year}\right] = \left(BoD\left[\frac{head}{year}\right] * s_{beef}^{BoD}\,[\%]\right) * W_{BoD_{steer}}^{Carcase}\left[\frac{kg}{head}\right] \qquad (5.16)$$

$$B_{cull}\left[\frac{kg}{year}\right] = CC\left[\frac{head}{year}\right] * W_{cull_{cow}}\left[\frac{kg}{head}\right] * \alpha_{beef}^{cull}\,[\%] \qquad (5.17)$$

$$B\left[\frac{kg}{year}\right] = B_{pure}\left[\frac{kg}{year}\right] + B_{BoD}\left[\frac{kg}{year}\right] \qquad (5.18)$$

Therefore, the total quantity of meat from dairy sector ($M_{dairy}$) was calculated as the sum of veal and beef:

$$M_{dairy}\left[\frac{kg}{year}\right] = V\left[\frac{kg}{year}\right] + B\left[\frac{kg}{year}\right] \qquad (5.19)$$

Based on the assumptions and equations set out above, the values shown in *Table 5.4* were obtained for the reference farm.

*Table 5.4 Stock values summary – Meat system*

| Stocks - meat | Symbol | Value | U.o.M. |
|---|---|---|---|
| **Veal** | $V$ | 4.473 | kg/year |
| **Beef** | $B$ | 12.378 | kg/year |
| **Meat from dairy sector** | $M_{dairy}$ | 16.851 | kg/year |

The stock and flow diagram related to both dairy and meat sub-chapters is reported in *Figure 5.5*.

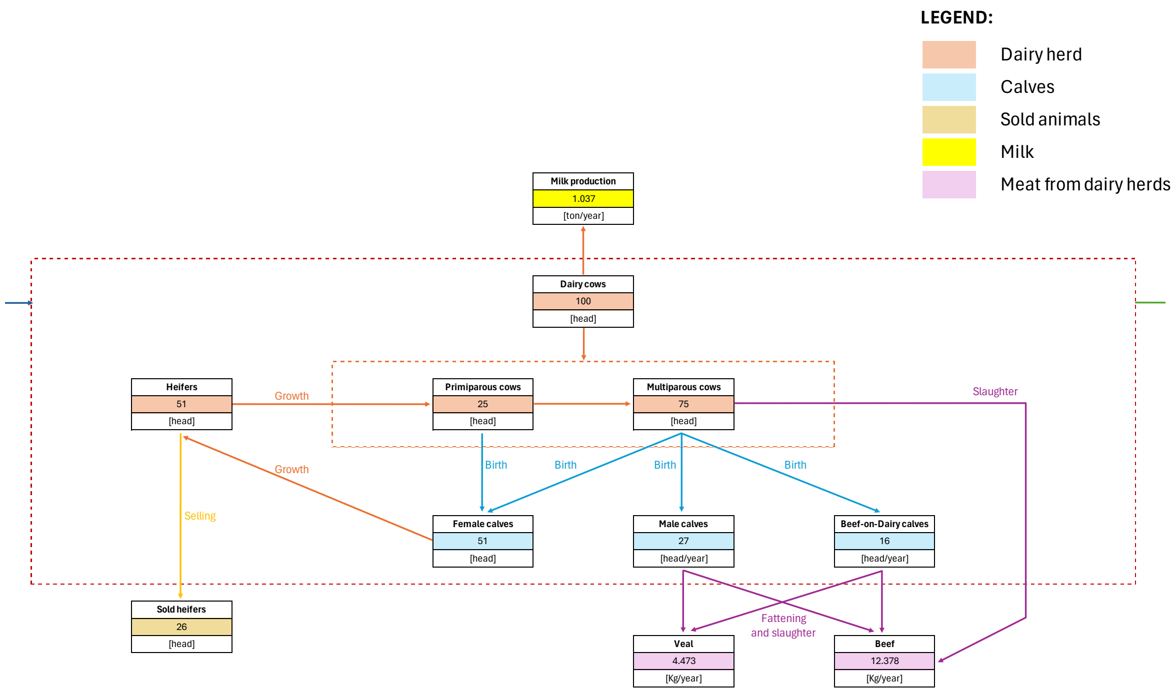


*Figure 5.5 Stock and flow diagram - Dairy and Meat systems*

### 5.2.4 Feed

As regards feed, the first part of the model focuses on estimating the herd's annual dry matter intake (DMI).

Dry matter intake (DMI) refers to the amount of feed consumed by an animal, expressed in terms of dry matter. This indicator is commonly used in livestock farming because it allows feed intake to be compared and quantified regardless of the moisture content of the various feeds. (*Dry Matter Intake*, n.d.)

However, the calculation is not straightforward, as dry matter intake varies according to the animal's age and the physiological stage it is going through.
In particular, dairy cows have different requirements depending on whether they are in the dry period, in the weeks immediately preceding calving, in the first few weeks following calving or during the remainder of the lactation period. This distinction was applied to both primiparous and multiparous cows.
Instead, heifers and female calves have a constant average daily DMI throughout the year.

For this reason, specific values, reported in *Table 5.5*, for daily DMI for each phase were used in the model.

*Table 5.5 Dry matter intakes - (Fantini, 2022; Studio demitri, n.d.)*

| Variable | 21ymbol | Value | U.o.M. |
|---|---|---|---|
| **DMI in dry period (-60 to -21 days before calving)** | $DMI_1$ | 13,9 | kg/head/day |
| **DMI in close-up period (-21 to 0 days before calving)** | $DMI_2$ | 12,3 | kg/head/day |

| | | | |
|---|---|---|---|
| **DMI primiparous cow (first 2 weeks post-partum)** | $DMI_p$ | 20,8 | kg/head/day |
| **DMI multiparous cow (first 2 weeks post-partum)** | $DMI_m$ | 25,8 | kg/head/day |
| **DMI lactating cow during the rest of the year** | $DMI_3$ | 23,0 | kg/head/day |
| **DMI calves** | $DMI_c$ | 5,0 | kg/head/day |
| **DMI heifers** | $DMI_h$ | 9,8 | kg/head/day |

Male calves and beef-on-dairy calves were not included in the calculations, as they remain on the farm for a limited period after birth. Consequently, their contribution to the farm's overall feed consumption was considered marginal in relation to the model's objectives.

The annual dry matter intake for primiparous cows $(DMI_{prim})$, multiparous cows $(DMI_{multi})$, heifers $(DMI_{heifers})$, and female calves $(DMI_{calves})$ were therefore calculated by multiplying the daily DMI values by the number of days associated with each phase and summing the results obtained. The equations used are shown below.

$$DMI_{prim}\left[\frac{kg}{head*year}\right]=\left(DMI_1\left[\frac{kg}{day*head}\right]*39\left[\frac{day}{year}\right]\right)+$$
$$+\left(DMI_2\left[\frac{kg}{day*head}\right]*21\left[\frac{day}{year}\right]\right)+\left(DMI_p\left[\frac{kg}{day*head}\right]*14\left[\frac{day}{year}\right]\right)+$$
$$+\left(DMI_3\left[\frac{kg}{day*head}\right]*291\left[\frac{day}{year}\right]\right) \tag{5.20}$$

$$DMI_{multi}\left[\frac{kg}{head*year}\right]=\left(DMI_1\left[\frac{kg}{day*head}\right]*39\left[\frac{day}{year}\right]\right)+$$
$$+\left(DMI_2\left[\frac{kg}{day*head}\right]*21\left[\frac{day}{year}\right]\right)+\left(DMI_m\left[\frac{kg}{day*head}\right]*14\left[\frac{day}{year}\right]\right)+$$
$$+\left(DMI_3\left[\frac{kg}{day*head}\right]*291\left[\frac{day}{year}\right]\right) \tag{5.21}$$

$$DMI_{heifers}\left[\frac{kg}{head*year}\right]=DMI_h\left[\frac{kg}{day*head}\right]*365\left[\frac{day}{year}\right] \tag{5.22}$$

$$DMI_{calves}\left[\frac{kg}{head*year}\right]=DMI_c\left[\frac{kg}{day*head}\right]*365\left[\frac{day}{year}\right] \tag{5.23}$$

Where, 39 days/year are the dry period, 21 days/year are the weeks immediately preceding calving, 14 days/year are the first two weeks following calving, and 291 days/year are the remainder lactation days of the year. For heifers and calves, since the feed intake is constant throughout the year, 365 days/year were considered in the equation.

Then, the annual DMI values per head were then multiplied by the number of animals in each category in the reference herd. The sum of these contributions enabled to estimate the farm’s total annual dry matter intake ($DMI_{tot}$), which amounted to 1.057 ton/year. The used equation is reported below.

$$DMI_{tot}\left[\frac{ton}{year}\right]=\begin{pmatrix}\left(DMI_{prim}\left[\frac{kg}{head*year}\right]*PC[head]\right)+\\+\left(DMI_{multi}\left[\frac{kg}{head*year}\right]*MC[head]\right)+\\+\left(DMI_{heifers}\left[\frac{kg}{head*year}\right]*H[head]\right)+\\+\left(DMI_{calves}\left[\frac{kg}{head*year}\right]*CF[head]\right)\end{pmatrix}*\frac{1\ ton}{1000\ kg} \tag{5.24}$$

The second part of the model focuses on estimating the amount of land required to produce the dry matter consumed annually by the herd.

In dairy farms, this land can be located either within the farms or outside them, depending on their level of self-sufficiency.

Both literature and interviews have highlighted that dairy farms adopt different strategies for feed supply. Some farms produce almost all the dry matter they require on-farm, whilst others rely heavily on off-farm productions. Consequently, the proportion of dry matter produced on-farm and off-farm can vary considerably among farms.

To establish a representative value for model calculations, the findings of Rolando et al. (2024) were used. Their study, which analyzes fourteen dairy farms located in Piedmont, found an average level of DM self-sufficiency equal to 60,9%. Therefore, in the model, the share of DMI produced on-farm was set at $s_{DMI}^{on-farm}$ = 60,9% and the share of DMI produced off-farm was set at $s_{DMI}^{off-farm}$ = 39,1%. (Rolando et al., 2025)

Based on these numerical data, the equations reported below, were used to calculate the quantity of DMI produced on-farm ($DMI_{on-farm}$) and the quantity of DMI produced off-farm ($DMI_{off-farm}$).

$$DMI_{on-farm}\left[\frac{ton}{year}\right] = DMI_{tot}\left[\frac{ton}{year}\right] * s_{DMI}^{on-farm}[\%] \qquad (5.25)$$

$$DMI_{off-farm}\left[\frac{ton}{year}\right] = DMI_{tot}\left[\frac{ton}{year}\right] * s_{DMI}^{off-farm}[\%] \qquad (5.26)$$

Subsequently, a conversion factor of $Y = 10\ ton_{DMI}/ha$ was applied to obtain the total land-use area, expressed in terms of cultivated hectares both on-farm

($ha_{on-farm}$) and off-farm ($ha_{off-farm}$), required to meet the herd's annual feed requirements. (Rolando et al., 2025)

The following formulas were used.

$$ha_{on-farm}\left[\frac{ha}{year}\right] = \frac{DMI_{on-farm}\left[\frac{ton}{year}\right]}{Y\ \left[\frac{ton}{ha}\right]} \tag{5.27}$$

$$ha_{off-farm}\left[\frac{ha}{year}\right] = \frac{DMI_{off-farm}\left[\frac{ton}{year}\right]}{Y\ \left[\frac{ton}{ha}\right]} \tag{5.28}$$

*Table 5.6* shows the obtained numerical values.

*Table 5.6 Stock values summary – Feed system*

| Stocks - feed | Symbol | Value | U.o.M. |
|---|---|---|---|
| **On-farm feed** | $DMI_{on-farm}$ | 644 | ton/year |
| **Off-farm feed** | $DMI_{off-farm}$ | 413 | ton/year |
| **On-farm hectares** | $ha_{on-farm}$ | 64 | ha/year |
| **Off-farm hectares** | $ha_{off-farm}$ | 41 | ha/year |

Based on on-farm hectares and off-farm hectares, land occupation was calculated as follows:

$$LO\ \left[\frac{m^2}{kg}\right] = \frac{\left(ha_{on-farm}\left[\frac{ha}{year}\right] + ha_{off-farm}\left[\frac{ha}{year}\right]\right) * 10000\left[\frac{m^2}{ha}\right]}{M_{tot}\left[\frac{ton}{year}\right] * 1000\left[\frac{kg}{ton}\right]} \tag{5.29}$$

The obtained result is $LO = 1{,}02\ m^2/kg$, which is consistent with literature. In fact, Rolando et al. (2024), highlight for dairy farms in Italy, values of land occupation between $0{,}76\ m^2/kg$ and $4{,}83\ m^2/kg$. (Rolando et al., 2025)

The stock and flow diagram related to this sub-chapter is reported in *Figure 5.6*.

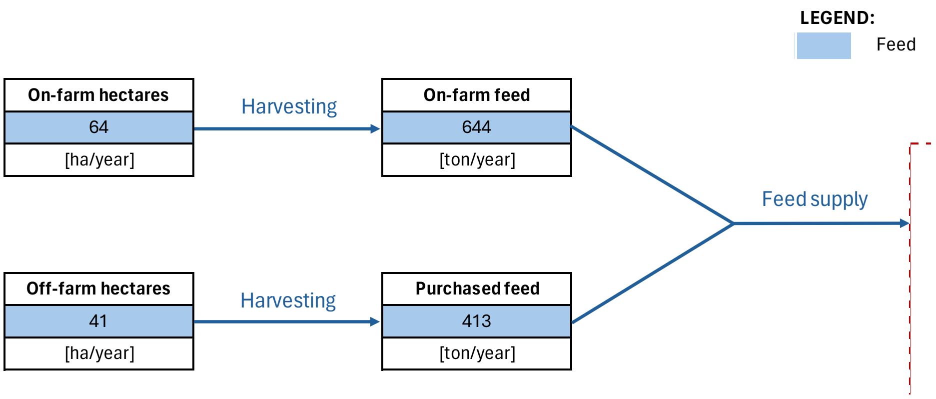


*Figure 5.6 Stock and flow diagram - Feed system*

## 5.2.5 Biogas

This subchapter aims to estimate the amount of electricity, heat, and digestate that can be generated annually from manure produced by a dairy farm.

The model begins with estimating the amount of manure produced by the herd. As manure production varies according to the animal's age, different values, reported in *Table 5.7*, have been assigned to each age category considered in the herd model.

*Table 5.7 Manure per year - (Scarlat et al., 2018)*

| Variable | Symbol | Value | U.o.M. |
|---|---|---|---|
| **Dairy cow manure per year** | $M_{cow}$ | 19,3 | ton/head/year |
| **Heifer manure per year** | $M_{heifer}$ | 7,3 | ton/head/year |
| **Calf manure per year** | $M_{calf}$ | 2,9 | ton/head/year |

As with feed calculations, male calves and beef-on-dairy calves have not been considered in these calculations because their contribute is negligible in relation to the model's objectives.

By multiplying the number of animals in each category with the corresponding manure production value and summing these contributions, the annual manure production ($M$) was calculated.

$$M\left[\frac{ton}{year}\right] = \left(DC\,[head] * M_{cow}\left[\frac{ton}{head * year}\right]\right) + \left(H\,[head] * M_{heifer}\left[\frac{ton}{head * year}\right]\right) + \\ + \left(CF\,[head] * M_{calf}\left[\frac{ton}{head * year}\right]\right) \tag{5.30}$$

$M$ = 2.448 ton/year was obtained for the reference dairy farm.

From this quantity of manure, both biogas and digestate values were obtained.

As regards biogas, calculations are based on the methodology proposed by Scarlat et al. (2018). They analyze biogas potential of livestock farms with plants with an efficiency of 35% for electricity production ($\eta_{el}$) and 45% for heat production ($\eta_{th}$), and an annual operation time of 7500 h ($T_{annual}$). (Scarlat et al., 2018)

Biogas is mainly composed of methane (50%-75%) and carbon dioxide (25%-50%), but since methane is the major and most energetic component, in the model biogas potential was expressed in terms of methane ($CH_4$). (Scarlat et al., 2018)

Each animal is associated with a specific methane yield, expressed in $\mathrm{m}^3$/head/year, which varies according to its age. Methane production was then calculated by multiplying the number of animals in each category by the corresponding methane yield and summing the contributions of all categories. The table with methane yields and the used equation are shown below:

*Table 5.8 Methane yields - (Scarlat et al., 2018)*

| Variable | Symbol | Value | U.o.M. |
|---|---|---|---|
| **Dairy cow methane yield** | $Y_{cow}^{CH4}$ | 302,6 | $\mathrm{m}^3$/head/year |
| **Heifer methane yield** | $Y_{heifer}^{CH4}$ | 99,3 | $\mathrm{m}^3$/head/year |
| **Calf methane yield** | $Y_{calf}^{CH4}$ | 39,7 | $\mathrm{m}^3$/head/year |

$$CH_4 \left[\frac{m^3}{year}\right] = \left(DC\ [head] * Y_{cow}^{CH4} \left[\frac{m^3}{head * year}\right]\right) + \\ + \left(H\ [head] * Y_{heifer}^{CH4} \left[\frac{m^3}{head * year}\right]\right) + \left(CF\ [head] * Y_{calf}^{CH4} \left[\frac{m^3}{head * year}\right]\right) \tag{5.31}$$

With this equation, $CH_4$ = 37.314 $m^3/year$ was obtained.

Then, the energy contained in methane, both in megawatt-hours $\left(E_{tot}^{GJ}\right)$ and gigajoules $\left(E_{tot}^{GJ}\right)$, was calculated. This was done, with the equations below, by converting the volume of methane into energy units using its lower calorific value.

$$E_{tot}^{MWh}\left[\frac{MWh}{year}\right]=\frac{CH_4\left[\frac{m^3}{year}\right]*LHV_{CH4}^{kWh}\left[\frac{\mathrm{kWh}}{\mathrm{m}^3}\right]}{1000\left[\frac{kWh}{MWh}\right]} \tag{5.32}$$

$$E_{tot}^{GJ}\left[\frac{GJ}{year}\right]=\frac{CH_4\left[\frac{m^3}{year}\right]*LHV_{CH4}^{MJ}\left[\frac{\mathrm{kWh}}{\mathrm{m}^3}\right]}{1000\left[\frac{MJ}{GJ}\right]} \tag{5.33}$$

Where $LHV_{CH4}^{kWh}=9{,}97\ kWh/m^3$ and $LHV_{CH4}^{MJ}=35{,}9\ MJ/m^3$ are the lower heating values of $CH_4$. (Scarlat et al., 2018)

The obtained energy contents were subsequently converted into electricity ($E_{el}$) and heat ($E_{th}$), using the following equations.

$$E_{el}\left[\frac{MWh}{year}\right]=E_{tot}^{MWh}\left[\frac{MWh}{year}\right]*\eta_{el}[\%] \tag{5.34}$$

$$E_{th}\left[\frac{GJ}{year}\right]=E_{tot}^{GJ}\left[\frac{GJ}{year}\right]*\eta_{th}[\%] \tag{5.35}$$

For the reference dairy farm, the electricity and heat produced amount to: $E_{el}=130\ MWh/year$ and $E_{th}=603\ GJ/year$.

