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# SUSTAVIANFEED

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ALTERNATIVE ANIMAL FEEDS  
IN MEDITERRANEAN POULTRY  
BREEDS  
TO OBTAIN SUSTAINABLE  
PRODUCTS

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STAKEHOLDER  
INTERACTIONS ALONG  
THE SUPPLY CHAIN

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DELIVERABLE 4.2

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## SUMMARY

SUSTAavianFEED project aims to develop a new approach for the farming sector in which a circular economy and the preservation of our ecosystems are promoted while offering new opportunities to different relevant actors along the whole supply chain. The objectives of this document are to analyse the supply chain of the sector and to detect and propose possibilities for circularity and reduction of waste in each stage.

The first step is an analysis of the resource flow in the aviculture supply chain, including a detailed explanation of the use of resources in the global context, both for chicken meat and egg production. The process was classified into seven main stages: primary production, animal feeding, breeding/farm, slaughterhouse, processing, distribution and selling point, and end consumption. The supply chain of the farming sector, in general, and the aviculture sector, in particular, is formed by several actors of different nature and sizes and operates in different stages of the supply chain. For this reason, it was also necessary to include considerations about the nature and sizes of those actors and business interactions among them.

Then, a study of the differences between Mediterranean regions was conducted with the inputs from project partners who contributed with their view and particularities from their regions. This study covers key aspects for each supply chain stage which are consumer awareness, differences from the meat to egg sector, and legislation for each region.

With this information, a circular economy approach to the aviculture supply chain was conducted, combining information on the resources flow and business interactions to propose possible next use of the main outputs of each stage.

Finally, the pillars for a sustainable approach for future implementation were identified. The main aspects to take into account for large-scale implementation of the SUSTAavianFEED approach are: change in our consumption habits, consumer empowerment, resilient systems, R&D for the development of sustainable diets, policy changes, and stakeholder collaboration.

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## ACRONYMS AND ABBREVIATIONS

| Abbreviation | Description                               |
|--------------|---|
| BSF          | Black Soldier Fly                         |
| FAO          | Food and Agriculture Organization         |
| IPCC         | Intergovernmental Panel on Climate Change |
| LCA          | Life cycle assessment                     |
| LL           | Living Lab                                |

## 1 INTRODUCTION

The farming sector has a huge impact on climate change and the ecological crisis the society is facing. Not only intensive practices are associated with a contribution in terms of GHGs emissions, but also a loss of biodiversity, hydric stress or deforestation events, consume large amounts of natural resources, result in negative health impacts (due to both under- and over-nutrition) and do not allow fair economic returns and livelihoods for all actors, in particular for primary producers.

The recent IPCC report on Climate Change and Land, highlights the importance of changing our food system in order to keep global temperatures at safe levels and deal with air, soil and water pollution, as well as to avoid further biodiversity loss (Masson-Delmotte *et al.*, 2019).

In the framework of the European Green Deal, the European Commission (2019) has developed the Farm to Fork Strategy. This strategy aims to make food systems fair, healthy and environmentally-friendly. In addition, this strategy has the objective of putting our food systems on a sustainable path, so new opportunities for operators in the food value chain are offered. New technologies and scientific discoveries, combined with increasing public awareness and demand for sustainable food, will benefit all stakeholders.

In that context, SUSTAvianFEED project aims to develop a new approach for the farming sector in which circular economy and the preservation of our ecosystems are promoted, while offering new opportunities to different relevant actors along the whole supply chain.

The aviculture sector involves a huge number of stakeholders along the whole supply chain. In order to implement a circular economy approach on it, it is necessary to understand the relationship among different actors, the resources consumed in each stage of the supply chain, as well as the specific characteristics of each region, with its constraints and strengths.



## 2 STAKEHOLDERS' INVOLVEMENT ALONG THE SUPPLY CHAIN

In order to develop a circular economy approach it is necessary to deeply understand how the aviculture supply chain operates. To this aim, there are three crucial aspects which should be analysed:

1. In the first place, it is necessary to study the impact of the farming sector and aviculture supply chain, in order to get the global picture and the main challenges we are facing and SUSTAvianFEED project aims to contribute to deal with.
2. In second place, it is key to analyse the resources flow among the different stages of the supply chain and the possibilities that by-products and wastes can be considered as resources and used in other stages of the aviculture supply chain as well as in other activity sectors.
3. In third place, it is key to understand how the different stakeholders interacts from a business perspective and which are the factors that make them interact.

### 2.1 The aviculture supply chain: use of resources in the global context

The Food Agriculture Organization (FAO) calculates that 40% of all arable land is being used to produce animal feed (2012). In addition, livestock takes up nearly 80% of global agricultural land, yet produces less than 20% of the world's supply of calories (Ritchie, 2017). Furthermore, according to Tamminga (2003) fifty percent of fertiliser applied to agricultural land and 70% of herbicides used in agriculture are attributed to animal feed production, and feed production uses 37% of all the water estimated to be used in crop production (Gerten, 2011).

Furthermore, FAO (2013) estimates the emissions of the livestock sector at 7.1 gigatonnes CO<sub>2</sub>-eq per annum (poultry meat and eggs contributing 8 percent to the sector's emissions), representing 14,5 percent of human-induced GHG emissions.

This contribution to climate is also a determining factor for the sector, as food systems will suffer the inevitable effects of climate change. In several aspects:

- On one hand, the climate crisis will drastically affect the supply chains in a global view. Floods, droughts, sea-level rise and other extreme events may affect not only the crop cultivation, but also damage in ports, roads, or trains, which will affect the global supply chains of raw materials.  
A recent example of this occurred in Canada during the floods in November 2021. Road and rail closures delayed cargo arrivals at the port of Vancouver, which handles most of the country's grain exports. This resulted in ships returning to Asia with empty containers due to a lack of space to store the containers, leading to additional delays in Canadian exports and, in turn, affecting international shipping (Marowits, 2021).
- On the other hand, it is crucial to mention that the Mediterranean area is suffering a severe drought, which will be even more important in the future. This, joined with the fact that floods and extreme events will increase, makes it important to adapt the farming sector to the inevitable impacts of climate change.
- Finally, the relations between inequality and these effects are something to be considered for the implementation of the actions for fighting the climate crisis.

The current emissions and temperature trajectory also translates into global food shortages and higher prices, which would particularly hurt the poorest people and increase the risk of social unrest. One of the most striking examples is that of maize. The probability of losing 10% or more of the harvest in several parts of the world in one year rises from almost 0% under the current climate scenario, to 86% if emissions continue to rise. It may be limited to 7% only if emissions are drastically reduced (Robaina, 2022).

Therefore, the development of more sustainable and resilient food systems is key to mitigating climate change and also adapting our world to its inevitable effects, which is crucial for the next years and decades. New food chains must be environmentally friendly, foster local economies and consider social aspects. Approaches for this in the aviculture sector are listed in section 3 of the document.

However, prior to this, it is necessary to distinguish the difference between intensive and extensive farming in the use of resources and wastes generated and also to include some particular information regarding the aviculture sector.

There are environmental factors such as greenhouse gases, energy use, erosion of land, etc. to be considered. It is not only what system has lower carbon footprints; waste management is also an increasing challenge. The blue water footprint (volume of surface and groundwater) and grey-water footprint (pollution of surface or groundwater), and feed conversion efficiency are also to be evaluated. In the case of intensive systems, that has larger dependence on concentrated feed, the intensification of animal production will result in increasing blue and grey water footprints per unit of animal product (Mekonnen & Hoekstra, 2010) as well as other critical environmental impacts.

Taking into account that most animal products today are being produced in intensive farming systems (approximately 66% according to Niamir, 2016), it is necessary to develop appropriate policies to mitigate their impact. Investment, access to credit, regulation, incentives for sustainability, and adequate fiscal and trade policies related to the environmental costs of production, are actions necessary to mitigate the environmental and social impact. A unified global standard for certificate schemes on production is also an interesting measure. The main factors influencing the sustainability of intensive and extensive systems are described in Figure 1. Conceptual framework for sustainability in the livestock sector Figure 1