As regards digestate, calculations were based on the DPReg n. 119/Pres (Regione Friuli Venezia Giulia, 2022) which provides the equations used to estimate digestate production and the related nitrogen content. (Regione Friuli Venezia Giulia, 2022)

First of all, total digestate production ($D$) was estimated based on the amount of manure fed into the digester with the following equation:

$$D\left[\frac{ton}{year}\right] = M\left[\frac{ton}{year}\right] - \frac{CH_4\left[\frac{m^3}{year}\right] * \rho_{CH4}\left[\frac{kg}{m^3}\right]}{1000\,\frac{kg}{ton}} \tag{5.36}$$

where $\rho_{CH4} = 0{,}718\ kg/m^3$ is the value of methane density. (Scarlat et al., 2018)

The estimated digestate quantity, equal to $D = 2.421\ ton/year$, was divided in liquid and solid fraction. To do this, the coefficients $s_{liquid} = 85\%$ and $s_{solid} = 15\%$ were used. (Rossi & Bezzi, 2024)

$$D_{liquid}\left[\frac{ton}{year}\right] = D\left[\frac{ton}{year}\right] * s_{liquid}[\%] \tag{5.37}$$

$$D_{solid}\left[\frac{ton}{year}\right] = D\left[\frac{ton}{year}\right] * s_{solid}[\%] \tag{5.38}$$

The application of these equations to the reference farm resulted in a yield of 2.058 ton/year of liquid digestate ($D_{liquid}$) and 363 ton/year of solid digestate ($D_{solid}$).

Then, since digestate produced by anaerobic digestion can be used as an organic fertilizer, the model also estimates the total agricultural area that can be fertilized by applying it. This step was included to highlight the link between livestock production, digestate management and agricultural activity.

To calculate this area, the total amount of nitrogen contained in digestate ($N_{tot}$) was first estimated. This value was obtained by multiplying the nitrogen produced per animal, reported in *Table 5.9*, by the corresponding number of animals in each category, and then adding up all the contributions. The used equation is reported below.

*Table 5.9 Nitrogen produced per animal - (Regione Friuli Venezia Giulia, 2022)*

| Variable | Symbol | Value | U.o.M. |
|---|---|---|---|
| **Nitrogen produced per cow** | $N_{cow}$ | 82,8 | $kg_N$/head/year |
| **Nitrogen produced per heifer** | $N_{heifer}$ | 36 | $kg_N$/head/year |
| **Nitrogen produced per calf** | $N_{calf}$ | 12 | $kg_N$/head/year |

$$N_{tot}\left[\frac{kg_N}{year}\right] = \left(DC\ [head] * N_{cow}\left[\frac{kg_N}{head * year}\right]\right) + \\ + \left(H\ [head] * N_{heifer}\left[\frac{kg_N}{head * year}\right]\right) + \left(CF\ [head] * N_{calf}\left[\frac{kg_N}{head * year}\right]\right) \tag{5.39}$$

Subsequently, the agricultural area required for the application of the digestate was calculated. To this regard, legislation establishes that there is a maximum limit of nitrogen that can be applied per hectare, which varies depending on whether the area is classified as nitrate-vulnerable or non-vulnerable. Particularly, in vulnerable zones the limit is $N_{lim}^{NVZ} = 170\frac{kg_N}{ha*year}$ and in non-vulnerable zones the limit is $N_{lim}^{non-NVZ} = 340\frac{kg_N}{ha*year}$. This distinction is based on the differing environmental sensitivity of the areas and the varying risk of contamination of surface and groundwater caused by nitrate leaching. Consequently, the limits on nitrogen that can be applied differ depending on the area's classification. (Regione Friuli Venezia Giulia, 2022)

In the model, the required agricultural area was calculated for both farms located in nitrate-vulnerable zones ($A_{req}^{NVZ}$) and farms located in non-vulnerable zones ($A_{req}^{non-NVZ}$). The equations are reported below.

$$A_{req}^{NVZ}[ha] = \frac{N_{tot}\left[\frac{kg_N}{year}\right]}{N_{lim}^{NVZ}\left[\frac{kg_N}{ha * year}\right]} \tag{5.40}$$

$$A_{req}^{non-NVZ}[ha] = \frac{N_{tot}\left[\frac{kg_N}{year}\right]}{N_{lim}^{non-NVZ}\left[\frac{kg_N}{ha * year}\right]} \tag{5.41}$$

The results are $A_{req}^{NVZ} = 63\ ha$ and $A_{req}^{non-NVZ} = 32\ ha$ .

However, for modelling purposes, it was necessary to select one of the two obtained values, to have a single reference coefficient. To this end, a comparative analysis was carried out between the distribution of nitrate-vulnerable zones and the location of the main dairy farms in Italy. In *Figure 5.7* and *Figure 5.8* those are depicted.


*Figure 5.7 Concentration of livestock farms in Italy - (Coderoni & Pontrandolfi, 2016)*

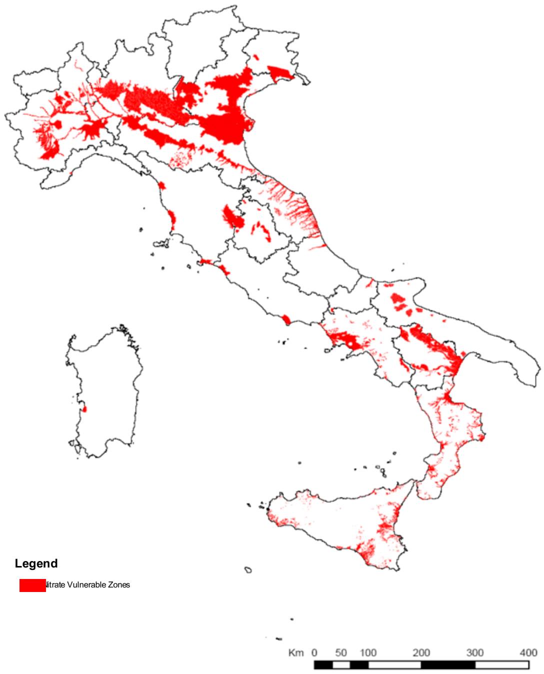


*Figure 5.8 The nitrate affected zones in Italy - (Capri et al., 2009)*

As can be seen, the areas characterized by the highest density of dairy farms largely coincide with territories subject to such environmental constraints. Therefore, the value related to nitrate-vulnerable zones was deemed the most representative of the analyzed context and was adopted in the model.

In *Table 5.10* a summary of the main results obtained is reported and in *Figure 5.9* the stock and flow diagram related to this sub-chapter is depicted.

*Table 5.10 Stock values summary – Biogas system*

| Stocks - Biogas | Symbol | Value | U.o.M. |
|---|---|---|---|
| **Manure** | $M$ | 2.448 | ton/year |
| **Methane** | $CH_4$ | 37.314 | m$^3$/year |
| **Electricity** | $E_{el}$ | 130 | MWh/year |

| | | | |
|---|---|---|---|
| **Heat** | $E_{th}$ | 603 | GJ/year |
| **Digestate – liquid part** | $D_{liquid}$ | 2.058 | ton/year |
| **Digestate – solid part** | $D_{solid}$ | 363 | ton/year |
| **Required land area (NVZ)** | $A_{req}^{NVZ}$ | 63 | ha |

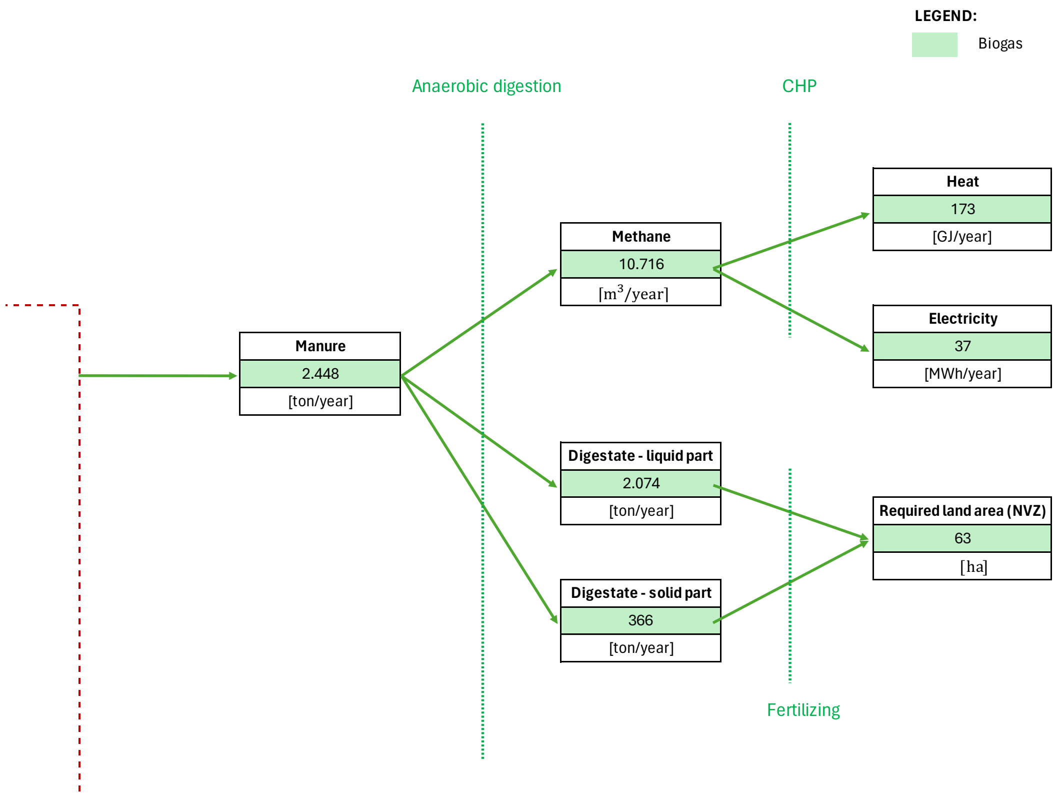


*Figure 5.9 Stock and flow diagram – Biogas system*

### 5.2.6 Model summary

*Figure 5.10* presents the complete stock and flow diagram of a dairy farm and the baseline values obtained for the reference farm of 100 lactating dairy cows.

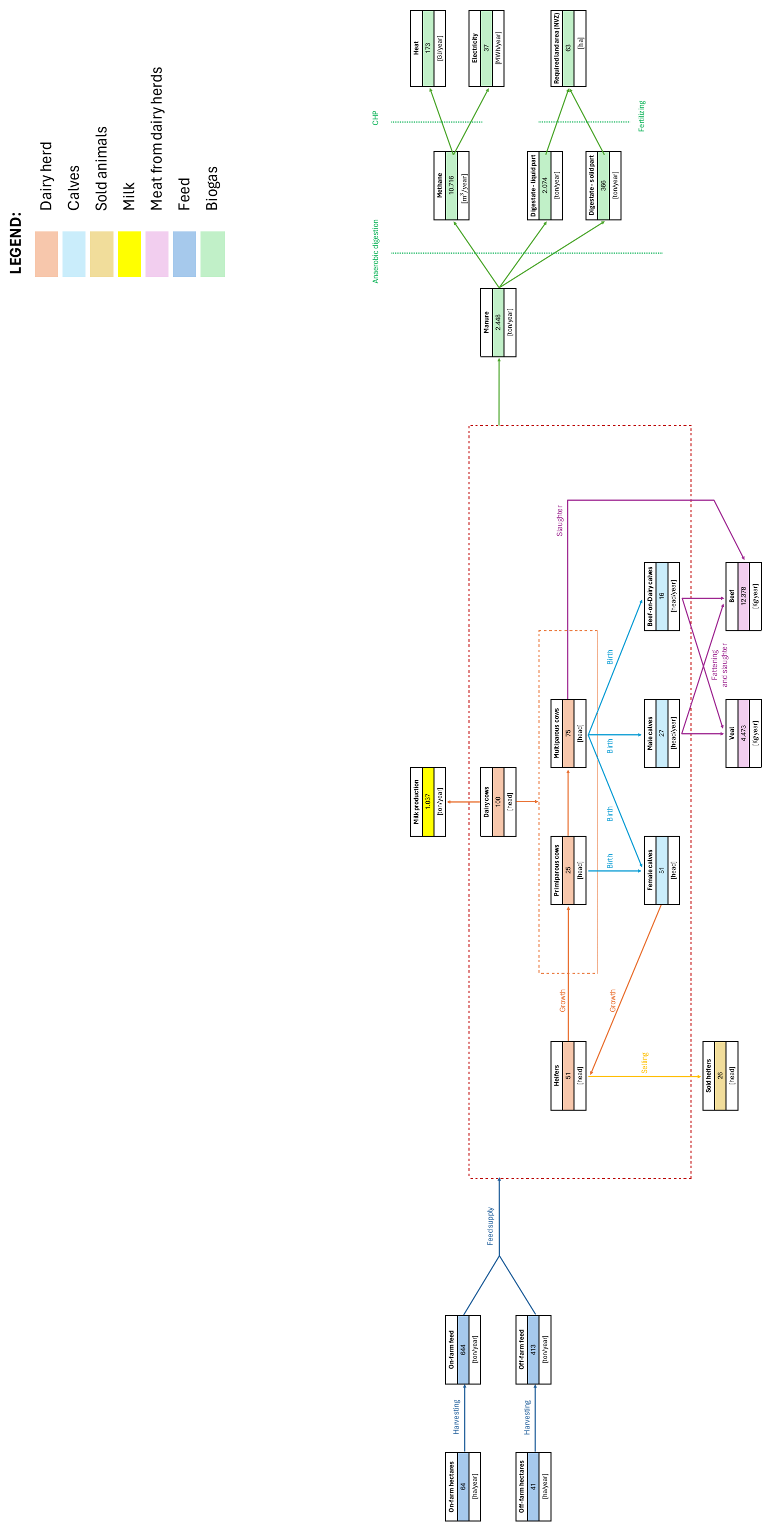


*Figure 5.10 Stock and flow diagram of a dairy farm*

## 5.3 Specialized beef farm Excel model

This section applies the same modelling approach previously adopted for dairy farms to specialized beef farms. The aim is to estimate the main stock and flows associated with feed consumption, biogas production, and digestate management. The adoption of the same calculation method and, when possible, of the same data sources ensures comparability between the dairy and beef cattle farms. This section was included in the model to provide a more comprehensive representation of the livestock system and to form a necessary basis for the scenario analysis presented in the following chapter.

According to AGENT, approximately 40% of the meat available on the market comes from the dairy sector. Based on this assumption, the quantity of meat supplied to the market by beef cattle farms ($M_{meat}$) was estimated using the following equation:

$$M_{meat}\left[\frac{kg}{year}\right] = \left(V\left[\frac{kg}{year}\right] + B\left[\frac{kg}{year}\right]\right) * \frac{60\%}{40\%} \tag{5.42}$$

Consequently, a meat production of $M_{dairy} = 16.851\ kg/year$ in the dairy sector corresponds to a meat production of $M_{meat} = 25.277\ kg/year$ of beef cattle farms.

The next step was to estimate the amount of beef cattle (BC) required to produce that quantity of meat. According to Parmigiani (2025), most of the beef supply in Italy comes from steers, i.e. cattle slaughtered between one and two years of age. Therefore, the same weight before slaughtering and the same dressing percentage previously adopted for male calves ($CM$) intended for beef production were used. (Parmigiani, 2025; Treccani, n.d.)

The number of beef cattle present in a specialized beef farm in a year was calculated as follows:

$$BC\ [head] = \frac{M_{meat}\left[\frac{kg}{year}\right]}{W_{pure_{steer}}\left[\frac{kg}{head}\right] * \alpha_{beef}^{pure}[\%]} * 1year \tag{5.43}$$

The application of this equation resulted in a herd size of $BC = 74\ head$.

Once the herd size was determined, the associated feed requirements and land use were estimated. According to a report published by the Italian Ministry of Health, the daily dry matter intake of beef cattle varies between 7 and 11 kg/head/day. Consequently, an average value of $DMI_{unit} = 9\ kg/head/day$ was considered. (Bertocchi et al., 2020)

By multiplying the daily intake by the number of animals and the number of days in a year, the total dry matter intake of the herd ($DMI_{BC}$) was calculated. Subsequently, the cultivated hectares, also referred as to land occupation, required to produce this feed ($ha_{BC}$) were estimated using the same conversion factor ($Y$) adopted in the dairy model:

$$DMI_{BC}\left[\frac{ton}{year}\right] = \frac{\left(DMI_{unit}\left[\frac{kg}{head * day}\right] * BC\ [head] * 365\left[\frac{day}{year}\right]\right)}{1000\left[\frac{kg}{ton}\right]} \tag{5.44}$$

$$ha_{BC}\left[\frac{ha}{year}\right] = \frac{DMI_{BC}\left[\frac{ton}{year}\right]}{Y\left[\frac{ton}{ha}\right]} \tag{5.45}$$

The resulting values are $DMI_{BC} = 242\ ton/year$ and $ha_{BC} = 24\ ha/year$.

Then, the potential contribution of the beef cattle sector to renewable energy production was assessed. To ensure consistency with the dairy farm model, the same biogas plant configuration was used. According to Scarlat et al. (2018), steers produce $M_{male} = 9{,}10\ kg/head/day$ of manure and have a methane yield of $Y_{male}^{CH4} = 124\ m^3/head/year$. (Scarlat et al., 2018)

Based on these parameters, total manure production ($M_{BC}$), methane generation ($CH_4^{BC}$), energy content, both expressed in MWh/year ($E_{BC}^{MWh}$) and in GJ/year ($E_{BC}^{GJ}$), electricity production ($E_{el}^{BC}$) and heat production ($E_{th}^{BC}$) were estimated using the following equations:

$$M_{BC}\left[\frac{ton}{year}\right] = M_{male}\left[\frac{ton}{head * year}\right] * BC[head] \tag{5.46}$$

$$CH_4^{BC}\left[\frac{m^3}{year}\right] = Y_{male}^{CH4}\left[\frac{m^3}{head * year}\right] * BC[head] \tag{5.47}$$

$$E_{BC}^{MWh}\left[\frac{MWh}{year}\right] = \frac{\left(CH_4^{BC}\left[\frac{m^3}{year}\right] * LHV_{CH4}^{kWh}\left[\frac{kWh}{m^3}\right]\right)}{1000\ \left[\frac{kWh}{MWh}\right]} \tag{5.48}$$

$$E_{BC}^{GJ}\left[\frac{GJ}{year}\right] = \frac{CH_4^{BC}\left[\frac{m^3}{year}\right] * LHV_{CH4}^{MJ}\left[\frac{MJ}{m^3}\right]}{1000\left[\frac{MJ}{GJ}\right]} \tag{5.49}$$

$$E_{el}^{BC}\left[\frac{MWh}{year}\right] = E_{BC}^{MWh}\left[\frac{MWh}{year}\right] * \eta_{el}[\%] \tag{5.50}$$

$$E_{th}^{BC}\left[\frac{GJ}{year}\right] = E_{BC}^{GJ}\left[\frac{GJ}{year}\right] * \eta_{th}[\%] \tag{5.51}$$

Where the parameters $LHV_{CH4}^{kWh}$, $LHV_{CH4}^{MJ}$, $\eta_{el}$ and $\eta_{th}$ were assumed to be the same as those adopted for dairy farms. The resulting values are $E_{el}^{BC} = 32\ MWh/year$ and $E_{th}^{BC} = 148\ GJ/year$.

Lastly, the amount of digestate produced and its potential use in agriculture were estimated. The total quantity of digestate, calculated as follows, amounts to $D_{BC} = 664\ ton/year$.

$$D_{BC}\left[\frac{ton}{year}\right] = M_{BC}\left[\frac{ton}{year}\right] - \frac{CH_4^{BC}\left[\frac{m^3}{year}\right] * \rho_{CH4}\left[\frac{kg}{m^3}\right]}{1000\left[\frac{kg}{ton}\right]} \tag{5.52}$$

Where $\rho_{CH4} = 0{,}718\ kg/m^3$ is the value of methane density.