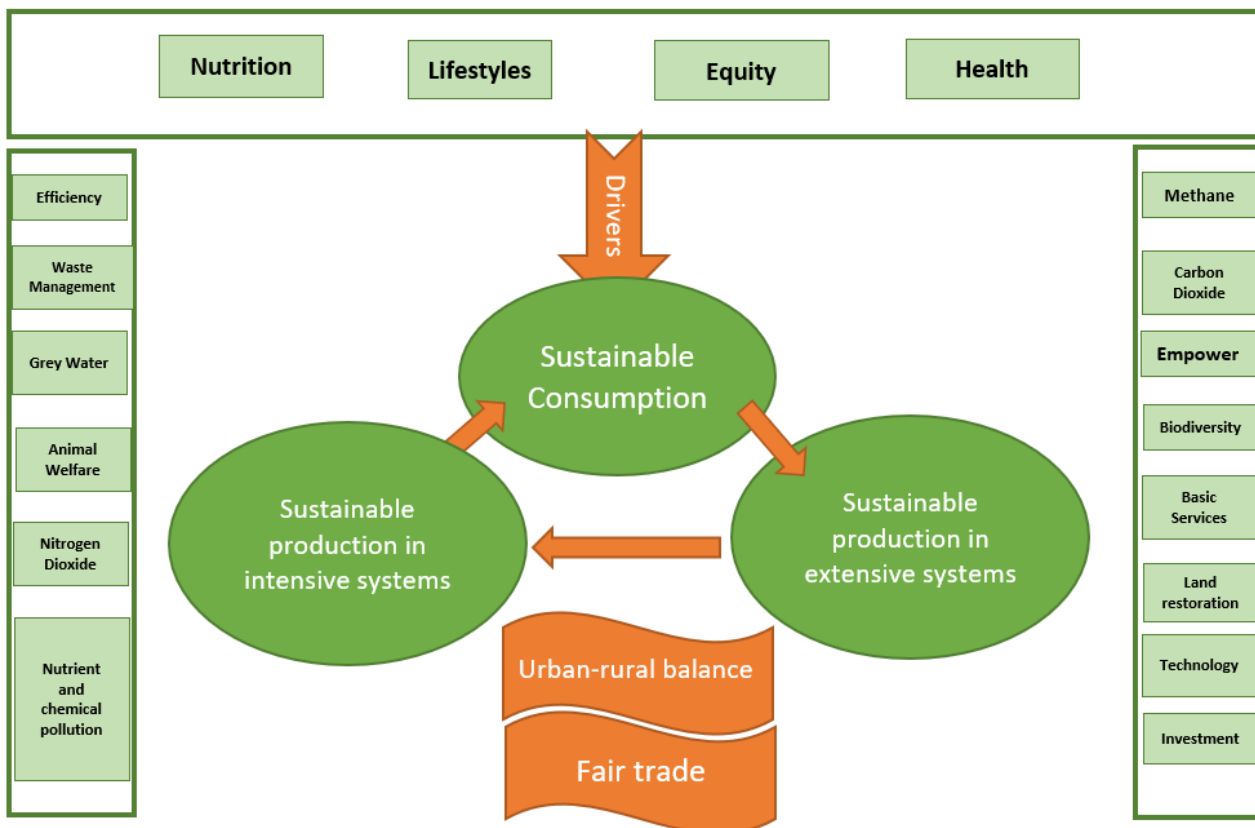


Figure 1. Conceptual framework for sustainability in the livestock sector (Adapted from Neami, 2016)

It will be also necessary to tackle overconsumption. The green economy is not only linked to production but also consumption patterns that have to be adequate to the limitations and respect for the capacity of regeneration of the planet's ecosystems. Consumers also have an important role in generating a responsible demand that impels a sustainable supply.

Environmental policy of governments will be inevitably related to the moderation of growing demand for animal products in countries where the consumption of animal products is still quickly rising, one of the keys of the policies may be promoting a dietary shift away from a meat-rich diet (Mekonnen & Hoekstra, 2010).

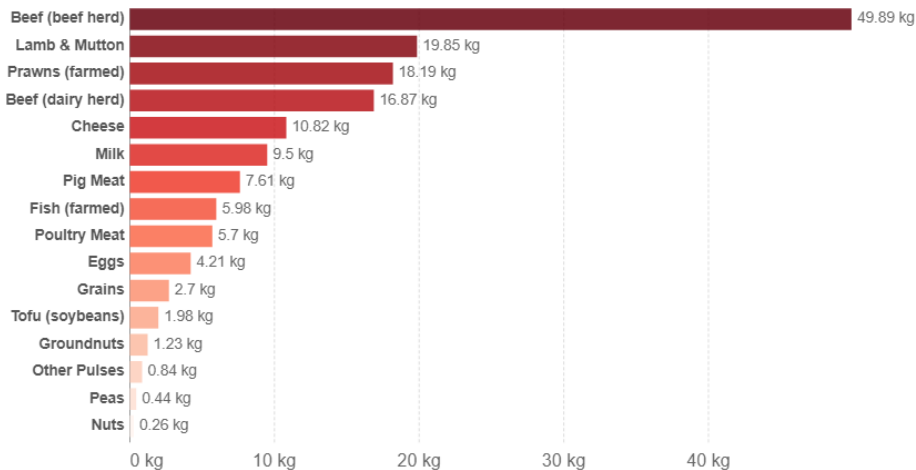
In this logic of making the food system more sustainable, there is also one aspect, which should be considered: several regions as North-African countries, because of the improvements of the socio-economic conditions of the population, will have more access to resources and animal food products and quality sources of proteins.

In order to satisfy this expected increase in protein demand without creating an environmental impact, it is important to consider the climate impact of different animals and plant-based products is essential. This is, we should promote more environmentally friendly food chains and also foster those food of proteins which a lower environmental impact as explained in Figure 2 and Figure 3.

### Greenhouse gas emissions per 100 grams of protein

Our World in Data

Greenhouse gas emissions are measured in kilograms of carbon dioxide equivalents (kgCO<sub>2</sub>e) per 100 grams of protein. This means non-CO<sub>2</sub> greenhouse gases are included and weighted by their relative warming impact.



Source: Poore, J., & Nemecek, T. (2018). Additional calculations by Our World in Data.  
 Note: Data represents the global average greenhouse gas emissions of food products based on a large meta-analysis of food production covering 38,700 commercially viable farms in 119 countries.  
 OurWorldInData.org/environmental-impacts-of-food • CC BY

Figure 2. Greenhouse gas emissions per 100 grams of protein (Our World in Data)

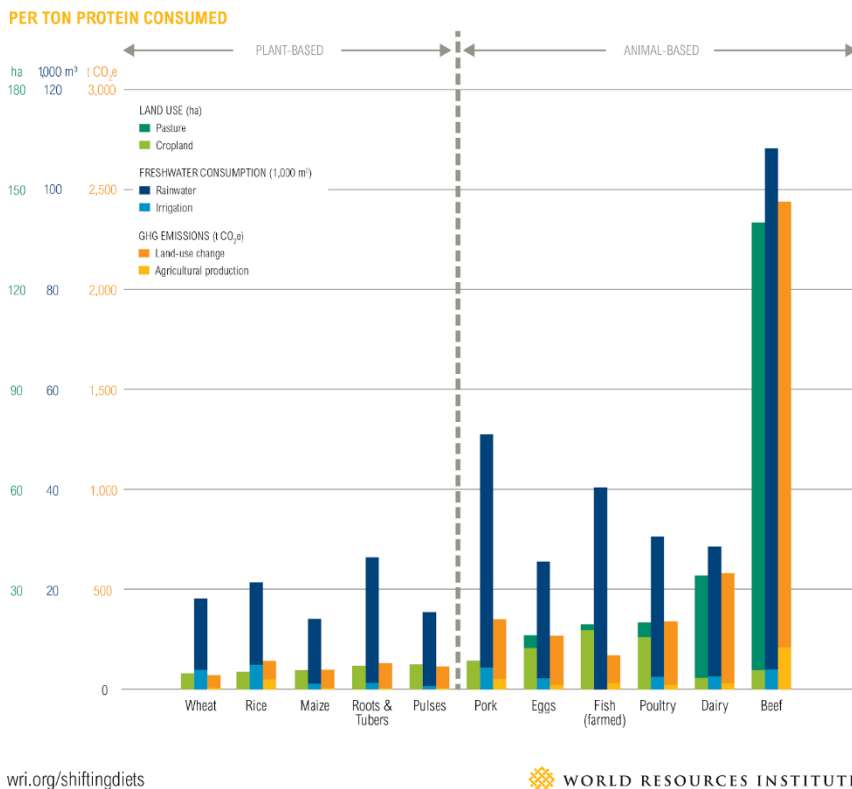


Figure 3. Environmental impact per ton of protein (World Resources Institute)

It is clear that meat consumption has a greater impact in terms of sustainability than a plant-based diet. However, it is also well known that meat consumption will not disappear and the animal-based diet will continue to be the majority in the following years.

In that context, to deeply understand the supply chains so sustainable approaches are proposed is a must. Furthermore, poultry meat and eggs have a lower environmental impact than beef, dairy products, pig or fish, so, promoting sustainable food chains in these two sectors becomes especially relevant.

## 2.2 The aviculture supply chain: resources flow

The aviculture sector involves seven main stages to be considered during the entire supply chain:

1. Primary production
2. Animal feeding
3. Breeding/ Poultry farm
4. Slaughterhouse
5. Processing: Meat elaborates / Egg packing plants
6. Distribution and selling point
7. Consumers

### Primary production

The primary production makes reference to the stage involving the production of primary agricultural crops and insects to be used in the animal feeding.

FAO (2013) identifies 4 types of feed crops: second grade crops (food crops that do not match quality standards for human consumption and that are fed to livestock), feed crops with no co-products (crops cultivated as feed, e.g., maize, barley), crop residues (residues from food of feed crops, e.g., maize stover, straw), and by-products from food crops (by-products from food production and processing, e.g. soybean cakes, bran).