Subsequently, considering a nitrogen content in the digestate of $N_{male} = 29\ kg_N/head/year$, the nitrogen contained in the digestate of the overall beef cattle ($N_{BC}$) and the agricultural area required for its application ($A_{BC}$) were estimated using the same calculations , reported below, adopted for the dairy sector. (Regione Friuli Venezia Giulia, 2022)

$$N_{BC}\left[\frac{kg_N}{year}\right] = N_{male}\left[\frac{kg_N}{head * year}\right] * BC[head] \tag{5.53}$$

$$A_{BC}[ha] = \frac{N_{BC}\left[\frac{kg_N}{year}\right]}{N_{lim}^{NVZ}\left[\frac{kg_N}{ha * year}\right]} \tag{5.54}$$

In line with the assumptions adopted in the previous section, the calculation was carried out taking into account the nitrogen application limits established for Nitrate Vulnerable Zones (NVZs). The resulting values are $N_{BC} = 2166\ kg_N/year$ and $A_{BC}^{NVZ} = 13\ ha$.

In *Table 5.11* a summary of the main results is reported and in *Figure 5.11* the overall stock and flow diagram is depicted.

*Table 5.11 Stock values summary – Specialized beef farm*

| Stocks - Biogas | Symbol | Value | U.o.M. |
|---|---|---|---|
| **Meat from beef sector** | $M_{meat}$ | 25.277 | $kg/year$ |
| **Beef cattle** | $BC$ | 74 | head |
| **Feed** | $DMI_{BC}$ | 24 | ton/year |
| **Cultivated hectares** | $ha_{BC}$ | 24 | ha/year |
| **Manure** | $M_{BC}$ | 671 | ton/year |
| **Methane** | $CH_4^{BC}$ | 9.144 | m$^3$/year |
| **Electricity** | $E_{el}^{BC}$ | 32 | $MWh/year$ |
| **Heat** | $E_{th}^{BC}$ | 148 | $GJ/year$ |
| **Digestate** | $D_{BC}$ | 664 | $ton/year$ |
| **Required land area (NVZ)** | $A_{BC}^{NVZ}$ | 13 | $ha$ |

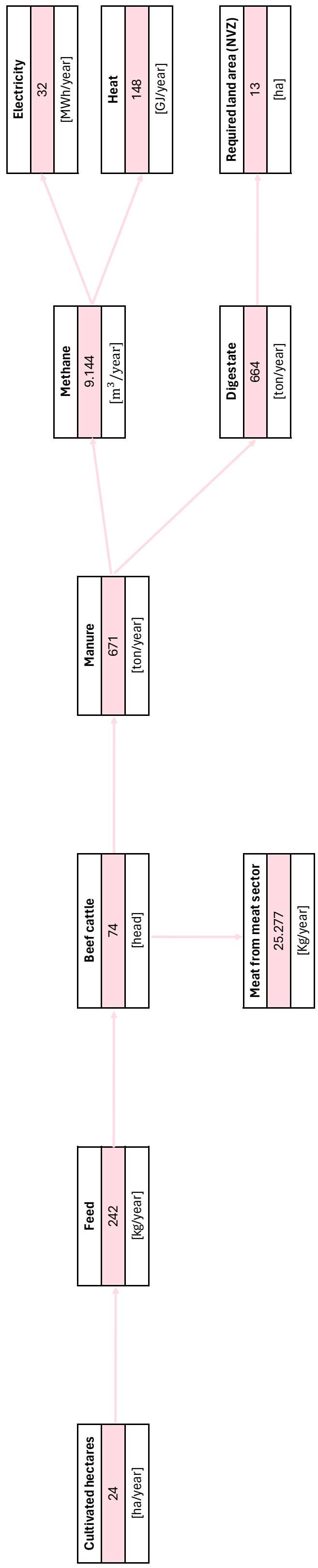


*Figure 5.11 Stock and flow diagram of a specialized beef farm*

# 6 Scenario analysis

The system dynamics model developed in the previous chapter highlighted how the dairy sector is part of a broader system characterized by several interdependencies.

Particularly, the causal loop diagram (CLD) showed how lab-grown milk, traditional milk, and beef are closely related and how changes in any of these can influence the entire system through multiple feedback mechanisms.

Subsequently, the Excel model provided a graphical representation and enabled the quantification of the links between the dairy sector, the beef sector, and related activities. This made it possible to estimate how changes in milk and meat production might propagate along the supply chain and influence various aspects and actors of the system.

The integration of the results obtained with these tools form the basis for the development of this scenario analysis.

Three scenarios were developed, combining trends in dairy products with different trends in beef, in order to assess the potential effects on the system.

It should be noted that the purpose of this scenario analysis is not to predict the future development of the sector, but rather explore a range of plausible futures and to understand how different transition pathways might affect the dairy sector and related sectors. To this end, specific indicators derived from the Excel model were calculated for each scenario, thereby enabling a comparison between them and an assessment of their main implications.

This chapter, therefore, describes the process of scenario building, the dynamics of each scenario, and the indicators used to evaluate them. The obtained results are also presented and discussed.

## 6.1 Scenario development

The construction of the scenarios began with the identification, in literature, of possible future trajectories regarding the spread of alternative proteins and their impact on traditional animal-based products. Since lab-grown milk is still in the early stages of development, quantitative forecasts regarding its future spread are limited. Therefore, it was necessary to refer to studies that analyze more generally the evolution of novel protein markets.

Among the identified sources, one of the most frequently cited studies is the report published by Kearney, a global strategic consulting firm, in 2019. It is titled "*How Will Cultured Meat and Meat Alternatives Disrupt the Agricultural and Food Industry?*", and it analyzes the potential impact of cultured meat and novel vegan meat replacements on the global animal protein market, providing a forecast of market trends. (Kearney, 2019)

As can be seen in *Figure 6.1*, Kearney (2019) predicts that the total value of the global meat market will continue to grow, rising from approximately $1.200 billion in 2025 to about $1.800 billion in 2040. At the same time, the market share of conventional meat will gradually decline, falling from 90% in 2025 to 40% in 2040. During the same period, novel vegan meat replacements will reach a 25% market share, while cultured meat will grow to account for approximately 35% of the global market.

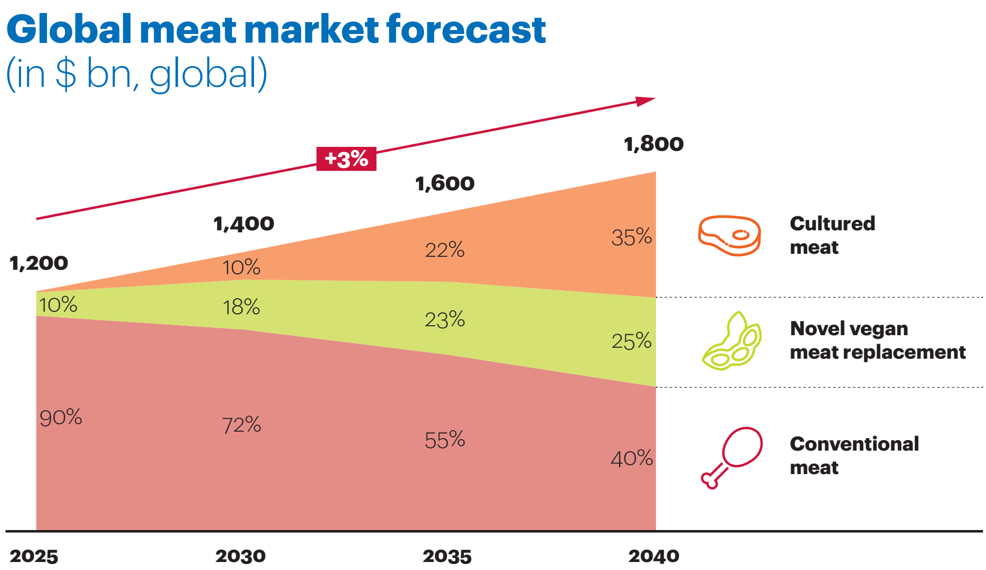


*Figure 6.1 Global meat market forecast - (Kearney, 2019)*

Overall, the study predicts that by 2040, alternative proteins will account for about 60% of the global market, exceeding conventional animal production for the first time. Furthermore, cultured milk will surpass plant-based alternatives becoming the primary choice in consumer diets. (Kearney, 2019)

Although the report refers to a global context, it has subsequently been cited in numerous scientific studies analyzing protein transition within the European context. For example, Rovira-Alsina et al. (2025) refer to these projections to discuss the potential of microbial proteins produced via electro-cultivation in Europe. This suggests that the dynamics proposed by Kearney (2019) may serve as a useful reference point for exploring possible future trajectories of the European agri-food system. Given that Italy operates within the European market and regulatory framework, these projections can therefore provide a plausible basis for constructing the scenarios developed in this research. (Rovira-Alsina et al., 2025)

Despite these projections refers to the beef sector, the report is significant for this research because it provides a precise and quantitative trajectory of how a traditional sector is evolving following the introduction of alternative protein sources. Furthermore, both cultivated meat and lab-grown milk are produced through the same technology. These projections were therefore used as reference trajectories for the evolution of traditional meat, traditional milk, plant-based beverages, and lab-grown milk.

On the other hand, regarding beef, a single reference trajectory has not been defined. Given the high uncertainty surrounding future meat consumption, various trends were explored in order to assess how different levels of consumption might amplify or mitigate the effects of the spread of lab-grown milk.

This choice was motivated by the fact that lab-grown milk is more advanced than cultured meat in terms of technology and market potential. In fact, Kearney (2019) himself stated that, «*as the structure of cultured milk […] is not as complex as meat, this product might hit the market even earlier than cultured meat*». (Kearney, 2019)

This is mainly due to the different biological complexity of the production processes. In fact, in the case of lab-grown milk, precision fermentation allows to produce specific dairy proteins using engineered microorganisms. Cultured meat, on the other hand, requires the *ex vivo* production of a three-dimensional tissue composed of muscle, fat, connective tissue, extracellular matrix, and blood vessels. (Kirsch et al., 2023; Kwon et al., 2024)

This greater complexity brings both technical and economic challenges. For example, animal cells proliferate slowly and require expensive culture media, thereby, making it difficult to scale up production. Furthermore, as the final product is considerably thick, oxygen diffusion and nutrient supply within the tissue are limited, making it difficult to ensure uniform cell growth and, consequently, a homogeneous final product. (Kirsch et al., 2023)

For these reasons, cultured meat is currently at a less advanced stage of technological development compared to lab-grown milk.

### 6.1.1 Dairy sector assumptions

The projections developed by Kearney (2019) were therefore used to define the evolution of the dairy sector over the period 2025-2040. Since the objective of this research was to assess the effects of changes in market composition, rather than changes in the overall size of the market, total dairy production was assumed to remain constant throughout the considered time horizon. The market shares reported in the report were allocated to traditional milk, plant-based beverages, and lab-grown milk, and were assumed to be representative of production shares. Consequently, they were converted into production volumes and implemented in the model. The obtained trajectory is reported in *Table 6.1*.

*Table 6.1 Dairy sector production share forecast - (Kearney, 2019)*

| | 2025 | 2030 | 2035 | 2040 |
|---|---|---|---|---|
| **Traditional milk** | 90% | 72% | 55% | 40% |
| **Plant-based beverages** | 10% | 18% | 23% | 25% |
| **Lab-grown milk** | - | 10% | 22% | 35% |

The shares for 2025 are consistent with the current Italian market situation. According to GFI Europe (2026), in fact, in 2025 traditional milk accounted for approximately 91,5% of total sales volume, while plant-based beverages accounted for the remaining 8,5%. Therefore, for modeling purposes, these values can be reasonably approximated to the 90% and 10% shares used as the starting point for the trajectory developed by Kearney (2019). (Breewood, 2026; Kearney, 2019)

These assumptions regarding market shares were presented to the experts during the joint interview. Both participants considered the initial adoption rates of lab-grown milk to be relatively optimistic. Particularly, CELL1 stated that «*starting with 10% is very ambitious*» and CELL2 stated that «*I would shift everything forward by at least 10 years*». Furthermore, both interviewees agreed that a gradual market transition might be more plausible, starting from a market share of around 1% and gradually increasing to 5% and 10% over time. These observations led to changes in the time horizon and in the considered production shares of lab-grown milk.

After setting the shares for lab-grown milk, the shares of traditional milk and plant-based beverages shares were recalculated. For both of them, the same trends have been retained, while the values have been proportionally adjusted to take account of the current market penetration of lab-grown milk.

The new trajectories, reported in *Table 6.2*, are kept constant across all the analyzed scenarios.

*Table 6.2 New dairy sector production share forecast*

| | 2025 | 2035 | 2045 | 2055 |
|---|---|---|---|---|
| **Traditional milk** | 90% | 79% | 67% | 55% |
| **Plant-based beverages** | 10% | 20% | 28% | 35% |
| **Lab-grown milk** | - | 1% | 5% | 10% |

### 6.1.2 Beef sector assumptions

Unlike the dairy sector, for which a single reference trajectory was adopted, meat production was varied across the scenarios. This decision reflects the uncertainty surrounding the future evolution of the beef sector and the differing levels of maturity achieved by the technologies for the two alternative products.

Therefore, three possible future trajectories for the beef sector were considered:

1) In the first scenario, beef declines along the same trajectory as that projected for traditional milk, assuming that alternatives are adopted simultaneously in both sectors.
2) In the second scenario, beef remains constant throughout the entire analyzed time horizon, representing a situation in which the transition affects only the dairy sector.
3) In the third scenario, beef follows the same decline projected for milk, but with a time lag. This assumption reflects the greater technological complexity associated with cultivated meat, which could slow their adoption compared to lab-grown milk.

Since the constructed scenarios are based on production volumes, rather that market shares, and since meat alternatives are not considered in this research, the projected market shares reported in *Table 6.2* were converted into relative production levels. The equation below was used:

$$m_n = \frac{s_n}{s_{2025}} - 100\%$$

Where $m_n$ is the percentage decrease in production compared to 2025, $s_n$ is the market share of the current year, and $s_{2025}$ is the market share of 2025 (90%).

With this method, for each scenario the following variations were obtained:

*Table 6.3 Traditional meat production forecast*

| | 2025 | 2035 | 2045 | 2055 |
|---|---|---|---|---|
| **Scenario 1** | - | -12% | -26% | -39% |
| **Scenario 2** | - | - | - | - |
| **Scenario 3** | - | - | -12% | -26% |

The considered trajectories, which represent the differentiating element among the scenarios, are shown in *Figure 6.2*.

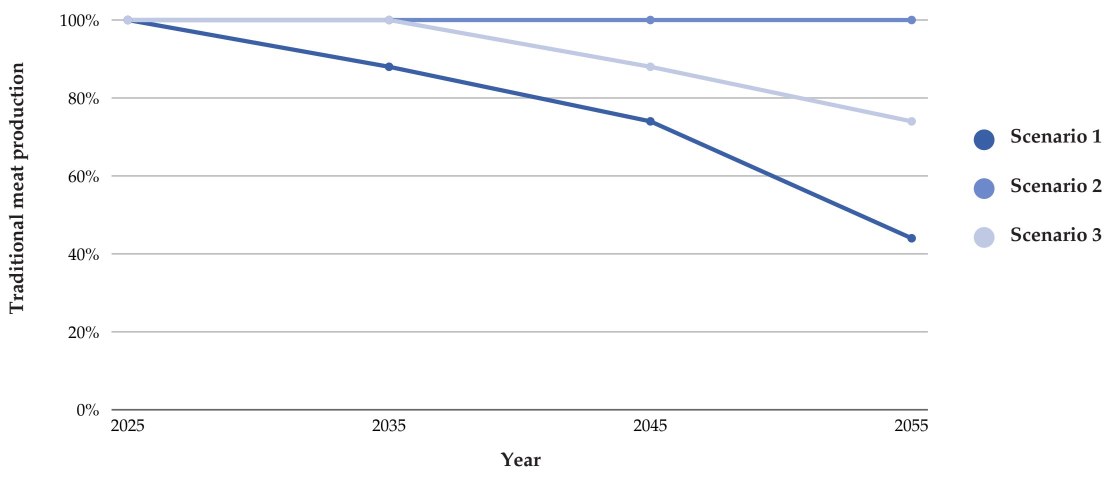


*Figure 6.2 Traditional meat trajectories among scenarios*

### 6.1.3 Scenario definition

By combining the trajectory of dairy products presented in *Section 6.1.1* with the three alternative meat trajectories described in *Section 6.1.2,* three different scenarios were developed.

Each scenario depicts a different trend in protein transition and enables an assessment of how the dairy-beef system responds to different market conditions.

## 4.6 Scenario implementation

Each scenario was implemented in the Excel model presented in *Chapter 5* to quantify the evolution of the main variables characterizing the dairy-beef system.

The considered indicators include meat production from dairy farms, meat production from specialized beef farms, total meat production, land occupation, and electricity generation.

To assess the effects of changes in traditional milk, the equation between the number of dairy cows and milk production described in *Chapter 5* was rearranged, as follows, so that the number of dairy cows depended on traditional milk.

$$DC[head] = \frac{M_{tot}\left[\frac{ton}{year}\right]}{M_{cow}\left[\frac{kg}{head * day}\right]} * \frac{1000\left[\frac{kg}{ton}\right]}{305\left[\frac{days}{year}\right]} \tag{6.1}$$

In this way, the projected traditional milk was used as an input to estimate the number of dairy cows needed to meet that required production and, consequently, to calculate the associated impacts.

The baseline value of traditional milk was set at 13.458.338 tons, corresponding to the total volume of milk produced in Italy in 2025. Since in 2025 traditional milk represented 90% of the total, total dairy production was estimated at 14.953.709 tons. Consequently, in 2025, plant-based beverages, accounting for the remaining 10%, corresponded to 1.495.371 tons. (CLAL.IT, n.d.)

Total dairy production was then multiplied by the projected shares for each year in order to calculate the corresponding volumes of traditional milk, plant-based beverages, and lab-grown milk.

With regard to meat, total meat produced associated with the 2025 baseline dairy production was estimated, with the Excel model, at 546.744.713 kg. This value, which includes both beef coming from dairy herds and beef from beef herds, is consistent with the order or magnitude of bovine meat production reported for Italy in recent years. (Parmigiani, 2025)

The percentages shown in *Table 6.3* were applied to total meat production. For each year, meat produced from specialized beef farms was calculated by subtracting the quantity of meat produced by dairy herds from total meat production. This approach allowed the effects of different meat production trajectories to be assessed across the entire livestock system.

As regards electricity generation, alternative dairy products were not included in the calculations as they do not contribute to biogas production. In addition, their evolution is the same in each scenario. Therefore, changes in electricity generation are exclusively driven by changes in dairy and beef herd sizes.

As regards land occupation, it was calculated by considering the contribution of both traditional products and alternative products. While required land for traditional milk and meat was determined using the model, plant-based beverages and lab-grown milk were assigned, according to literature, land occupation coefficients of 0,40 $m^2/kg$ and 0,05 $m^2/kg$, respectively. Their contribution was then added to the ones of traditional milk and meat production to estimate the total land occupation associated with each scenario. (Berardy et al., 2022; Ghasemlou et al., 2025)

Numerical values obtained for each scenario are summarized in the following sub-chapters.

### 6.2.1 Scenario 1: Simultaneous Transition

Scenario 1 assumes a simultaneous transition in both dairy and beef sectors. Traditional milk and meat production follow the same decreasing trajectory, reflecting a context in which alternative to dairy and meat diffuse at a similar pace.

The numerical values referred to this scenario are reported in *Table 6.4*.