### Animal feeding

Animal feeding stage refers to the production of feeding from raw materials, which consists in a vast number of crops and in which the use of corn and soybean meal stands out.

### Breeding of laying hens and Poultry farming

This stage involves raising laying hens and broilers (chickens raised for meat are called 'broilers' and are different from egg-laying hens):

- Broiler Production
- Breeding: the broiler chain begins with a primary breeding company that is responsible for formulating broiler breeders (parent stock). A breeding company is responsible for producing strains with desired characteristics in the broiler stage and chicken meat.
- Hatching: Fertile eggs collected from broiler breeder flock are delivered to hatcheries where they are incubated and one-day old broiler chicks are produced.

- Grow-out houses: Chicks spend several weeks (depending on the type of farming) growing until they reach market weight.
- Laying Hen Production
  - Breeding: The process starts with a primary breeding company or parent stock (layer breeders). Layer breeders lay eggs intended for hatching. These eggs are sent to hatcheries.
  - Hatching and pullet farm: After hatching, the chicks are immunized and go to pullet houses to gain weight. 'Pullets' (young hens), will reach 'point of lay' (age at which they lay their first egg), between their 16th and 24th week of age, depending on the breed.
  - Layer farm: At this moment (after reach 'point of lay'), the pullets are transferred to the layer farms, in the ensuing laying period, which lasts one year on average, the hens lay at least 300 consumer eggs.

It is necessary to distinguish between different kind of species: commercial, commercial hybrid and autochthonal breeds.

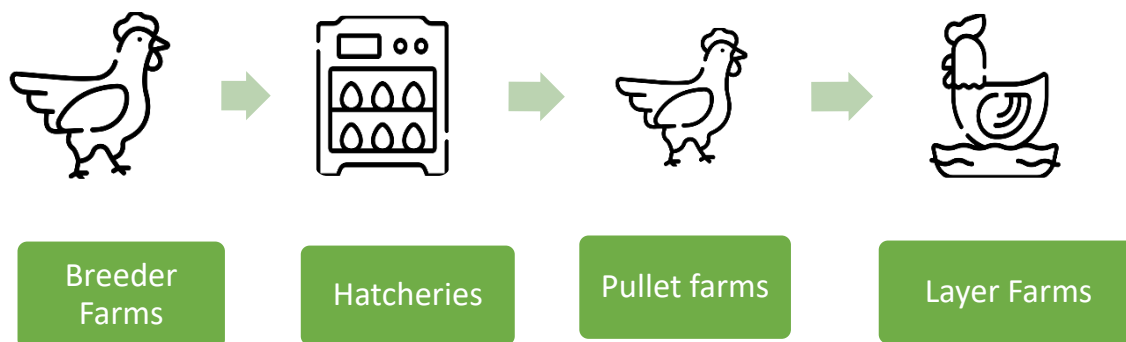


Figure 4. Stages involved in the breeding of laying hens

## Egg production



Figure 5. Egg production systems according to the method used to house the laying hens

There are four main productions systems, depending on the method to house the laying hens. These are:

- Cage production: In this system, hens are housed in sheds with automatic feed and watering. The collection of eggs and manure is also automatized. In Europe, 45,5% of the laying hens were kept in enriched cages by 2021 (European Commission, 2022).
- Barn laid: Hens are housed in large barn systems without cages, and are free to roam within the shed, however, do not have outdoor access.
- Free-range production: Hens are given the opportunity to roam indoor and outdoor during daylight hours.
- Organic: These systems are free-range and hens are fed organic feed.

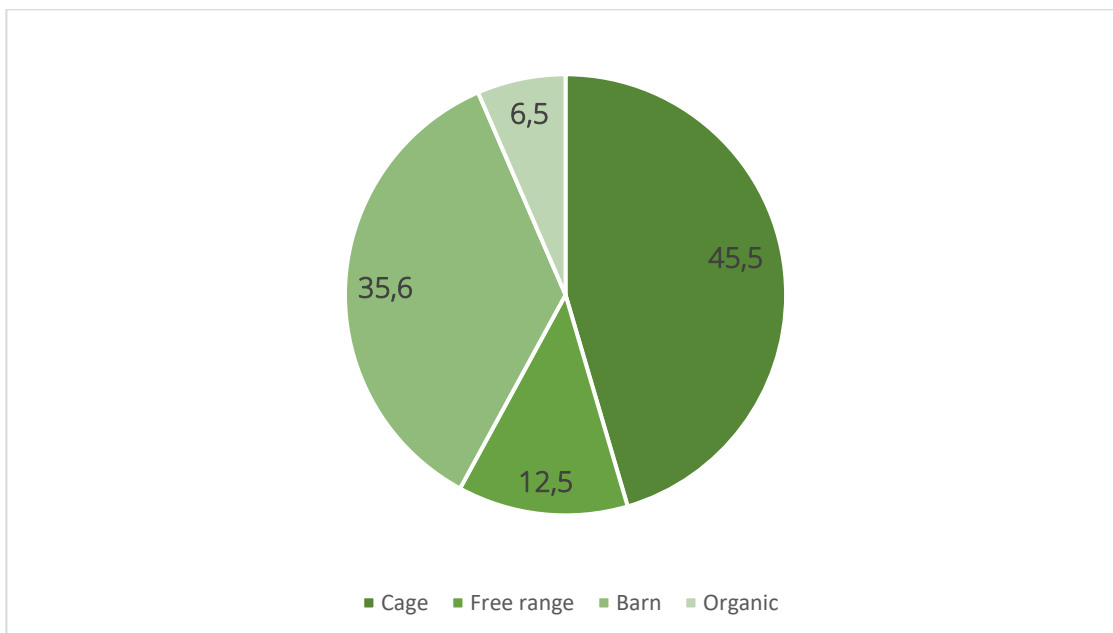


Figure 6. EU Number of Laying Hens 2021 by way of keeping  
Based on notifications under Commission Implementing Regulation (EU) 2017/1185. Eu without UK.  
Source: European Commission.

The poultry farm stage uses animal feed produced in the previous stage and other complements as veterinary consumables or medicines.

## Slaughterhouse

When broilers grow to the ideal weight, in the slaughterhouse stage, the animals are sacrificed and prepared for the meat elaborates process.

There are two main factors that determine processing timeframes: weight and/or the animal's age. The age being the most commonly used in intensive farming to avoid overfeeding, and since the feed is controlled, it is easier to predict the maturity and weight of the animal based on its age.

According to Baxter *et al.* (2021) a slaughter weight of 2.5 kg can now be reached in 38 days compared to 63 days in the 1960, as modern broilers are characterised by their rapid growth rate, high feed efficiency and high meat yield.

Free-range broilers will usually be slaughtered at 8 weeks old and organic broilers at around 12 weeks old. In this case, weight is a better indicator of the maturity, as there is less control over feed ratios and what animals are eating.

## Processing: Meat elaborates/Egg packing plants

Regarding the meat elaborates stage, different additives produced by specific manufacturers are added to the final product besides the fresh meat obtained from the slaughterhouse.

At the same stage, in the case of eggs, egg packing plants are in charge of egg conditioning (sorting, grading, labelling and packaging), this process can be done by the layer facility or by other egg marketing companies. Typically, eggs are distributed the same day as laid.

There are some marketing standards designed to ensure the quality of the eggs. For that reason, eggs should be marked and graded by quality and weight.

## Distribution and selling point

Distribution has to be considered not only in the last stage but also between all of them, as transportation is required from one stage to another. Distribution of raw materials, feed, hens, elaborates and eggs, as well as wastes. Selling points offer the final product to the client, most of the time it refers to retailers or big surfaces.

Some farms have direct relationships with retailers; others sell to wholesale outlets and distributors. The logistics for getting this kind of products safely, involve dedicated distribution centres and fleets of refrigerated trucks.

The destinations of the products after the processing phase, could be:

- Public sales and markets
- Direct to restaurants and food services
- Wholesalers that supply the manufacturing, food service and catering sectors
- Smaller retailers (e.g., small supermarket chains)
- Larger companies (e.g., suppliers and distributors)





Figure 7. Poultry products by purpose

### Consumers

And finally, consumers as the last and one of the most important actors of the supply chain. The consumers' concerns have created a market for products, which are aware of animal welfare and environmental impact.

Worldwide, average per capita consumption of eggs is estimated at about 200 eggs annually, ranging from the high of 350 (Mexico) to a low of 57 (UAE, Nigeria and India). Residents of the US and Europe eat an average of 250 and 240 eggs per year, respectively. Consumers demand for cheap and uniform products, this caused eggs and poultry to be one the most intensively produced and industrialised of all protein supply chains, with highly controlled environments, large-scale flocks and few production facilities (Pullman and Wu, 2021).

In the case of meat, the consumption stage is the one that has the greatest influence on the waste of meat products, however, is difficult to collect the by-products generated in this stage due to the dispersion of the households and the complexity of the separation from other wastes Pinto *et al.* (2022).