*Table 6.4 Numerical values of Scenario 1*

| | | 2025 | 2035 | 2045 | 2055 |
|---|---|---|---|---|---|
| **Traditional milk** | (000 ton) | 13.458 | 11.813 | 10.019 | 8.225 |
| **Plant-based beverages** | (000 ton) | 1.495 | 2.991 | 4.187 | 5.234 |
| **Lab-grown milk** | (000 ton) | 0 | 150 | 748 | 1495 |
| **Meat (total)** | (ton) | 546.745 | 479.920 | 407.021 | 334.122 |
| **Meat (dairy farms)** | (ton) | 218.698 | 216.511 | 207.763 | 196.828 |
| **Meat (beef farms)** | (ton) | 328.047 | 263.410 | 199.258 | 137.294 |
| **Electricity produced** | (GWh) | 899 | 813 | 713 | 610 |
| **Land occupation** | (000 ha) | 1.748 | 1.734 | 1.669 | 1.588 |

As it can be seen, meat production from dairy farms decreases over the simulated period, falling from 218,7 thousand tons in 2025 to 196,8 thousand tons in 2055. A similar trend, at a higher rate, is observed for specialized beef farms, whose meat production falls from 328,0 thousand tons to 137,3 thousand tons over the same period. *Figure 6.3* shows the evolution of meat production.

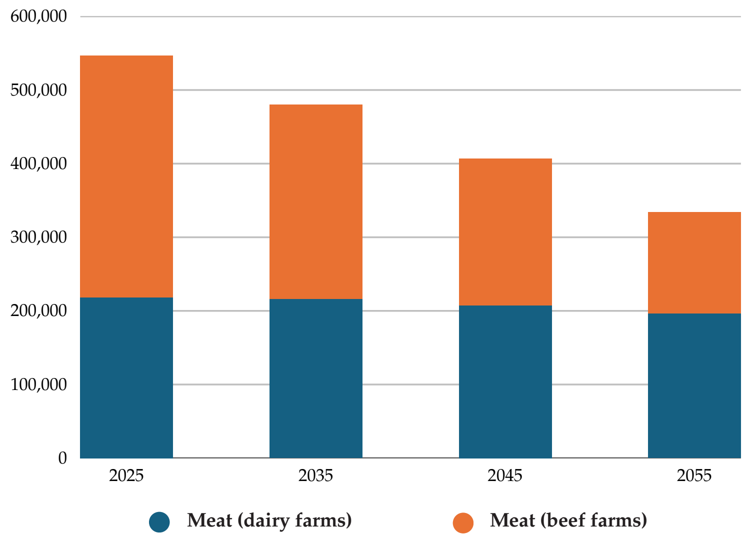


*Figure 6.3 Evolution of meat production from dairy and specialized beef farms under Scenario 1*

The decline in both dairy and meat production also affects the demand for feed and the availability of manure, leading to a decrease in electricity generation and biogas production.

As shown in *Table 6.4*, electricity produced from farms decreases of 32%, going from 899 GWh in 2025 to 610 GWh in 2055.

Land occupation follows a similar trend. The reduction in livestock production decreases the land required for forage cultivation, by approximately 9%. However, the reduction is not proportional to the decline of traditional milk production, because plant-based beverages and lab-grown milk, whose productions are growing, also require land.

### 6.2.2 Scenario 2: Dairy-only transition

Scenario 2 assumes that the transition to alternative proteins occurs exclusively in the dairy sector, while traditional meat production remains constant throughout the simulated period. Under this assumption, the reduction in traditional milk production is not associated to a decline in meat production.

The numerical values referred to this scenario are reported in *Table 6.5*.

*Table 6.5 Numerical values of Scenario 2*

| | | 2025 | 2035 | 2045 | 2055 |
|---|---|---|---|---|---|
| **Traditional milk** | (000 ton) | 13.458 | 11.813 | 10.019 | 8.225 |
| **Plant-based beverages** | (000 ton) | 1.495 | 2.991 | 4.187 | 5.234 |
| **Lab-grown milk** | (000 ton) | 0 | 150 | 748 | 1495 |
| **Meat (total)** | (ton) | 546.745 | 546.745 | 546.745 | 546.745 |
| **Meat (dairy farms)** | (ton) | 218.698 | 216.511 | 207.763 | 196.828 |
| **Meat (beef farms)** | (ton) | 328.047 | 330.234 | 338.982 | 349.917 |
| **Electricity produced** | (GWh) | 899 | 897 | 889 | 879 |
| **Land occupation** | (000 ha) | 1.748 | 1.798 | 1.803 | 1.791 |

As illustrated in the previous section, the contraction of the dairy sector leads to a substantial decrease in meat production from dairy farms. However, since total meat production is assumed to remain unchanged, specialized beef farms are supposed to gradually expand their production to compensate for the reduced availability of meat from dairy farms.

As shown in *Table 6.5*, meat production from dairy farms decreases by 10% over the simulated period. As a result, specialized beef farms increase their production from 328 thousand tons in 2025 to 350 thousand tons in 2055. Consequently, the contribution of specialized beef farms to total meat production becomes increasingly significant over time. This is also evident in *Figure 6.4*, where this trend is depicted.

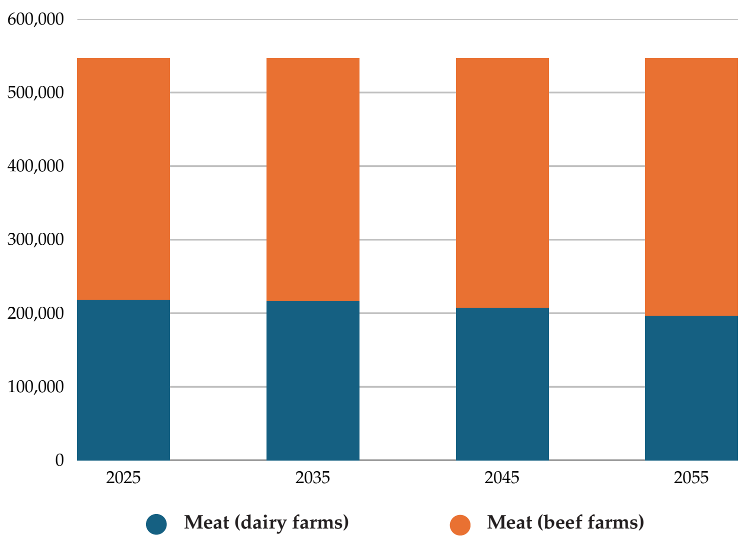


*Figure 6.4 Evolution of meat production from dairy and specialized beef farms under Scenario 2*

The changes in the dairy sector lead to a decline in energy and biogas production. However, the increase in meat production from specialized beef farms offsets this trend.

As regards to electricity production, there is a small decline of approximately 2%, falling from 899 GWh in 2025 to 879 GWh in 2055. In fact, the increased number of beef herds helps maintain the availability of manure and biogas production.

As regards land occupation. Although the replacement of traditional milk with plant-based beverages and lab-grown milk reduces land requirements, the expansion of specialized beef farms compensate this reduction. In fact, beef herds have a higher land occupation, in terms of hectares per animal, compared to dairy herds. As a result, land occupation slightly increases from 1,75 million hectares to 1,79 million hectares by 2055, an increase of about 2%.

Overall, Scenario 2 highlights how the environmental benefits associated with the dairy sector's transition can be partially offset if traditional meat consumption remains unchanged. The results suggest that the evolution of the beef sector plays a crucial role in determining the overall impacts of the protein transition.

### 6.2.3 Scenario 3: Delayed meat transition

Scenario 3 represents a middle ground between the two previous scenarios. While traditional milk production decreases, traditional meat production remains constant during the early years and begins to decline only after a certain delay. This scenario reflects the possibility that meat alternatives may spread more slowly compared to dairy alternatives, due to greater technological complexity and lower consumer acceptance.

The numerical values referred to this scenario are reported in *Table 6.6.*

*Table 6.6 Numerical values of Scenario 3*

| | | 2025 | 2035 | 2045 | 2055 |
|---|---|---|---|---|---|
| **Traditional milk** | (000 ton) | 13.458 | 11.813 | 10.019 | 8.225 |
| **Plant-based beverages** | (000 ton) | 1.495 | 2.991 | 4.187 | 5.234 |
| **Lab-grown milk** | (000 ton) | 0 | 150 | 748 | 1495 |
| **Meat (total)** | (ton) | 546.745 | 546.745 | 479.920 | 407.021 |
| **Meat (dairy farms)** | (ton) | 218.698 | 216.511 | 207.763 | 196.828 |
| **Meat (beef farms)** | (ton) | 328.047 | 330.234 | 272.157 | 210.193 |
| **Electricity produced** | (GWh) | 899 | 897 | 805 | 702 |
| **Land occupation** | (000 ha) | 1.747 | 1.798 | 1.739 | 1.658 |

Until 2035 total meat production remains constant. Therefore, the decline in meat production from dairy farms is offset by an increase in production from specialized beef farms.

After 2035, total meat production begins to decline. As a result, specialized beef farms no longer have to fully compensate for the reduction in meat production from dairy farms, leading to a decrease in beef herds. By 2055, total meat production reaches approximately 407 thousand tons. This dynamic is depicted in *Figure 6.5*.

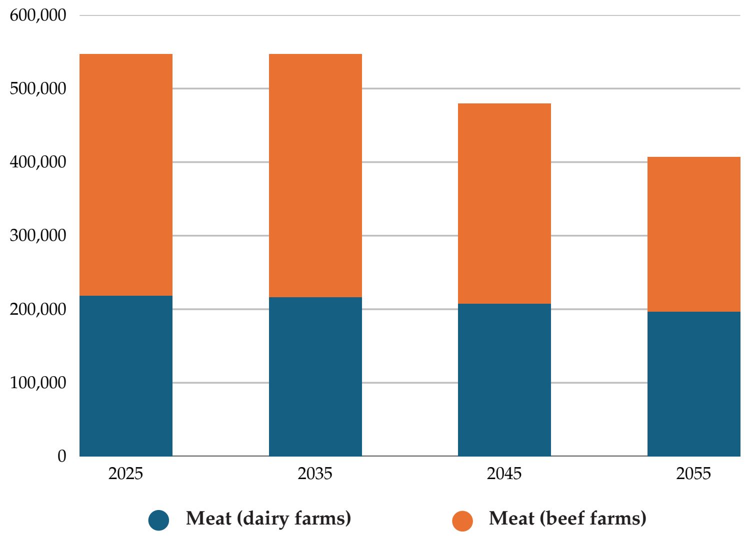


*Figure 6.5 Evolution of meat production from dairy and specialized beef farms under Scenario 3*

As regards to electricity production, it declines from 899 GWh in 2025 to 702 GWh in 2055. As regards to land occupation, it decreases from 1,75 million hectares to approximately 1,66 million hectares, a reduction of about 5%. Both indicators remain between the values obtained under the two extreme scenarios, reflecting the gradual nature of the transition.

Overall, Scenario 3 shows that a compromise between a simultaneous transition in both sectors and a transition limited to dairy products may still generate reductions in livestock-related impacts.

# 4.7 Comparison of scenarios

Significant differences emerge among the scenarios in terms of meat production, electricity production, and land occupation.

## 6.3.1 Meat production

The most significant differences across scenarios are found in meat production. *Figure 6.6* compares the baseline period (2025) with the results obtained in the three scenarios for 2055.

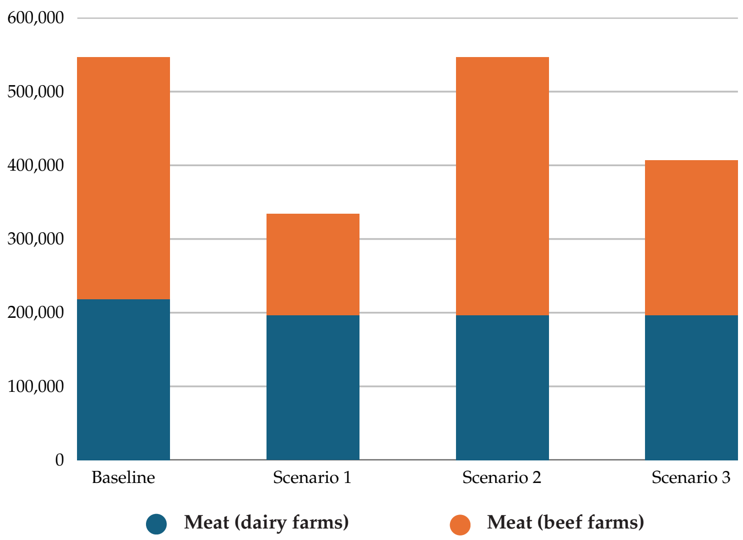


*Figure 6.6 Scenario comparison – Meat production*

Scenario 1, which assumes a simultaneous transition in both the dairy and beef sectors, results in a greater reduction in total meat production compared to the other scenarios. This decline affects both dairy farms and specialized beef farms. In fact, compared to 2025 values, meat production from dairy farms decreases by 10%, while that from specialized beef farms decreases by 58%. Consequently, both sectors experience a reduction in herd size over the simulated period.

In contrast, Scenario 2 assumes that total meat production remains constant at 547 thousand tons throughout the entire period under consideration. Therefore, as dairy herds decline, specialized beef farms increase their herds to offset this reduction.

Scenario 3 represents an intermediate path, reaching approximately 407 thousand tons by 2055. Between 2025 and 2035, as in Scenario 2, specialized beef farms initially increase their herds to offset the reduction in meat produced by dairy farms. However, once meat alternatives enter the market, the amount of meat produced by specialized beef farms decreases. In 2055 it is evident that meat produced from beef herds and total meat produced reach values that are relatively close to those observed in Scenario 1.  This suggests that, despite the delayed transition assumed in Scenario 3, the long-term effects on the livestock system are essentially comparable to those resulting from a simultaneous transition in both the dairy and beef sectors.

### 6.3.2 Electricity generation

*Figure 6.7* compares the evolution of electricity generated from manure across the three scenarios.

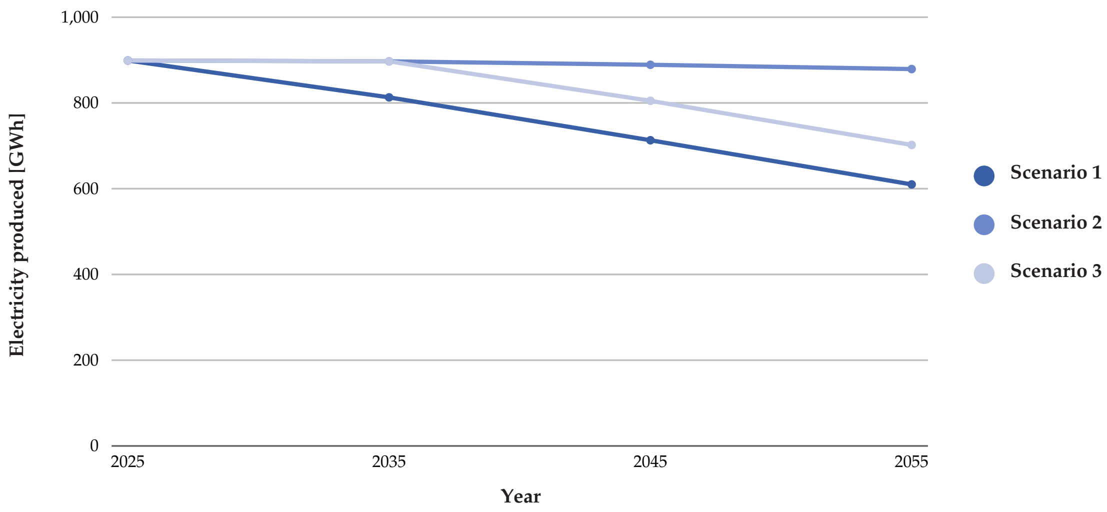


*Figure 6.7 Scenario comparison – Electricity generation*

As it can be seen, Scenario 2 produces the highest amount of electricity, while Scenarios 1 and 3 show a more significant decline over time.

This difference is explained by changes in the number of herds. Since electricity is generated by biogas plants, a larger number of livestock translates into a greater supply of manure and, consequently, higher electricity production.

In Scenario 2, the expansion of specialized beef farms partially offsets the reduction in dairy herds, allowing electricity production to remain relatively high. In contrast, Scenarios 1 and 3 result in a more pronounced contraction of livestock activities and, consequently, lower electricity production.

In all scenarios, electricity production decreases. In fact, the model considers only the electricity generated on-farm and does not account for the energy required to produce milk and alternative dairy products. As livestock number declines, the amount of available manure decreases, leading to lower electricity production. At the same time, the increasing diffusion of lab-grown milk could require additional energy input due to its production process. Consequently, the reduction in electricity production could represent not only a decline in livestock farming activities, but also a shift in energy supply from renewable sources on-farms toward external energy inputs that are not explicitly accounted for in the model.

### 6.3.3 Land occupation

The evolution in land occupation, reported in *Figure 6.8*, follows a similar path compared to that of electricity generation.

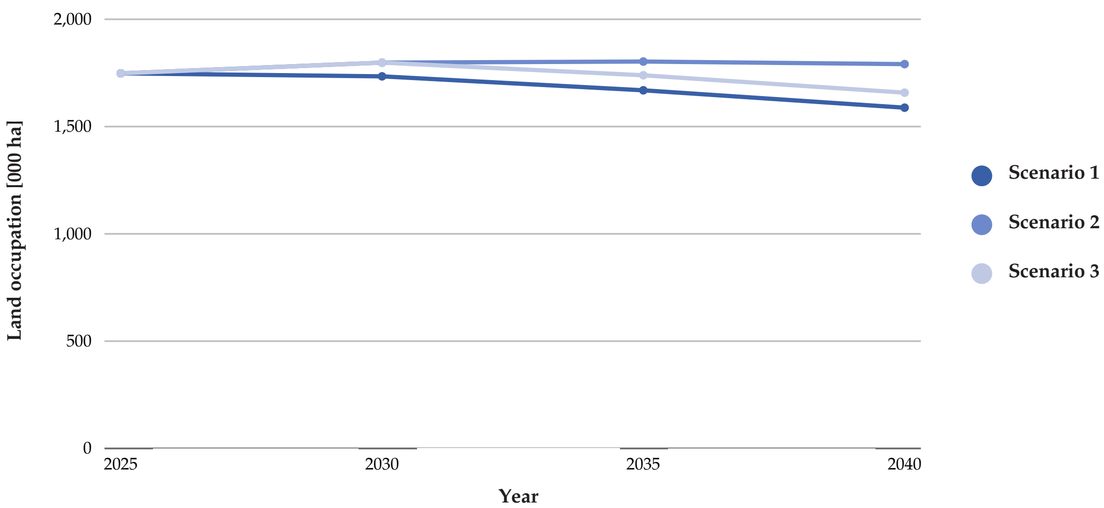


*Figure 6.8 Scenario comparison – Land occupation*

Scenario 1 shows the greatest reduction in land occupation, while Scenario 2 maintains the highest values throughout the simulation period. Scenario 3 once again occupies an intermediate position.

The high land occupation of Scenario 2 is attributed to the expansion of beef herds. Although traditional milk production gradually declines and is replaced by plant-based beverages and lab-grown milk, the additional feed required for beef cattle offsets the land savings associated with the transition of the dairy sector, leading to an increase in the overall land occupation.

In contrast, Scenario 1 considers a simultaneous transition in both traditional milk and meat production. As both dairy and beef herds decrease, feed requirements substantially decrease, leading to the highest reduction in land occupation among the analyzed scenarios.

Scenario 3 yields similar results to Scenario 2, in fact, as it can be noticed from *Figure 6.8*, land occupation in 2055 is similar in both scenarios. Although the delayed transition assumed in Scenario 3, the long-term effects on the livestock system are essentially comparable to those resulting from a simultaneous transition in both the dairy and beef sectors. This is the same dynamics observed for meat production.

# 7 Conclusion

## 7.1 Summary of key findings

The aim of this thesis was to analyze how the spread of lab-grown milk could affect the Italian dairy sector and related sectors.

The results suggest that the adoption of alternatives to dairy products could lead to significant changes in livestock-related activities, with the future evolution of the beef sector emerging as a key factor in determining the extent of these impacts. In fact, the comparison between the scenarios highlights how different assumptions regarding meat consumption can substantially amplify or mitigate the impacts generated by the widespread adoption of lab-grown milk.

The expert validation process also suggested that Scenario 3 represents the most plausible future path. According to the interviewers, the uptake of lab-grown milk is likely to be gradual in the early days and will accelerate once price and quality become competitive with those of traditional milk. Experts also highlighted the close relationship between the dairy and beef sectors, arguing that a decline in traditional milk production would likely be associated with a decline in beef production. However, cultivated meat faces greater technological and consumer acceptance barriers, which could delay its uptake compared to lab-grown milk. Consequently, Scenario 3, characterized by a delayed decline in beef production, was considered the most realistic future trajectory.

At the same time, experts emphasized that the transition should not be seen as a disruptive replacement of conventional livestock farming. In the short and medium term, traditional milk production is expected to remain the main source of milk, as lab-grown milk is currently targeting niche market segments. Furthermore, growing demand for animal-based products in developing economies may continue to support conventional livestock production for many years. Therefore, the findings of this study should not be interpreted as an indication that dairy farming will disappear, but rather as a sign of a gradual transformation of the sector, in which conventional and alternative production systems are set to coexist.

These findings highlight the importance of considering multiple transition pathways when assessing the consequences of alternative proteins, as different assumptions lead to substantially different results. At the same time, the results reveal potential trade-offs associated with the protein transition, particularly between reducing the use of agricultural resources and decreasing renewable energy production on-farms.

Overall, by combining system dynamics, scenario analysis, and expert validation, this research provides a framework to understand the impacs of the uptake of lab-grown milk. Although considerable uncertainty remains regarding the future adoption of cellular agriculture, the findings suggest that its effects could extend beyond milk production alone, affecting the meat, feed, and energy sectors as well.

## 7.2 Limitations of the study and suggestions for future research

While this study provides valuable insights into the transition to lab-grown milk, several limitations should be acknowledged.

First, the study focuses on the Italian context. Although Italy is a pertinent case study, due to the importance of its dairy sector, the results may not be directly applicable to other countries. Future research could conduct comparative studies to assess how different geographic contexts influence transition pathways.

Second, the study uses a system dynamics approach that relies on some assumptions. Although these were introduced to ensure consistency and plausibility, some uncertainties remain, particularly regarding the evolution of lab-grown milk in the upcoming years. In this regard, further research could improve and validate the model based on emerging data.

Finally, the scope of the model only includes the interconnections between dairy production, meat production, feed demand, and biogas production. Other factors, such as GHG emissions, water and energy consumption, economic or international trade dynamics, were not taken into account. Future research could expand the analysis of the system to provide a more comprehensive overview of the impacts lab-grown milk adoption.

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# A Interview Protocol

## A.1. Dairy farmers interview protocol

Q1. Could you briefly describe your company and how you started working in it?

Q2. Could you describe how the calves are managed on your farm? To what extent does their sale contribute to the farm's revenue?

Q3. As for cull cows, after how many years are they usually slaughtered, and for what reasons? To what extent does their sale affect the farm’s revenue?

Q4. Which type of feed do you use? What percentage do you produce on-farm, and what percentage do you buy off-farm?

Q5. How does manure management work?

Q6. How has the dairy sector and, more specifically, your company changed in recent years? In your opinion, how will the sector change over the next 10-15 years? If milk consumption were to decline steadily, what would change at your company?

## A.2. Beef farmer interview protocol

Q1. Could you briefly describe your company and how you started working in it?

Q2. Could you describe how the production cycle works in your farm, from calves to slaughter?

Q3. In your opinion, does the meat supply chain depend on the dairy supply chain? Why?

Q4. How has the beef sector and, more specifically, your company changed in recent years? In your opinion, how will the sector change over the next 10-15 years?

Q5. How are consumer habits changing? Are meat production and sales stable, or are they changing?

## A.3. Sales agent interview protocol

Q1. Could you briefly describe what your role consists of and which stakeholders in the supply chain you interact with most frequently?

Q2. How has the dairy industry and, more precisely, dairy farms changed over the past 10-15 years? What are the main factors that have driven these changes?

Q3. In your opinion, does the meat supply chain depend on the dairy supply chain? Why?

Q4. What other sectors is the dairy sector connected to?

Q5. How do you see the dairy sector over the next 10-15 years?

## A.4. Cellular agriculture experts interview protocol

Q1. Do you consider the assumed market adoption percentages of lab-grown milk and the time horizon realistic? If not, how would you change them? Do you think it is plausible to assume that lab-grown milk might follow a similar adoption pattern to that of cultivated?

Q2. Among the presented scenarios, which one do you consider the most plausible? Which scenario do you consider the least plausible? Why?

# B Interview transcription

In this section are reported the main and most useful parts of the interviews which were recorded and transcribed. Here they are reported in Italian, the language in which these were performed.

## B.1. FARM1 interview transcription

**Q1**

Noi abbiamo 300 capi in mungitura e, in totale, in base all'ultimo censimento, sono 850. Alleviamo la razza frisona e il latte che otteniamo va per la produzione di Gorgonzola. La media produttiva è sui 30 litri a capo al giorno. Quindi, considerando le 300 vacche in lattazione, circa 90 quintali di latte al giorno.

Le mucche vengono munte due volte al giorno. La mattina arriva il camion che ritira il latte che viene conservato in una cisterna sotto stretto controllo.

In passato, raramente superavano i 20 litri per capo al giorno. Oggi, invece, sono più produttive grazie anche all'alimentazione studiata. Tutto sta anche nel benessere animale: più sta bene e più produce.

**Q2**

Dunque, il traguardo è che ogni mucca faccia un vitello all'anno. Poi non si riesce mai perché c'è il problema dell'ingravidamento: ci sono delle vacche che si ingravidano con facilità e altre meno. Nel 2024 abbiamo avuto circa 400 parti.

Tieni conto che devono fare i vitelli per produrre il latte. Infatti, il picco del latte comincia dopo il parto e poi pian piano scende, fino a quando arriva il settimo mese di gravidanza, allora addirittura non la mungi più per due mesi. In questi due mesi vengono chiamate "vacche asciutte"(sono quelle dal settimo mese di gravidanza in poi).

Per quanto riguarda l'inseminazione, nel mio caso c'è una differenza importante: fecondo tutte le manze, cioè i bovini che hanno raggiunto l'età per essere fecondati, ma che non hanno ancora partorito, e, quindi, non producono ancora latte con seme sessato. Così nascono quasi solo femmine; questo viene fatto perché le femmine servono per la produzione di latte, mentre i maschi vanno all'ingrasso. Invece, le vacche che hanno già partorito (non primipare) seguono la media normale.

Ecco, le vacche asciutte stanno in un box grande comune. Quando la vacca sta per partorire viene spostata in un box singolo. Noi abbiamo dieci box, uno in fila all'altro. Quindi partoriscono lì e rimangono con il loro vitello per non più di due giorni per due motivi: se resta di più, la vacca si abitua a dare il latte al vitello ed è più difficile mungerla e il vitello si abitua a prendere il latte dalla mamma e non accetta più il biberon.

Dopo i due giorni, la vacca va nel reparto di mungitura e i vitelli vanno in gabbiette singole. Queste sono 40 gabbiette singole (corridoio centrale, 20 di qui, 20 di là) in un'unica stalla. Sono singole per far sì che i vitelli non si passino le malattie tra di loro e per tenerli meglio sotto controllo. […] Comunque, il maggior rischio è nel primo mese.

Le gabbiette singole sono rialzate da terra un mezzo metro. Sotto c'è un reticolato grosso che supporta il peso del vitello e sopra tanta paglia, di modo che il vitello non dorme sul ferro. Perché? Perché in questa maniera le urine colano e vanno giù. Quindi lui sta sull'asciutto. Ecco, aggiungo che di questi reparti ne ho due: uno per le femmine e uno separato per i maschi.

Per quanto riguarda i maschi, restano nelle gabbiette, poi, ogni circa 15 giorni arriva un camion a prenderli. I vitelli maschi abili, sani e con il peso giusto (circa 15-45 giorni di età) vengono pesati, venduti e portati nei centri di ingrasso. Lì crescono fino a 4-5 quintali e poi vanno al macello. Quindi il maschio resta in azienda al massimo un mese. Una volta raggiunto il macello, viene messo all'ingrasso ed entro 20 mesi al massimo finisce il ciclo di vita e viene macellato.

Per quanto riguarda le femmine, restano nelle gabbiette singole per massimo 50-60 giorni e poi le sposto. Lì hanno acqua pulita, latte ricostituito e un mangime speciale perché ricco di fibra per preparare il rumine. Dopo i due mesi, devi metterle in box a terra, in gruppetti da 4-5-6 al massimo. Sempre avendo a disposizione acqua pulita, fieno e dei mangimi speciali. Fino a tre mesi rimangono lì. Al terzo mese vengono svezzati: non ricevono più il latte ricostituito, ma passano all'alimentazione solida. Da lì in poi vengono spostate in altri reparti con box diversi. Circa una volta al mese cambiano reparto perché a seconda dell'età cambia l'alimentazione. Un vitello che nasce oggi, tra due anni è mucca e partorisce a sua volta. Intorno ai 14-15 mesi di età le manze vanno a finire in un reparto sorvegliato perché lì comincia la fecondazione. Quindi, bisogna individuare il calore e fecondarle al momento giusto.

Per quanto riguarda il ritorno economico, ti faccio un esempio, sabato sono andati via 11 vitelli maschi con un peso medio di 48 kg ciascuno, quindi circa 500 kg in totale; per questi mi hanno dato iva compresa 4 €/kg. Il prezzo varia tutti i mesi. […]

**Q3**

In media una vacca viene riformata dopo 4 parti. Rimane comunque una media però. Infatti, c'è la vacca che dopo il primo parto non va perché non fa latte per mille motivi, e poi c'è la vacca che al sesto parto funziona ancora. I motivi comunque variano da vacca a vacca, se hanno malattie e se non sono più produttive. Poi, vengono mandate al macello. Tieni conto che oggi la quasi totalità della carne va ad un macello che si chiama Inalca, che è uno dei più grandi macelli in Italia e anche in Europa […].

Per quanto riguarda il ritorno economico, quando vanno in questo macello ci sono degli esperti il cui lavoro è quello di classificare gli animali in mezzena morti. […] In base alla classifica che gli danno, la pesano e gli danno un prezzo. Io vengo pagato in base a quello. Comunque, tanto per darti un'idea, nel 2024 le vacche da macello avevano un buon prezzo: mediamente le vacche andavano da 1000 a 2000, fai 1500 € di media. Poi, la carne che ne ricavano va tutta per gli hamburger. È carne buona comunque e non trattata, perché come ti dicevo è molto controllata.

**Q4**

L'alimentazione oggi è studiata. Dentro ci sono le giuste proteine, la soia, tanta fibra. Noi, in Italia, compriamo una quota sbalorditiva di mais per bestiame.

**Q5**

Noi li accumuliamo in delle vasche e poi nel momento giusto le utilizziamo per i campi.

**Q6**

Allora, il latte in questo momento sta scendendo di prezzo perché dicono che ce n'è troppo. Il motivo non te lo so dire. Però, che fa paura in Italia, è che ormai non c'è più il confine tra Italia e altri paesi in Europa […]. Così le grandi corporazioni vanno a comprare quello che costa meno e adesso il latte italiano è penalizzato perché l'Italia ha i suoi costi. Quando in Europa c'è qualche nazione che produce a meno, basta, comprano lì, ma è normale, ora si cerca anche la convenienza.

Il problema è questo ed è già successo un po' di anni fa. Negli anni '90 c'è stata una "ribellione" in Europa per il prezzo del latte, perché avevano inventato la quota latte. Per cui, hanno preso un anno di riferimento negli anni '80, adesso non ricordo bene quale, e hanno detto "tu azienda tal dei tali, abbiamo stabilito che la produzione che hai avuto negli anni 87-88, questa è la tua quota latte. Tu non devi fare un litro di latte in più". E lì ci hanno messo in crisi. Perché, nel tempo, tutto migliora e si va sempre più avanti. Nel campo dei bovini, a furia di selezione genetica e a furia di studio dell'alimentazione, la produzione aumenta. Se tu metti un limite è come tornare indietro, perché tu per la tua vita vai avanti e migliori sempre. […] Se dicessero a me una cosa del genere, la prima cosa che ad oggi farei sarebbe diminuire i miei dipendenti. Vedi che è tutto legato?

Se tu mi metti in condizioni di fermarmi o andare indietro, invece di avere 5 o 6 dipendenti ne devo avere di meno. E devo avere meno vacche perché altrimenti non sono in grado di gestirle. Poi, se non ho entrate non faccio investimenti. Vedi cosa vuol dire? La catena economica è tutta legata.

Io, nel mio caso, mi metto dalla parte del datore di lavoro. Faccio lavorare quattro persone, ma ho bisogno di guadagnare per magari assumere una persona in più e magari allungare la stalla e magari cambiare prima un trattore. Ma se non guadagno, di tutto questo non faccio niente. Bisogna tagliare tutto, ma se tutti tagliamo si ferma il mondo. Ecco, è lì la difficoltà.

La filiera del latte è tutta penalizzata comunque. Tieni conto che il prezzo del latte prima era di 0,60 €/litro. Ora però sta scendendo, si prevede che per marzo scenderà a 0,52 €/litro. […]

Comunque, ti dico una cosa per esperienza mia. Tu quando le cose non vanno tanto bene, trova il sistema di andare avanti ugualmente. Perché è un proverbio, ma è la verità. Un mercato che va a terra prima o poi si risolleverà. E quando si risolleverà tu dovrai essere pronto. Quindi non devi tanto demoralizzarti quando le cose non vanno bene, ma devi resistere ed essere pronto a fiorire quando le cose andranno bene. […]

Un'altra cosa che ti dico è che è importante diversificare. Per dirti, il mio fatturato è prima il latte, poi il riso e dopo la carne da macello. Voglio dire che nel momento in cui tu fai solo latte e ti produci tutto il mais per la tua stalla e non produci più riso, devi fare attenzione perché quando la tua fonte di guadagno è una sola, se per caso va male, si creano problemi. […]

## B.2. FARM2 interview transcription

**Q1**

Dunque, noi abbiamo circa 800 vacche, di queste 320-350 sono in lattazione. Per quanto riguarda la produzione chiaramente dipende da ciascuna. Comunque, per essere produttiva deve farne almeno 30-32 litri al giorno. Il latte che mungiamo, poi, lo diamo ad una cooperativa che lo distribuisce. Adesso sta andando per il Grana, ad esempio.

**Q2**

Dunque, le vacche in lattazione sono 350, quindi calcola 350 vitelli ogni anno circa. Se fai la media degli ultimi 5 anni, ti dico 65% femmine e 35% maschi nati. Poi, ora abbiamo iniziato ad usare il seme sessato sulle primipare, quindi aumenta il numero di femmine.

Una volta nato, il vitello viene separato dalla madre, indipendentemente dal fatto che sia maschio o femmina, e viene scolostrato. L'obiettivo è farlo entro le sei ore dalla nascita. Non sempre tutti riescono, perché a volte il parto avviene in momenti complicati o ci sono altre difficoltà, però cerchiamo comunque di stare dentro questo limite.

Da qualche tempo abbiamo iniziato anche la banca del colostro, che è il primo latte prodotto dalla vacca e che viene dedicato solamente al vitello senza entrare nel circuito del latte destinato alla vendita. Dunque, una volta passate le sei ore, il colostro viene raccolto. Se è di ottima qualità e ha tanti anticorpi viene congelato. In questo modo, in caso di carenza di un buon colostro, si può usare quello. Questo si dà sia al maschio che alla femmina.

Quindi, ti riassumo tutto. Dopo la nascita, il vitello non viene subito separato dalla madre, ma rimane con lei per circa mezz'ora, perché in questo tempo deve ricevere le prime leccate, che servono ad asciugarlo bene e ad attivare bene i suoi organi. Poi, viene spostato in una gabbietta singola. Questo serve sia a evitare la trasmissione di malattie sia ad evitare lo schiacciamento. Cosa vuol dire? Se si lascia un vitello appena nato in mezzo a dieci o quindici bovine, basta che una si muova di corsa e il vitello rischia di morire. Per questo viene messo da solo.

Poi, le vitelle femmine restano in azienda e si portano allo svezzamento e oltre.

Invece, i vitelli maschi, a partire dai 15 giorni di vita in su, vengono venduti ad altri allevamenti dove verranno poi allevati all'ingrasso: possono diventare vitelli da carne bianca oppure vitelloni da ingrasso. Quello che comunemente trovi al supermercato come vitellone o vitello da carne bianca deriva da vitelli maschi.
Noi li vendiamo tramite un commerciante che poi li distribuisce negli allevamenti da ingrasso. […]

A livello economico, ora, tra vitelli e vacche da macello si parla di circa 10-12 mila € al mese, quindi intorno ai 120 mila € l'anno. Se lo consideri però su un fatturato aziendale […] è una quota non molto rilevante. Adesso una vacca da macello viene pagata 1500-1600 €, mentre fino ad un anno e mezzo fa prendevi 700 €. Lo stesso vale per i vitelli, che oggi rendono di più.

**Q3**

Per quanto riguarda le vacche a fine carriera, non esiste più un numero fisso di lattazioni o di anni. Oggi la logica è: se l'animale rende, lo tieni; se non rende, va al macello. Rendere vuol dire che deve ingravidarsi in tempi brevi e produrre latte. Se una vacca non rimane gravida o non rientra nella media produttiva aziendale, mantenerla costa più di quello che produce. Ci sono troppi costi adesso e quindi i parametri che devono rispettare si sono abbassati.

Per esempio, la primipara, cioè la vacca al primo parto, se produce meno di 30 litri di latte al giorno è facile che venga mandata al macello. Ci sono vacche di secondo parto che vengono eliminate, ma anche animali di quinto o sesto parto che invece restano in stalla. Pensa che la media nazionale di lattazioni è molto bassa, circa due parti, e questo è preoccupante, perché più a lungo una vacca resta in stalla più si riesce a ripagare l'investimento fatto su di lei. Quindi, tu gli offri un tot di benessere a questo animale, ma ti torna indietro. Questa è la filosofia dei nuovi allevatori: investire nel benessere animale per far sì che la vacca rimanga in stalla più a lungo. In genere l'animale inizia a rendere davvero dalla seconda o terza lattazione. Ci sono vacche che appena dopo il parto producono 32-33 kg per mungitura, arrivando a circa 60 kg al giorno. Rispetto al passato, queste produzioni sono possibili grazie alla selezione genetica. […]

Il problema è che spesso non si riesce a fare tutto quello che si vorrebbe per farle stare bene, perché i costi sono diventati molto elevati. Ti faccio un esempio, quando abbiamo costruito la stalla nuova, tra il 2007 e il 2008, il costo era di circa 5.000 € a capo. Oggi siamo a circa 11.000 € e diventa molto più difficile rientrare dell'investimento.

Comunque, noi, anche le vacche a fine carriera le vendiamo a un commerciante che poi le manda al macello. Complessivamente, tra vitelli e vacche, il valore mensile è più o meno quello che ti dicevo prima. Un anno e mezzo fa, però, era circa la metà: i vitelli venivano pagati circa 1 € al chilo, quindi 40 € per un vitello da 40 kg, mentre una vacca valeva 700 €. Oggi i vitelli vengono pagati 2,50-3 € al chilo.