In summary, the importance in consumers resides the most in their consumption habits. More sustainable consumption habits would lead the aviculture to the adoption of more sustainable practices.

### Summary

Environmental impacts stem from the scale of production and a lack of consideration for the effects of inputs (land, water and energy) and surplus outputs, such as manure and by-products, which cause air, water and land pollution and the depletion of natural resources (Pinto *et al.*, 2022).

FAO (2013) estimated the mitigation potential for reducing GHG emission chains at 14 percent. This estimate is based on several assumptions, including constant output, no farming system change and the adoption of efficient production practices: improving feed conversion, optimal manure management, reduction of animal mortality in backyard systems and improved animal health care.

An approach to the aviculture supply chain used in this document is described in Figure 8.

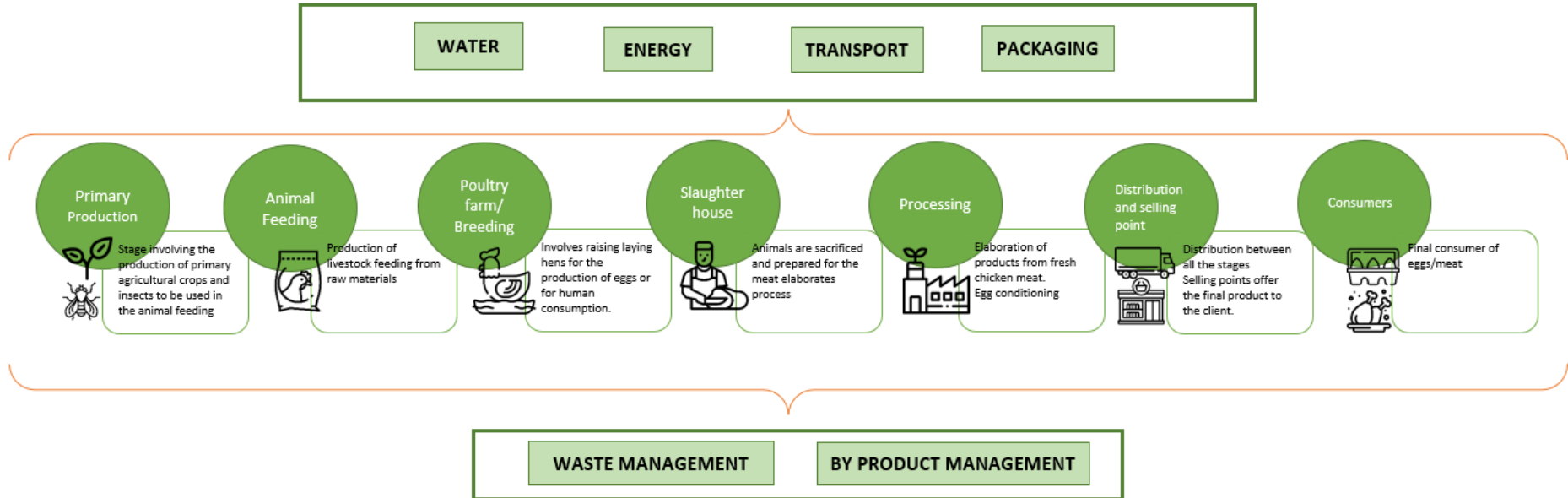


Figure 8. Description of the aviculture supply chain

## 2.3 Business interactions along the supply chain

The supply chain of the farming sector, in general, and the aviculture sector, in particular, is formed by several actors of different nature and sizes and operates in different stages of the supply chain.

The tendency in the last few decades in the sector is that big groups (companies and cooperatives, mainly) are gaining even more importance in the sector and they operate in all (or almost all) different stages of the supply chain. This is a big competence for small producers, smallholders, providers, and other actors which operates in a single stage of the supply chain, as they have power in controlling prices, margin benefits, and, in many times, even a great influence in changes on the legislation.

Nevertheless, the smallholders, feed producers and other actors, which operate in a single company, continue to have their importance and are still crucial actors. Many of them would have agreements with these big groups, while others may operate by themselves.

As an example of this last aspect, within the broiler supply chain, big groups often own the feed mills that supply the feed for their birds and provide veterinarian services and it is important to highlight that more than 90% of all chickens raised for human consumption in places such as the US and Europe are produced by independent farmers working under contract with integrated chicken production and processing companies such as Tyson (US) and LDC (Europe), (Pullman and Wu, 2021). This is, they directly work for these big groups.