**Q4**

Noi compriamo soia, mangimi finiti, farina di mais e una parte del fieno. Il resto del foraggio lo facciamo noi in campagna. Facciamo un miscuglio che mettiamo in trincea. Le trincee sono delle strutture rettangolari e lunghe dove si mette il prodotto che è in campagna e che viene raccolto mediante una trinciatura.

Tieni conto che più roba noi produciamo, meno roba compriamo. Però sei costretto per forza a comprare i mangimi con integrazione e la soia. E parte dalla farina, perché non riesci a produrti tutto in casa. […]

La spesa di mangimi non è indifferente, è elevata. Poi è logico, più produci, meno compri, meno spendi.

**Q5**

La distribuzione dei reflui viene eseguita due volte all'anno sui terreni in campagna. Non avendo abbastanza campi abbiamo degli accordi con delle aziende vicine per i loro campi.

**Q6**

Allora, l’azienda è cambiata soprattutto da quando ho assunto una nuova persona, ormai 2 anni fa. […] Innanzitutto prima venivano munte circa 180 vacche, poi ho ritirato una stalla vicina che aveva cessato l’attività e siamo passati a mungere tra le 300 e le 320 vacche. Quindi per forza avevo bisogno di una persona in più.
Invece, se parliamo del settore in generale, è cambiato molto negli ultimi anni. In un periodo il latte veniva pagato bene, poi il prezzo è stato abbassato di circa 7-10 centesimi al litro. E per gli allevatori è un problema. Gli allevatori, infatti, subiscono il prezzo sia quando acquistano i mezzi di produzione sia quando vendono il prodotto, senza poter contrattare. Noi siamo l'unico settore così.

Comunque, l'unica cosa, secondo me, dove c'è proprio la differenza è su quello che tu compri al supermercato che costa di più. […] Il problema, secondo me, non è la mancanza di latte, ma il sistema di distribuzione e di remunerazione. Perché di latte in giro adesso ce n’è.

Cioè, le aziende stanno diminuendo anche a livello europeo. In Olanda sono stati abbattuti molti capi per motivi ambientali, per i nitrati; in Germania e Francia manca il ricambio generazionale. Questo succederà anche in Italia. […]

Comunque, io penso che il consumo di latte non possa diminuire, non ci credo. Per un semplice motivo: la popolazione mondiale è destinata all'aumento. Noi siamo un settore primario e dobbiamo dare da mangiare alle persone.

Nei prossimi anni, secondo me, ci saranno diversi cambiamenti ancora. Cioè, le stalle diventeranno sempre di meno, ma diventeranno sempre più grosse. Il numero degli animali rimarrà quello però le popolazioni aumenteranno. […]

## B.3. FARM5 interview transcription[4]

**Q1**

Noi siamo un allevamento di bovini da latte e siamo soci di un consorzio da praticamente 70 anni. Fondamentalmente il nostro latte viene destinato a due indirizzi prevalenti: grana e gorgonzola.

**Q4**

Noi cerchiamo di essere il più indipendenti possibili, chiaramente è praticamente impossibile. Produciamo mais, cereali e pastone, poi produciamo i nostri foraggi, quindi fieno ed erba medica.

[4] Due to time constraints during the interview, questions 2,3 and 5 were omitted. Priority was given to questions 1,4 and 6, as sufficient in-depth data regarding the topics of questions 2,3 and 5 had already been gathered from the previous interviews.

Chiaramente ci dobbiamo avvalere anche un po' di quello che c'è al di fuori perché fisicamente ci sono dei prodotti che non possiamo produrre, ad esempio la soia. Per dirti, la quota amidacea e quindi energetica della razione degli animali, riusciamo a produrla noi al 50%. Dai mangimisti compriamo soprattutto la parte proteica. Loro ci forniscono anche una consulenza su come alimentare gli animali per avere la massima efficienza anche in termini di conversione di alimento per la produzione del latte.

La buona cosa è che più riusciamo ad autoprodurre i nostri prodotti, più siamo certi di quello che gli diamo, meno costi abbiamo. Infatti, per noi autoprodurre mais e cereali, soprattutto cereali, ha un costo molto inferiore che comprarceli. Chiaramente va del nostro lavoro, quindi sono nostre ore lavorative […] però, comunque, ci costa molto meno che andare sul mercato e avere l'incertezza. […]

**Q6**

Guardando gli ultimi anni, da quanto siamo entrati noi, abbiamo cambiato la configurazione dell'azienda: l'organizzazione della campagna, l'organizzazione degli animali e dell'alimentazione e abbiamo implementato nuove tecnologie.

Abbiamo come ambizione di fare un ampliamento nel prossimo anno compatibilmente con il mercato del latte, però abbiamo già fatto dei business plan affinché si possa fare. Anche visto il prezzo del latte abbiamo fatto un piano abbastanza conservativo. Abbiamo pensato anche ad ampliamenti più forti, però questo futuro non ci dà molte tranquillità. Facciamo una via intermedia in questo momento e poi vedremo, facciamo un passo di piccolo e poi vediamo di crescere passo per passo.

Stiamo pensando anche ad un altro robot, perché ovviamente un'altra macchina ci permetterebbe di avere circa un 50% in più di animali in mungitura. Altre cose, questo cambiamento comporterebbe avere capanni nuovi, strutture nuove e comunque tutte strutture più grandi, pensate meglio anche per un discorso di adeguamento al benessere animale. Abbiamo ormai dei regolamenti che ci impongono, giustamente, determinati standard in cui tenere gli animali. Anche perché poi questi animali qui, sono un po' come degli atleti: devi metterli nella miglior condizione possibile per avere il miglior ritorno economico e la miglior performance. Se li tratti bene ti danno tanto, però vanno trattati bene: ambienti alti, ampi, luminosi, bisogna investire in tecnologia che serve a monitorarli, a migliorarne la performance.

Se devo guardare, invece, il mercato nei prossimi 5 o 10 anni, vedo un mercato del latte che può essere solo trainato dalle nostre DOP. Pensare di fare latte alimentare ormai è quasi diventato anacronistico: se ne consuma sempre meno, non c'è tanto mercato, e questo vuol dire fare veramente la battaglia al prezzo, e non è quello che dobbiamo fare noi, soprattutto in Italia.

Se devo vedere la proiezione della mia azienda tra 10 anni, è pensare di slegarsi da questo mercato. Non nascondo che mi piacerebbe essere più indipendente e trasformare qui in azienda il prodotto e venderlo direttamente. Io penso che alla lunga un'azienda come la mia, che non è un'azienda che punta a diventare una grande industria, ma è un'azienda che punta all'essere molto efficiente e molto attenta anche all'animale in sé, credo che bisogni andare più in quella direzione lì. Io mi augurerei di andare in quella direzione, trasformare qui, vendere qui online e trovare dei canali di vendita.

Chiaro che implica modificare una cosa che per 70 anni è stata fatta in una certa maniera. Lì vuol dire stravolgere, mettere delle persone che si occupano anche dell'aspetto del marketing, dell'aspetto delle vendite, dell'aspetto della trasformazione eccetera. Però mi auspicherei di andare in quella direzione. Io non voglio più essere legato al mercato del latte, io voglio valorizzare il mio prodotto, perché comunque ci metto del lavoro, non poco, e voglio valorizzarlo come si deve, anche per una soddisfazione personale, al di là del ritorno economico. […]

## B.4. FARM6 interview transcription

**Q1**

[…] . In questa stalla ci sono circa 500 vacche in mungitura e un centinaio in asciutta. La rimonta, invece, viene gestita in un'altra azienda, sempre nostra. Lì abbiamo concentrato tutto l'allevamento della rimonta, la sala parto, e il post-parto, cioè tutte le fasi più delicate. Proprio per questo lì abbiamo costruito una struttura nuova, fatta apposta. […]

Il latte che produciamo viene conferito a una cooperativa di allevatori e poi viene collocato in base alle richieste del mercato. […] Tieni conto che in questo momento siamo intorno ai 170 quintali (35 kg per capo al gg) con circa 460-470 capi in lattazione. Ci sono stati periodi in cui producevamo di più, ma in questa fase il mercato è "pesante" il caseificio ci chiede di non aumentare la produzione. Di conseguenza cerchiamo anche di eliminare gli animali meno produttivi, proprio per evitare di aumentare la quantità prodotta.

**Q2**

Allora, la vacca partorisce nell'altra azienda. Il vitello viene colostrato e nelle prime dodici ore viene alimentato con il latte della madre, perché è quello più ricco di immunoglobuline e di sostanze utili per l'alimentazione, per lo sviluppo e soprattutto per la protezione, cioè gli anticorpi contro le patologie tipiche di questa fase. Dopo di che il vitello viene tenuto in una gabbietta singola per circa 15-20 giorni, perché è il periodo più delicato. Lo alleviamo singolarmente in modo da poterlo osservare bene e intervenire subito se compaiono problemi, soprattutto respiratori o intestinali, che sono i più frequenti in quel momento. Successivamente, viene spostato in box multipli da 10-12 capi e alimentato con un'allattatrice automatica. L'alimentazione così viene programmata con una curva di somministrazione: si parte con poco latte, si arriva a un picco e poi si scende gradualmente. In questa fase ci rimane circa un paio di mesi. Finita questa fase, esce dall'allattatrice automatica e viene svezzato. Per cui, non riceve più latte ricostituito ma solo mangime secco, con l'aggiunta eventualmente di un po' di fieno e paglia per abituarlo alla ruminazione. Questo dura ancora circa un mese. Poi, intorno ai quattro mesi, passa a una razione "miscelata" che è già molto simile a quella che avrà nel resto della rimonta, perché cominciano a esserci anche insilati e altri foraggi.

In generale i maschi vengono venduti a 15-20 giorni di vita.
Per quanto riguarda le femmine, noi teniamo le femmine frisone destinate alla rimonta, mentre una parte degli accoppiamenti la facciamo con tori da carne. Questo avviene su animali che, dal punto di vista genetico, sono meno interessanti. Per cui, invece di ottenere figlie da questi soggetti, utilizziamo il seme da carne, perché il vitello nato da quell'incrocio viene valorizzato meglio alla vendita come "baliotto", cioè nei primi 15-20 giorni.

Tieni conto che la grande maggioranza viene inseminata con piani di accoppiamento e tori di razza Frisona, in modo da migliorare le caratteristiche e ridurre eventuali difetti degli animali. Poi c'è una politica specifica sulle primipare, che sono la parte più fertile dell'allevamento: sulle prime fecondazioni usiamo seme sessato per avere più femmine. Questo ci consente, come dicevamo, di usare seme da carne sulle vacche, primipare o pluripare, meno interessanti dal punto di vista genetico, perché con il seme sessato aumentiamo comunque sempre la quota di femmine nate in azienda (oltre il 50% che si avrebbe normalmente). Avendo più femmine disponibili per la rimonta, possiamo permetterci una quota di fecondazioni con toro da carne. In questo caso, anche se nasce una femmina, spesso viene venduta nelle prime settimane di vita. In questo momento siamo intorno al 10% (inseminazioni da toro da carne) grossomodo.

Le manze vengono poi gestite per raggiungere le dimensioni adatte a essere fecondate una prima volta intorno ai 14-15 mesi, con l'obiettivo di avere il primo parto intorno ai due anni. Se va tutto bene, si riesce anche a 23 mesi, se invece servono più fecondazioni per ottenere la gravidanza si arriva a 25-26 mesi. L'obiettivo principale, comunque, è avere una primipara che partorisca a due anni. Una volta partorito, la vacca resta nella struttura "rimonta/parto" per i primi due o tre mesi e poi viene spostata in questa stalla, dove ci sono solo animali adulti in lattazione e la prima parte dell'asciutta.

Per quanto riguarda il reddito aziendale, incide poco: qualche punto percentuale. Negli ultimi anni il mercato li ha un po' rivalutati e si vendono ad un prezzo più alto, ma resta comunque una voce marginale.

**Q3**

Tendenzialmente noi facciamo fare tre parti. Dopo il terzo parto fecondiamo solo gli animali che meritano particolarmente, cioè quelli che hanno avuto buone performance produttive e che sono interessanti per noi dal punto di vista genetico e morfologico. Più un animale è vecchio, infatti, più il parto, che è un momento delicato, può portare complicazioni. Dopo tre parti, massimo quattro, di solito non fecondiamo più.

Detto questo, spesso l'animale resta in azienda ancora a lungo, perché può avere una lattazione molto lunga e viene venduto solo quando la produzione di latte cala a un livello che non è più sostenibile. A quel punto, le vendiamo ad un commerciante che le porta al macello e la carne entra nella filiera della carne. […]

**Q4**

Noi autoproduciamo i foraggi: silomais, erba medica ed erbasilo. Dal mercato, invece, acquistiamo sia materie prime, come farina di mais e farina di estrazione di soia, sia un nucleo ristretto che contiene tutti gli oligoelementi, le vitamine e tutto ciò che serve per l'integrazione e per una corretta alimentazione del bestiame.

**Q5**

Il liquame viene valorizzato tramite un impianto di biogas, che adesso è stato convertito a biometano. Il liquame entra dalla stalla, viene pompato verso l'impianto, contribuisce alla produzione di biogas insieme ad altre biomasse, e poi il digestato che esce dal sistema viene utilizzato come concime per i campi. I campi, a loro volta, producono foraggi per il bestiame. È un sistema circolare.

**Q6**

Negli ultimi anni abbiamo investito molto nelle stalle, soprattutto nelle fasi delicate, cioè preparto e post-parto. Abbiamo creato un'unità dedicata, con ambienti molto confortevoli e con molto spazio per animale a disposizione, proprio per ridurre i problemi al parto sia per la vacca sia per il vitello. In quella struttura abbiamo anche fatto tutte le migliorie possibili per rendere lo svezzamento e la cura dell'allevamento della rimonta il migliore possibile, perché nei decenni scorsi la rimonta, non essendo produttiva, veniva spesso trascurata. Oggi invece la filosofia è l'opposto: il vitello di oggi è la vacca di domani. Se metti tutte le attenzioni sul vitello, domani avrai una vacca che entra nel ciclo produttivo nelle migliori condizioni.

Per quanto riguarda il futuro, invece, se me lo avessi chiesto l'anno scorso avrei detto che le aspettative erano molto positive: avevamo vissuto una fase in cui il latte era valorizzato e ben pagato; quindi, c'erano tutte le ragioni per essere ottimisti. Purtroppo, però, il mercato del latte, per noi che siamo l'anello debole della filiera, non è mai stato costante. È sempre stato molto altalenante. Negli ultimi mesi dell'anno scorso queste ottime premesse sono venute a mancare e, oggi, se dovessi fare una foto della situazione, direi che il mercato non aiuta a essere ottimisti. Detto questo, siamo abituati a questi andamenti a ondate.

Quello che è successo nel tempo è che le strutture produttive sono diventate sempre più grandi e, nei momenti difficili, a chiudere sono state soprattutto le aziende più piccole e meno attrezzate, quelle che avevano investito meno. Io voglio vedere un futuro positivo per il settore, ma con allevamenti molto ben strutturati e con personale molto preparato, dove tutti gli aspetti dell'allevamento e della cura del bestiame vengono gestiti con grande attenzione. Solo lavorando in queste condizioni (massimo benessere animale, massima sanità, minor uso possibile di farmaci) si riesce a rimanere sul mercato, ad avere margini e ad investire.

Il consumo di latte sta diminuendo in modo stabile, però c'è un aspetto positivo: la materia prima latte può essere destinata a tanti prodotti diversi, come formaggi DOP, yogurt e altri trasformati. Quindi, anche se il latte alimentare è un mercato maturo e in contrazione, i formaggi invece hanno ampliato i mercati e aumentato l'esportazione, e questo permette di essere più ottimisti.

Detto questo, credo che nel nostro settore per superare fasi difficili come quella attuale servono allevamenti molto ben strutturati, aziende che negli anni hanno fatto migliorie, che sono rimaste aggiornate. Solo così, secondo me, si può guardare avanti con fiducia. Però questo significa inevitabilmente che diminuirà il numero degli allevamenti. Se fotografiamo il settore, negli anni il numero totale di animali non è diminuito, anzi in certi momenti è aumentato, mentre il numero di allevamenti è calato continuamente. Tendenzialmente sono usciti di scena gli allevamenti più piccoli e più obsoleti, dove spesso non c'era ricambio generazionale, e penso che questo continuerà soprattutto nei periodi di mercato difficile.

Dopodiché, io, avendo avuto la possibilità di vedere allevamenti anche in altri stati, ritengo che la Pianura Padana in particolare, e alcune zone d'Italia in generale, sia avvantaggiata: terreni fertili, disponibilità di acqua e clima adatto alla produzione di foraggi di ottima qualità. Questo consente una maggiore possibilità di sopravvivenza per aziende come la nostra. Da questo punto di vista mi sento privilegiato, perché se avremo difficoltà noi nell'area del Lodigiano, del Cremonese, del Bresciano, nel resto d'Italia; penso che nel resto d'Europa potrebbe essere ancora peggio.

Per questo voglio restare ottimista: qui l'allevamento si fa da millenni, probabilmente non è un caso, e penso che ci siano ancora buone prospettive. Il mercato, però, sarà probabilmente sempre un po' ballerino, con alti e bassi. Noi non abbiamo mai avuto euforie esagerate come in altri settori, ad esempio quello dei suini, e speriamo di non avere nemmeno depressioni tremende. I margini sono bassi e non sono mai stati tali da montarsi la testa; quindi, abbiamo sempre cercato di lavorare con buon senso. […]

## B.5. FARM7 interview transcription

**Q1**

Noi abbiamo 400 vacche in lattazione che sono divise in zone in quanto usiamo 3 sistemi di stabulazione diversi. […] La produzione media della stalla è sui 40 kg a capo, in due mungiture. […]

**Q2-Q3**

La nostra azienda oggi è un'azienda che compra le vacche. Ad oggi faccio solo rimonta con tori da carne. Infatti, i vitelli che hai visto sono tutti blu belga, che vengono venduti per la carne. Di vitelle femmine da latte non ne faccio più, io compro le fattrici. Nel senso che io vado in Germania e compro 30 animali già partoriti, quindi è una rimonta esterna, non più interna. […]

In Spagna è una cosa che stanno facendo in tanti. In Italia oggi questo sistema di allevamento penso che sia quasi mezzo e mezzo, nel senso che c'è gente che fa la rimonta interna e c'è gente che fa la rimonta esterna.

Oggi lo facciamo per più motivi, in primis per un motivo economico. Conviene di più, nel senso che io vendo 400-500 animali all'anno che valgono dei soldi; invece, la femmina è la tua rimonta. È vero, poi non devo comprare la vacca, però per esempio durante il Covid e durante delle crisi come c'è adesso del latte, io quando ho deciso di smettere di produrre […], ho venduto 40 animali ed ero a posto. La rimonta, invece, è una programmazione biennale. Tu a fare una femmina ci metti 24-25 mesi. Non è che se decidi che domani smetti allora smetti. Quelle manze lì le devi contare. […]

In realtà, però, quando abbiamo fatto questa scelta, i vitelli da carne non valevano così tanto: valevano 3-4 €. Oggi ne valgono 8-9 € ma sono anche arrivati a valerne 15 €. [….]

È stata una scelta dovuta alla specializzazione. […] Oggi la specializzazione è un po' tutto. Di solito quando tu arrivi a mungere tanti animali, la parte della rimonta è un angolo che ti porta via tanto tempo e tante energie. Quando c'è stato il Covid, chi faceva rimonta interna ha avuto problemi perché i prezzi erano alti.

Io quando ho preso questa scelta, da 200 vacche in mungitura, il giorno dopo sono passato a 400 con le stesse strutture. […] Così, in sei mesi, ho raddoppiato il fatturato. Questo perché avevamo belle strutture che mi hanno permesso subito di "switchare". […] Questa scelta mi ha permesso di concentrarmi di più sulle vacche in mungitura: io mungo e guardo il benessere animale. I vitelli li tengo un mese, gli dò da mangiare e da bere, poi viene un commerciante e li porta via. […]

**Q4**

In pratica noi usiamo due ricette principali, più quella delle asciutte, che hanno un carro secco. Ecco, qui nella cucina hai i nuclei, i fieni macinati, il fieno fasciato, e poi nelle trincee di là, che andiamo a vedere, c'è il pastone integrale e il mais. Produciamo tutto noi tranne l'erba medica che viene dalla zona di Voghera perché da noi si fa fatica a farla. Il pastone e il trinciato che sono nelle trincee li facciamo tutti noi.

**Q5**

Tutti i reflui e tutte le feci delle vacche vanno dentro al digestore. Il digestore è una vasca a temperatura controllata e senza ossigeno, in cui si fa una fermentazione anaerobica e viene prodotto metano. Questo metano viene poi portato a un motore e viene bruciato.

Da lì escono tre prodotti: il calore del motore, che purtroppo spesso non sai bene cosa farne, la corrente elettrica e le frazioni del digestato (parte liquida e parte solida). A me interessa molto la parte liquida perché viene usata come fertirrigazione: si accumula in campagna in vasche e poi d'estate, insieme all'acqua di irrigazione, si distribuisce. La parte solida viene stoccata o usata come bending. Se è in eccesso, si può stoccare e spargere nei campi. […]

Il vantaggio del biogas è che oltre alle vasche ti porti a casa un fatturato; che è piccolo, ma ti permette una gestione dei liquidi migliore. Oggi un 100 kilowatt porta a casa 120.000-130.000 euro all'anno puliti. Non sono tanti, però ti risolve anche il problema dei reflui: ciò che esce non puzza, perché ha fatto 50 giorni di digestione, ed è più sanificata.

E oggi è interessante anche per il discorso dei certificati verdi e della $CO_2$, andare ad estrarre metano dalle vacche. E poi, per la bancabilità e per le referenze che ci chiedono, se non hai un impianto di biogas oggi vieni guardato un po' male, perché tutto il metano andrebbe nell'aria. Così invece ne recuperi una parte importante. L'80%. […] Secondo me il 90% delle stalle ce l'ha. […]

**Q6**

Attualmente come investimenti stiamo pensando di aggiungere una stalla. […] Noi non crediamo ancora nel robot, ci stiamo ancora guardando attorno. Il "batch milking" non ci piace, e non ci piace nemmeno il robot di mungitura. Ci piace la sala robotizzata ma siamo ancora un po' indietro. […]

Per quanto riguarda il futuro del settore, è difficile dirlo. Il latte è un prodotto che, al di fuori delle crisi, nelle aziende agricole dà valore aggiunto. Ne parlavamo anche l'altra sera in un paio di riunioni: nelle zone dove hanno chiuso le stalle, le aziende non riescono più ad andare avanti. Non è tanto la marginalità che si tira fuori dal latte, perché col latte si marginalizza poco: gli ultimi tre anni sono andati bene perché valeva 60 centesimi e le materie prime costavano poco: la soia e il mais erano bassi. Quindi c'è stata una convergenza positiva negli ultimi tre anni.

Di solito il break-even del latte è molto vicino al prezzo reale: guadagni mezzo centesimo, un centesimo…. Però, in un'azienda come questa, se tu non avessi le vacche, il guadagno annuale che facciamo non ce l'hai. Perché, normalmente, se tu fai solo produzione agricola, fai gli anticipi: semini, compri, concimi e diserbi, fai tutte le spese, e poi ti pagano quando raccogli a fine anno. Quindi hai un periodo di grande esborso e un periodo in cui incassi. In quella finestra temporale tu hai 7-8 mesi di anticipazione. Quando hai aziende come le nostre devi anticipare cifre alte.

Quindi avere una stalla da latte, anche se ci guadagni poco, anche se andassi in pari e dicessi "quest'anno ho reso zero perché il latte non vale niente", intanto ho fatto letame e ho valorizzato i miei prodotti. Nel senso: io ho trinciato. Se devo darlo ai biogas, lo do (e infatti io vendo anche trinciato, perché ho tanti ettari). Il biogas mi dà un certo prezzo. Ma la conversione del mio trinciato in latte è molto più alta del valore del biogas. La terra ce l'ho, gli animali ce li ho, e mi porta questo cash flow: è un vantaggio enorme.

Però sul mercato del latte io dico questo: oggi in Europa latte non ce n'è. Anche se adesso non vale niente. Hanno avuto problemi sanitari enormi in Germania l'anno scorso per la Blue Tongue e mancheranno le vacche. Quindi, adesso, il latte vale poco, ma io sono sicuro che se fra sei mesi mi chiami, il latte varrà molto di più. Adesso c'è stata una caduta libera per una convergenza di un sacco di problemi: il Grana Padano ha fatto troppa produzione, pochi consumi, il Mercosur… e altre problematiche che hanno portato questo default totale, che secondo me durerà sei mesi e poi si tornerà come prima.

Anche perché, quando la specializzazione del latte era bassa, c'erano tanti "pellegrini", cioè gente che non era capace a fare il mestiere ma sopravviveva. Oggi, con due o tre "sventagliate" come queste, sono stati selezionati tutti. La cooperativa di Granarolo in tre anni è passata da 700 soci a 430, e il latte è aumentato del 10%. Cosa vuol dire? Vuol dire che le stalle che vanno avanti, vanno avanti; quelle che chiudono, chiudono. Se perdi soci ma il latte aumenta, vuol dire che c'è un focus chiaro: vanno avanti le stalle specializzate. […]

## B.6. FARM8 interview transcription

**Q1**

Dunque, io importo bovini da diverse zone della Francia, poi dalla Germania, Cechia, Paesi Bassi. Diciamo però 90% dalla Francia. È poi faccio anche l'allevamento di bovini da carne.

È un'azienda di circa 1000 capi, che rimangono da noi all'incirca sei mesi. Gli animali una volta arrivati, vengono "condizionati". Con condizionamento intendo che vengono vaccinati e sottoposti a trattamenti sanitari, ad esempio trattamenti antiparassitari. E vengono sverminati, ossia, per esempio, viene "pulito" il fegato dai vari batteri che possono prendere al pascolo.

Dopo questa fase, inizia il ciclo di ingrasso. L'ingrasso è basato in larga parte su prodotti aziendali, direi per un 70-80%. A questo si aggiunge quello che compriamo all'esterno: un'integrazione di sali minerali e un'integrazione di un nucleo proteico, che serve a completare la razione. Gli alimenti che somministriamo sono principalmente mais e paglia, e queste integrazioni servono proprio a bilanciare e rendere più completa l'alimentazione.

Fatto questo, l'animale rimane in azienda circa sei mesi. C'è anche un aspetto importante: dopo sei mesi di permanenza in stalla l'animale può rientrare in un premio di macellazione, che varia ogni anno e, in genere, va dai 40 ai 60 € per animale. La condizione è che l'animale abbia meno di 24 mesi e che resti in azienda almeno sei mesi. Quindi, generalmente, il ciclo di ingrasso viene organizzato tenendo conto anche di questi criteri.

Quando parlo di "premio di macellazione", mi riferisco a una misura legata alla PAC. La PAC è l'insieme degli aiuti comunitari all'agricoltura. Tra le misure dell'Unione Europea, poi applicate attraverso normative italiane, esiste anche questo premio per i bovini macellati tra i 12 e i 24 mesi, a condizione che abbiano avuto una permanenza di sei mesi in stalla. È, di fatto, un aiuto all'allevamento.

**Q2**

In pratica, il nostro ciclo produttivo funziona così: noi acquistiamo i vitelli. Lavoriamo con un contratto di filiera, cioè gli animali vengono inseriti in un sistema che certifica alcuni requisiti: che siano rimasti sei mesi in stalla, che l'allevamento abbia un determinato punteggio di benessere animale, e che vengano effettuate analisi a campione su mangimi, acqua e altri elementi. Tutto questo serve per poter inserire gli animali nella filiera della grande distribuzione. Nel nostro caso, ad esempio, la filiera è quella di Esselunga.

I vitelli che acquistiamo provengono da allevamenti da carne: la Charolaise è una razza da carne; quindi, il nostro è un ciclo "pura carne".

Esistono poi realtà italiane che lavorano anche con vitelli che possono provenire dalla filiera del latte, e lì si apre un mondo diverso, che probabilmente è anche quello più interessante per la sua ricerca. Nella filiera del latte, infatti, si possono distinguere diversi casi. In sostanza, ci sono due grandi tipologie di vitelli: c'è il vitello frisone puro, che spesso deriva dall'uso di seme sessato, con l'obiettivo di ottenere femmine per la rimonta, cioè manze che entreranno a far parte della mandria da latte. Oppure si utilizza seme da carne su vacche da latte, per avere un vitello che è figlio di una madre da latte e di un toro da carne: in questo modo si ottiene un animale più adatto all'ingrasso rispetto al frisone puro.

Anche qui poi c'è un'ulteriore distinzione: alcuni vitelli vengono inseriti subito nel ciclo del "vitello" vero e proprio, cioè vengono macellati sotto i nove mesi di età (quello che sul mercato viene venduto come carne di vitello). In una parte più piccola dei casi, invece, vengono svezzati: esistono aziende specializzate nello svezzamento, che allevano questi vitelli fino a 4-5 mesi, e poi li rivendono agli ingrassatori. In quel caso non si fa più il vitello giovane, ma si inserisce l'animale in allevamenti da carne e si porta avanti il ciclo fino a ottenere un bovino più adulto.

Un vitello proveniente dalla filiera del latte, svezzato e destinato all'ingrasso, si comporta in modo molto simile a quello che io acquisto in Francia: alla fine io compro un vitello pronto per entrare in un ciclo di ingrasso. In Italia esistono filiere che fanno questo tipo di prodotto: ad esempio alcune lavorano su scottone e vitelloni. Il vitellone, in questo contesto, è un animale sotto i 24 mesi che abbia avuto almeno sei mesi di stalla, e da qui nasce la distinzione tra scottona e vitellone nella filiera italiana.

Comunque, questi vitelli rimangono in azienda circa 6-8 mesi. Il ciclo è continuo: appena esce una partita, ne rientra un'altra. […]

**Q3**

Più che "dipendere", è più corretto dire che le due filiere si incontrano e si ottimizzano a vicenda.

Se la filiera del latte usasse solo seme sessato per fare manze, produrrebbe troppe femmine rispetto al fabbisogno. L'uso del seme da carne su una parte delle vacche da latte permette invece di destinare una parte dei vitelli a un percorso più adatto all'ingrasso.

In passato, prima che queste pratiche venissero gestite in modo scientifico, si potevano creare esuberi di vitelli frisoni che, a seconda dei periodi di alto o basso consumo e del mercato, potevano anche valere pochissimo. Così tanto da arrivare anche a situazioni molto brutali, in cui gli animali venivano anche ammassati e sotterrati perché erano considerati senza valore. […]

Il dialogo tra i due mondi, carne e latte, ha quindi portato alla creazione di un vitello che vada meglio per l'allevamento da ingrasso.

**Q4**

Negli ultimi anni il settore della carne, e in generale il nostro lavoro, è cambiato parecchio. È un settore che richiede parecchio lavoro e ci sono poche persone disposte a farlo. C'è una mancanza di organico e anche una diminuzione delle aziende. Pensi che la produzione italiana di carne copre circa il 38% di quello che consumiamo: il resto viene importato dall'estero. Questo è negativo per molti motivi. Primo, perché sono lavori che richiedono investimenti enormi. Secondo, perché richiedono una presenza quotidiana, continua, sia degli operai sia del titolare. [...] Di conseguenza diminuiscono le aziende, diminuiscono le persone che fanno questo mestiere e diminuisce il numero delle vacche. [...]

Per i prossimi anni, se il valore degli animali resta alto, per un'azienda come la mia è positivo. Io penso che siamo arrivati a un punto in cui il lavoro è più riconosciuto e quindi si può fare un buon lavoro. Però, nonostante questo, gli attori sul mercato diminuiranno ancora: aumenteranno i grandi gruppi, spariranno i piccoli, e tendenzialmente diminuirà anche la produzione, perché uno più uno, in agricoltura e allevamento, non fa quasi mai due. [...] È un processo che è successo ovunque: il piccolo allevatore, come il piccolo mungitore da 50 capi, praticamente non esiste più, perché non è sostenibile con i costi attuali.

Costi che continuano ad aumentare sempre di più. E la cosa che aumenta di più o che comunque è più difficile da ammortizzare, sono i macchinari. Un macchinario che ho nel mio allevamento, bene o male, potrebbe esserci anche in un allevamento da 500 capi: quindi più cresci, più riesci a spalmare e ammortizzare i costi. Infatti, nei prossimi anni io vorrei aumentare di altri 200-300 capi, perché ho fatto i conti e con le attrezzature e gli uomini che ho oggi potrei gestire circa 200 capi in più. Quindi ammortizzerei meglio.

**Q5**

Penso che dal punto di vista mondiale i consumatori di carne stiano aumentando in realtà. La diminuzione dei consumi, per me, è un falso problema. È una cosa che magari ti dura un mese ma poi riaumenta.

Tieni conto che negli ultimi cinque o sei anni il nostro mondo è stato stravolto: siamo passati dal chiedere tutte le volte “per favore macellate, perché ho animali pronti”, a trovarci con una carenza di materia prima (vitelli), sia di animali da ingrassare sia di animali pronti per il macello. C’è sempre meno disponibilità.

Quindi è un falso problema. Infatti, i mercati si sono ampliati: in Nordafrica, ad esempio, si è iniziato a consumare più carne. Dove arriva un minimo di benessere economico, le persone tendono a mangiare meglio, cioè passano da alimenti base come patate e riso a introdurre più proteine nobili, tra cui la carne.

Anche l’aumento molto forte dei prezzi degli animali, che in cinque o sei anni hanno raddoppiato il valore, è legato al fatto che c’è scarsità di animali disponibili, non al fatto che si vende di meno. E, guardando le statistiche FAO, ci sarà sempre più richiesta di proteine.

## B.7. AGENT interview transcription

**Q1**

Io sono un agronomo e mi occupo dell’alimentazione del bovino da latte, però parto dalla campagna, perché devo cercare di fare negli allevamenti dei foraggi di qualità da somministrare agli animali. Poi, io metto insieme tutti i componenti della razione per cercare, dai vitelli fino alle vacche in lattazione, di migliorare il benessere animale e, ovviamente, il reddito dell'allevatore. Questa è un po' la mia figura, quello che faccio.

Ormai sono nel settore da quindici anni. In particolare, ora collaboro con delle ditte commerciali. Adesso lavoro per una ditta dove produciamo mangimi e integratori per bovini da latte. […] Io sono un consulente esterno e insieme al responsabile tecnico del mangimificio metto insieme materie prime proteiche, amidacee, energetiche eccetera per produrre mangimi di qualità e offrire un prodotto migliore agli allevamenti. Quindi io parto dalla campagna ma seguo anche la formulazione.

**Q2**

Innanzi tutto, un fattore sono i prezzi. Ti consiglio un sito da consultare, si chiama CLAL.IT ed è un database dove si possono vedere diverse informazioni e notizie del mercato. Anch'io mi baso su questo. Per esempio, se vai su "Prezzi e strumenti" e "Formaggi", poi "Italia". Qui vedi tutti i formaggi DOP prodotti in Italia. Noi adesso concentriamoci sulla Lombardia: cosa produciamo? Fondamentalmente Grana Padano e Gorgonzola. Prendiamo il Grana Padano nove mesi, per esempio. Il nove mesi sul Grana Padano è il prezzo di riferimento di mercato. È quello che guardiamo tutti per l'indicizzazione anche del prezzo del latte. Se clicchi, qui ti dà la quotazione, vedi come è calato? Adesso sta riprendendo qualcosa, però guarda la differenza tra 2025 e 2026. Tieni conto che questa è la quotazione del prodotto venduto all'ingrosso. Poi, ti faccio vedere un'altra cosa: dove c'è scritto "Prezzi e strumenti". Vai su "Latte stalla spot" e "Italia". Guarda la voce "Latte crudo spot nazionale" vedi che sta scendendo? Ora ti spiego le dinamiche di prezzo.

Allora, il latte spot: che cos'è? È il latte fuori contratto. Cioè, in Italia gli allevamenti consegnano ai primi acquirenti, che possono essere cooperative, centrali del latte oppure direttamente gli industriali. Queste sono le tre vie principali. Il latte che viene così venduto è un latte indicizzato, ossia sotto contratto.

Perché il latte adesso è calato? Gli industriali si sono trovati con un'offerta di latte elevatissima, perché è aumentato il numero di capi e perché ne arriva di più anche dall'estero. Quindi, gli industriali trovano latte anche a basso costo. E cosa fanno? Comprano quello che costa meno. Di conseguenza disdicono i contratti, ma l'allevatore il latte lo deve vendere da qualche parte. Ecco allora che la cisterna finisce sul latte spot. Non è più indicizzato, è latte sul libero mercato.
Essendo sul libero mercato, se tu immetti sul mercato una quantità normale, il prezzo del latte spot rimane alto. Ma se continui a buttare sul mercato latte senza contratto, il latte spot scende, perché hai sempre il solito meccanismo di domanda e offerta: offerta molto elevata e domanda limitata. E quindi il latte spot scende.
Adesso siamo intorno ai 28,3 euro.

Questa è la motivazione per cui il latte alla stalla sta calando: c'è tantissimo latte spot, quindi crolla del prezzo. Questo è quello che sta succedendo adesso, molto in sintesi, a livello di mercato. […]

Comunque, tutto è partito nel 2022, anno in cui abbiamo subito una siccità molto importante. La siccità in Italia si è sentita parecchio, ma c'è stata anche in Francia e in Germania ecc. Prima cosa, cosa è successo? Abbiamo prodotto foraggi di scarsa qualità e anche in scarsa quantità. Quindi, in quel momento gli allevatori si sono trovati a dover gestire una situazione molto difficile e hanno dovuto abbattere gli animali per ridurne il numero nelle stalle. Questo è successo anche nei Paesi del Nord. […]

Quindi, torniamo a noi, a partire dal 2022, abbiamo avuto una riduzione non indifferente della produzione di latte. Ma, ovviamente, per formaggi e latticini in generale la richiesta era sempre alta. In particolare, cosa è successo in Italia? In Italia produciamo tanti formaggi DOP. I due principali sono Gorgonzola e Grana Padano. Per questi prodotti non puoi utilizzare latte estero: deve essere assolutamente prodotto all'interno di un comprensorio in Italia. Ancora di più vale per il Parmigiano Reggiano che può essere prodotto solo all'interno di un territorio ben definito, che comprende le province di Parma, Reggio Emilia e la provincia di Mantova al di sotto del Po. Cioè, esiste un comprensorio preciso definito da un disciplinare firmato dal Consorzio. Il disciplinare è molto rigido: indica le province, le tecniche di produzione, gli additivi ammessi, le materie prime che si possono utilizzare eccetera.
Dunque, lì cosa è successo? Anche in quelle zone si sono trovati ad aumentare il prezzo del latte per incentivare gli allevatori a produrne di più. Capisci però che, a un certo punto, hanno aumentato il numero di capi, hanno aperto nuove stalle, alcune stalle addirittura si sono raddoppiate. Finché, ad un certo punto, inevitabilmente, il mercato si è saturato. […]

C'è anche un'altra cosa da dire: ci sono tanti allevatori che sono arrivati a fine carriera. Molte stalle, infatti, stanno chiudendo perché non c'è ricambio generazionale. Noi abbiamo un buco tra i 30 e i 45 anni: in quella fascia non ci sono tanti che fanno questo mestiere. Invece, ci sono alcuni giovani che stanno entrando negli allevamenti.

Dunque, gli allevatori stanno riducendo i capi. Pensa al macello Inalca, che è il nostro di riferimento e uno dei più grandi in Europa, ha fatto dei record di macellazione giornaliera: 1.600-1.700 capi al giorno. In questo momento siamo su questi numeri. Purtroppo, la ricerca genetica ci ha portato ad avere animali molto produttivi e se tu togli qualcosa sull'alimentazione, rischi di avere conseguenze peggiori (l'animale sta male), dunque si cerca di ridurre le mandrie mandando via gli animali che sono zoppi o che hanno problematiche croniche, cercando così di ridurre la produzione complessiva.

**Q3**

Sono molto connesse, anche in termini di prezzi. Infatti, le femmine vengono utilizzate per la produzione di latte, ma abbiamo anche tutti i maschi che vengono comprati dagli allevatori da latte e portati agli ingrassatori.
Quindi sì, sono connessi: se io aumento sempre di più il numero di animali, avrò sempre più vitelli che arrivano sul mercato e quindi un abbassamento del prezzo. È tutto correlato.

Secondo me, circa il 40% della carne sul mercato viene dagli animali da latte.
Infatti, se pensi al Piemonte, ad esempio, ci sono allevamenti da carne anche grossi. Qui in Lombardia invece sono poco diffusi. Non me la sento di dire due terzi. Io credo che un 40% sia una percentuale realistica, perché abbiamo i vitelli maschi (e anche femmine non destinate alla rimonta) che vanno agli ingrassatori. Poi ci sono le vacche a fine carriera: anche quello è un numero non indifferente.
Più tutti quegli animali che, per motivi biologici, finiscono nella filiera carne. Ti faccio un esempio: nei parti gemellari, se nasce maschio e femmina, gli ormoni del maschio possono influenzare la femmina. Quella femmina, in gergo, la chiamiamo "mula", non sarà mai produttiva, perché non sviluppa correttamente ovaie e utero. Quindi sono tutti animali che vanno sul mercato della carne.

Nel pratico, in questo momento siamo in una fase di "svuotamento": stanno abbassando il numero di capi; quindi, nel breve periodo abbiamo tanta carne.

Quando finirà questa fase, la filiera continuerà, ma a un certo punto avremo una riduzione dell'offerta di animali provenienti dalle stalle da latte. Cioè, quando il sistema si stabilizzerà, secondo me nel giro di un anno avremo una riduzione dell'offerta e quindi un innalzamento del prezzo, stavolta a favore degli allevatori.

**Q4**

Sul discorso mangimistica: è molto interconnesso. Anche se non tanto sul prezzo in sé perché anche le stesse aziende mangimistiche comprano sul mercato, ovviamente in quantità completamente diverse rispetto a un'azienda agricola. […] C'è un'interconnessione abbastanza stretta perché, ad esempio, la soia è soggetta a speculazione elevata: quella che arriva dal Sud America è molto soggetta al prezzo di mercato. Lì probabilmente si creano equilibri nelle zone di produzione e il risultato è che abbiamo prezzi molto altalenanti. L'allevatore, quindi, dal punto di vista mangimistico, subisce un prezzo di mercato. Ad esempio, c'è stato un periodo in cui la soia aveva raggiunto 50-60 euro perché in quel periodo la Cina aveva acquistato grandissime quantità di soia. Il motivo è che dalla soia intera, viene estratta la parte che noi usiamo per alimentare i bovini. Quello che rimane sono gli oli, che servivano alla Cina in quel periodo. Poi dopo, quella soia è stata in parte rimessa sul mercato e nel giro di 6-8 mesi il prezzo è tornato a livelli normali.

Tieni conto che la spesa più grossa in una stalla è l'alimentazione. Poi viene la manodopera e poi tutto il resto. Comunque, è tutto proporzionato: se passi da 100 a 80 vacche, si ha una riduzione del latte prodotto, ma hai anche una riduzione della principale voce di spesa, che è l'alimentazione. Quindi mungi meno, ma spendi anche meno. […]

Anche nell'approvvigionamento: spendi meno di acquisto esterno e spendi meno anche nell'utilizzo dei tuoi foraggi. Quando io faccio il costo di razione presso un cliente, per me la stalla e la campagna sono due entità diverse, anche se in realtà sono un'unica azienda. È come se la stalla "comprasse" dalla campagna. Quindi, riducendo il numero di capi, hai una maggiore disponibilità di foraggi e riesci comunque a stare sul mercato.

Ti spiego cosa facciamo nel pratico in un allevamento. Facciamo un'analisi di quello che hanno in azienda, quindi di tutte le materie prime che si sono autoprodotti: fieni, foraggi verdi, foraggi insilati (mais, pastoni, erbe mediche, eccetera). In base a quello che loro hanno "in casa", facciamo le analisi sulle diverse componenti. Ecco, questa è la parte che loro producono internamente. Poi noi, in base alle analisi che facciamo sui foraggi, produciamo un mangime che risulta personalizzato per quella stalla. Inoltre, se vai a vedere, anche la razione è personalizzata: io non posso avere una razione uguale in tutte le stalle, perché hanno foraggi diversi, ma soprattutto hanno esigenze diverse. Cioè, non posso utilizzare lo stesso mangime o lo stesso integratore in una stalla che produce 30 litri e in una che produce 35 litri di media: capisci che c'è uno squilibrio. Quindi, in base alla produttività di quella stalla, io faccio un mangime personalizzato. E così anche l'unifeed, che è la miscelata messa davanti alle stalle in allevamento, il quale viene personalizzato in base alle esigenze della stalla.

Un altro settore connesso è il mercato delle pelli sicuramente, ma non lo seguo.

Un altro settore impattato è quello dei concimi: allevamenti e aziende agricole sempre più grandi richiedono sempre più concimi minerali, antiparassitari, eccetera. Anche qui domanda e offerta incidono.

Infine, anche l'energia elettrica. Tieni conto che d'estate, tra la sala di mungitura e le ventole per raffreddare gli animali, l'assorbimento energetico è molto alto. Nelle stalle ormai ci sono ventilatori enormi che lavorano anche 24 ore su 24, anche perché il clima è sempre più caldo. […]

**Q5**

Io lo vedo legato soprattutto al benessere animale e alla sostenibilità. Le stalle dovranno essere tassativamente sostenibili: vuol dire dare agli animali gli spazi giusti per ottenere una produzione sostenibile e non impattante sulla loro salute.

Io vedo una riduzione del numero di stalle. Se prendiamo la Lombardia, avremo una riduzione consistente: si parlava, tra il 2025 e il 2030, di un calo del 20-25% del numero di allevamenti. Il numero di capi invece rimarrà più o meno costante. Quindi: meno stalle, ma più grandi.

Gli allevamenti nuovi saranno però più sostenibili, quindi vedo un futuro più "pulito" e regolamentato, anche dal punto di vista ambientale. Ci sono anche delle leggi che arrivano dall'Unione Europea che ci impongono il benessere animale. Non è più come 30 anni fa, oggi chi vuole fare l'allevatore deve garantire sia benessere animale sia uno standard di produzione elevato, soprattutto dal punto di vista qualitativo della materia prima ottimale. Ma è anche giusto, perché se noi andiamo avanti dobbiamo garantire al consumatore un prodotto altamente di qualità. L'unica negatività che questo porta è che ci sarà un'elevata concentrazione, quindi sempre meno stalle e sempre più grandi. Diventeranno quasi delle industrie.

## B.8. CELL interview transcription

**Q1**

[CELL1]

Allora, il latte coltivato, seppure sia un'idea assolutamente biologicamente possibile, per quanto riguarda il processo basato sulle cellule, io non ho ancora conoscenza al momento di start-up che facciano questo tipo di prodotto. Perlomeno c'era qualcuno che ci aveva pensato. So che ci sono delle cellule, delle linee cellulare che fanno cose di questo genere, però start-up che sono arrivate su scala industriale su volumi produttivi abbastanza interessanti o che recentemente abbiano dato annunci di successi regolamentatori, piuttosto che commerciali, piuttosto che tecnologici, al momento non me ne viene in mente nessuna. Mentre per la carne, sicuramente qualcosa c'è.

Dunque, la mia preoccupazione è che partire tra quattro anni con un 10% del mercato globale rappresentato da latte coltivato mi sembra molto ambizioso. Io almeno traslerei queste stime, cioè le farei partire con zero nel 2030, secondo la mia percezione attuale di quello che è l'offerta in termini di start-up e di potenziale prodotto. Poi anche partire con un 10% è ambizioso, penso ci sia comunque la regolamentazione a Singapore che vada veloce, probabilmente la potranno approvare in tempi ragionevoli, però Singapore non fa una parte significativa a livello globale. Dunque, anche lì conta sempre un due anni di ritardo su tutto quello che è processo regolamentatorio. Secondo me è più probabile che nel 2035 inizieremo ad avere una stima del 5%, però anche così è molto ambiziosa, del mercato globale. Dunque, ecco, io traslerei tutto quanto più avanti.

Per quanto riguarda le bevande vegetali, ti dico la sincera verità, al momento non ho contezza di quanto coprano, però sicuramente quello che dicevi prima, che è più facile produrre il latte piuttosto che la carne, probabilmente mi trovo d'accordo.

Se invece parliamo di fermentazione sicuramente ci sono già delle scale che si approcciano alla produzione industriale. Ho letto di aziende che stanno su scale industriali con migliaia di litri di bioreattore per fare ingredienti per il latte coltivato. La mia personale convinzione in questo settore è che saranno utili poi per fare più che altro dairy, non tanto latte. […] Invece nel dairy vegano ha senso che inserisco la caseina per poter avere le proprietà organolettiche che altrimenti non riuscirei mai ad ottenere. Dunque, secondo me, se andassi in quella direzione lì non parlerei tanto di latte coltivato, ma di dairy in generale se ti posso dare la mia prospettiva su questo punto. E comunque sì, la stima del 10% nel 2030 rimane comunque ambiziosa.

Tieni conto che io parlo comunque di Europa, perché per fare questo tipo di proteine che si trovano nel latte tu devi fare OGM. Per esempio, la leghemoglobina di soia che era una proteina brevettata da un'azienda statunitense, dovrebbe averci messo circa cinque anni per avere una risposta sulla sicurezza come Novel Food all'interno dell'Unione Europea solo dal pannello OGM dell'EFSA. Non penso nemmeno siano arrivati alla fase di discussione all'interno della Commissione Europea. Io immagino che anche tutte queste altre proteine prodotte tramite ingegneria genetica, in un modo o nell'altro, debbano passare attraverso questo tipo di regolamentazione e a mio avviso non è semplice.

[CELL2]
Vorrei aggiungere che c'è sicuramente la questione dell'alimentazione. Il latte è un alimento che c'è nell'agricoltura cellulare, ma è una componente minima, e a differenza della carne, il prodotto finito non è composto prevalentemente da biomassa, ma da acqua.

Per quanto riguarda la fermentazione, dico che sicuramente ci aiuterà prima a fare un prodotto che si avvicina al latte tradizionale. Secondo me aumenterà anche molto sia a livello assoluto, ma anche a livello di maturazione e di produttività.

In ogni caso, il boost più grande ci sarà quando si raggiungerà la parità di prezzo. Secondo me anche per il latte bisogna pensare a come diminuire il costo. Come dicevi giustamente tu, c'è tutto un aggancio della filiera della produzione del latte che si lega anche a quella della carne. Quindi ecco, è una rivoluzione che va a toccare tanti aspetti non solo dell'allevamento ma anche dell'agricoltura in generale.

**Q2**

[CELL1]

Allora, io parto con una considerazione. Prima ci dicevi che il 40% della carne bovina sul mercato ora deriva dall'allevamento dai dairy farms. Dunque, se io riduco il latte, necessariamente il prezzo della carne va ad aumentare per la disponibilità di carne. Dunque, immagino, che dovrebbe scendere anche il consumo di carne.

Quindi, per quanto riguarda gli scenari, secondo me, è più probabile che il latte tradizionale diminuisca e la carne tradizionale anche.

Allora, lo scenario 1 potrebbe essere più probabile, posto che le alternative abbiano un costo e proprietà organolettiche comparabili alle offerte tradizionali. Non vedrei un motivo per cui il latte tradizionale dovrebbe scendere e la carne tradizionale no. A meno che non ci sia una barriera maggiore di accettazione per la carne. Riterrei probabile anche questo. Quindi si, anche lo scenario 3 potrebbe accadere, anche se, se riusciamo ad accettare il latte, teoricamente, dovremmo accettare anche la carne coltivata.

[CELL2]

Allora, in linea di massima sono d’accordo con CELL1. Sicuramente il primo è un po’ ottimistico. Però il secondo, dire che non diminuirà mai, mi sembra poco realistico.

In base alle proiezioni sappiamo che per un certo tipo di alimenti, tra cui la carne, c'è sicuramente un aumento del consumo. Uno degli obiettivi delle proteine alternative, tra cui anche la carne coltivata, è infatti cercare di inserirsi in quella forbice di domanda che si sta creando, anche per mitigare l'impatto ambientale.

Secondo me sarà, comunque, prevalentemente una questione di quanto si riesce ad andare vicini rispetto al prodotto tradizionale e quanto il prezzo sia uguale o inferiore. Però, sicuramente se intendiamo latte coltivato tramite fermentazione, secondo me non siamo lontani. Quindi può aver senso dire che per la carne manca più tempo e quindi ci sarà una transizione un po’ più ritardata. Secondo me, tanto si giocherà non solo a livello tecnico ma anche politico. […] Se si giocasse ad armi pari, la battaglia sarebbe più facile da combattere.

Secondo me, il terzo scenario è più probabile. Poi, per quanto riguarda le percentuali e dove si trova la curva, c’è da limare. Il latte potrebbe entrare prima, non so se sottoforma di ingredienti o di prodotto finito, ma comunque si parla di più avanti del 2030. Però, dovrebbe essere comunque più facile. Quindi ti direi, è possibile che la carne arrivi un po’ dopo. Shifterei comunque tutto in avanti di almeno 10 anni.

[CELL1]
Anche secondo me le percentuali sono troppo ottimistiche. Fai conto che c’è un post di Elliot Swartz che ipotizza le tonnellate di carne coltivata prodotte al mondo oggi e siamo sull’ordine delle centinaia di tonnellata. Tra l’altro, prodotti principalmente

per test inauguratori, test per approvazioni regolatorie e simili. Non siamo neanche all'1% del mercato della carne totale.

Quindi è più probabile dire che entreranno con un 1% nel mercato, e poi si andrà verso il 5% o 10%. Anche perché devi confrontarti con il mercato della carne tradizionale, che è una filiera molto consolidata e grande in termini di volume. Oggi, anche unendo tutte le aziende di carne coltivata non si arriva al 10% della carne totale. Anche da un punto di vista di materie prime: ci vogliono dei bioreattori, dunque ci vuole acciaio che deve essere recuperato. […]

[CELL2]
Io mi trovo d'accordo. Tieni conto che parlare anche solo di un kg è tanto, soprattutto se fai ricerca e sviluppo. È un processo industriale già consolidato.

Forse considerando il pet food, ci sono delle aziende che sono più avanti. Anche perché hanno meno barriere regolamentatorie. Per esempio, in Europa, c'è un'azienda in Repubblica Ceca che si chiama "Bene Meat". Loro hanno fatto anche un trial in cui davano biscottini per cani che contenevano 18% di carne coltivata. Altrimenti, in UK, c'è un'azienda che si chiama "Meatly". Anche loro stanno andando abbastanza avanti. In particolare, hanno stimato i loro costi per produrre carne coltivata per pet food molto molto bassi. Siamo dell'ordine degli 0,01 pound al litro. Secondo me, molto ottimistico, però comunque sono le loro stime.

# C Interview notes

In cases where recording was not possible, detailed notes were taken during the interview and expanded immediately afterwards. These notes, in Italian as well, are reported below.

## C.1. FARM3 interview notes

Numero di vacche: 52 vacche in lattazione e circa 100 totali.

Per la mungitura viene utilizzato un robot di mungitura automatico. Le vacche entrano quando vogliono all'interno del mungitore (anche 2-3-4-5 volte) e quando entrano vengono rilevate tramite un sensore messo al collo della mucca. A questo punto accadono 3 step:

1) Le mammelle vengono pulite e spinate tramite dei rulli/spazzole che contemporaneamente stimolano l'ipofisi della vacca che le fa uscire il latte.
2) Tramite un laser il robot rileva la posizione delle 4 mammelle della vacca, che vengono agganciate.
3) Le mammelle vengono nuovamente pulite.

I rulli vengono disinfettati ad ogni vacca e se una vacca non può essere munta per vari motivi, il mungitore automatico lo rileva e la vacca viene rimandata insieme alle altre.

Per l'alimentazione viene utilizzato un sistema di alimentazione automatico. Per cui, le vacche entrano nel sistema, il sensore si connette e gli viene data automaticamente la razione di cibo che gli spetta. Più latte producono, più cibo gli viene dato.

Il latte prodotto viene destinato al Gorgonzola (DOP). Secondo il disciplinare della DOP, almeno il 50% dei foraggi usati per alimentare le vacche, deve essere prodotto internamente all'azienda.

Negli ultimi anni la produzione di latte è aumentata del 30% grazie ad un aumento nel numero di vacche del 15%.

## C.2. FARM4 interview notes

Numero di vacche: circa 120 in totale.

L'azienda si occupa sia di animali da latte che da carne. Ha due comparti.

Latte:

- sulle manze viene usato il seme sessato, mentre sulle altre il seme normale.
- mediamente le vacche hanno una gravidanza ogni 1 anno e 4 mesi.
- le vacche sono divise in due zone principali: in una ci sono le vacche molto produttive (chiamate fresche), mentre in un'altra ci sono le vacche mediamente produttive. Le prime sono generalmente quelle che hanno appena partorito e dunque sono nel loro picco produttivo che si aggira attorno ai 39 kg di latte al giorno. Le seconde, invece, producono circa 34 kg di latte al giorno.

- le vacche incinte possono essere vendute. Per esempio, quando l'azienda ha avuto troppi parti in uno stesso momento e non riesce a gestirli tutti.

Carne:

Alcune vacche da latte vengono inseminate con tori da carne blu belga. I vitelli nati (sia femmine che maschi) vengono tenuti in azienda e cresciuti. Poi, dopo circa 45 giorni, raggiunti i 60-70 kg, vengono venduti ad un macello. Altri, invece, vengono castrati da piccoli, cresciuti in azienda e poi venduti da adulti. Le femmine potenzialmente potrebbero fare latte, ma non conviene perché ne fanno poco e di qualità inferiore. Dunque, indipendentemente dal sesso, vengono usati per la carne.

Mungitura:

Per la mungitura, utilizzano una sala non automatizzata. Le vacche entrano a gruppetti di 15 e una persona pulisce le mammelle e le spina (toglie il primo latte) così, intanto, si stimola l'ipofisi che manda fuori da sola il latte in risposta. Poi, la persona attacca le mammelle al macchinario che pompa il latte. Una volta terminata la mungitura, la persona ripulisce le mammelle.

Foraggi:

Quello che c'è nelle trincee si chiama Insilato e viene raccolto dai campi, frullato e pressato. In questo modo, l’aria esce e il foraggio non si ossida né ammuffisce. Poi, successivamente, viene messo nelle trincee e coperto con dei teli per preservarlo meglio. Quando la sua temperatura scende naturalmente sotto i 31 gradi, può essere usato. Man mano (per il discorso ossidazione) viene scoperto ed usato.

# List of Figures

# List of Tables

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