Finally, the public administration and policymakers have a big influence in the different interactions of the supply chain. Incentives for small producers or easiness for big groups would be determining to promote one or other type of organization.

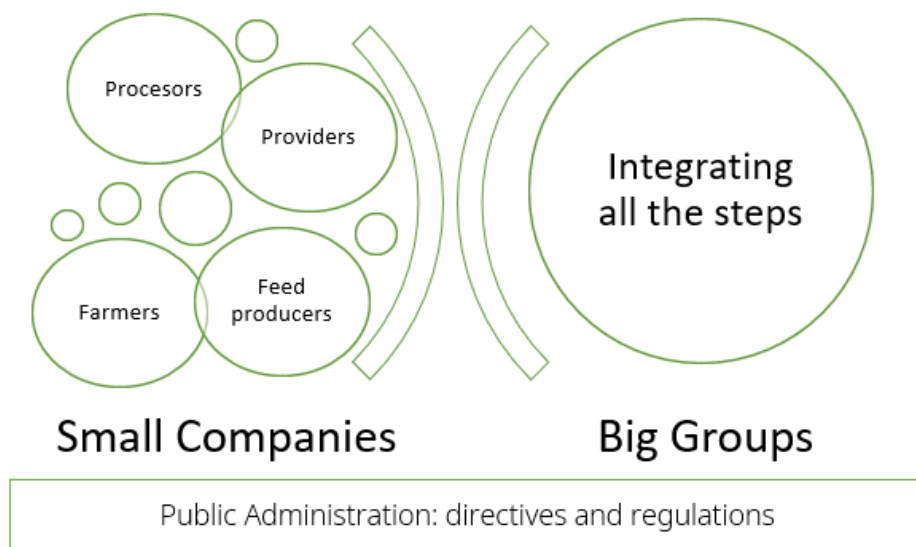


Figure 9. Main groups of stakeholders involved in the poultry supply chain

The main stakeholders interacting in each stage of the supply chain are included in section 3, while the patterns of waste of that stage are analysed.

## 2.4 Differences and similarities in Mediterranean regions

After all this analysis, it is also important to study the differences and similarities of different regions. In this case, the different project countries' situations have been studied. Insects' production, a key aspect of project which has been studied in detail in Deliverable 2.2 "Potential for insect production in each pilot area", has been included in this analysis:

### a) Spain

#### Primary sector

In Spain, big companies and cooperatives are the ones in charge of the primary production. Small and family producers have been displaced and, for decades, they have much lower importance. This applies to farming and livestock and it is relevant to the aviculture sector and other kinds of farming practices.

#### Feed producers and farms

The feed producers are also big companies or group of companies/cooperatives which produces a vast amount of feed. In the past, around 40 years ago, it was usual to have animals at home and to feed them with local materials, food leftovers, etc. This was typical, especially in villages and the rural context. People used to have little farms at home.

However, by now, this has changed and it is strange to find this kind of practice even in rural places. Even more, the tradition is just maintained in a minor way by the elderly, and no generation turnover is expected until now.

In addition, small producers do not have a big market share. The organic market may increase the possibilities for small and local producers, even though big groups may adapt to the market if needed also for this organic share.

#### Processing and distribution

Regarding the processing stage, it works very similarly to the feed producers and farms stages. In some cases, big groups control the whole process or subcontract some processes.

Small producers and families are also involved sometimes in the whole process, although they just produce a little number of eggs/meat, due to the lack of resources.

For the distribution stage, big groups with high economic capacity usually have their own distribution fleets. In some cases, they also subcontract a logistic company.

Regarding small and local producers, they may try to use clean means of transport in order to have some kind of differentiation in environmental aspects, even though this is difficult for them due to lack of capacity.

### **Selling stage**

Big supermarkets are displacing more and more local markets and small markets/stores. This happens especially in the big cities. There is still a presence of small commerce, however, the tendency is the opposite.

### **Organic production**

The industrial model has major importance nowadays in Spain. The organic market is offering new opportunities to small producers; however, they just represent a little market share. Big groups may adapt to the organic market as well if there is a need and a consumer's demand, so they will be also part of the transition to the organic market. They have marketing power in order to sell these changes just because of the regulation.

It is true that even though just for a minor group of the population, local markets and local consumption habits are having more influence in the last years. This may continue in the following years.

### **Consumer awareness**

Although there is a lot to be done, we can say that the consumers' awareness is in the best momentum ever. The new labelling for eggs in Spain is also introducing the animal welfare aspect in place, as it shows if the hens are in cages, barn, free-range or organic.

In addition, the number of consumers, which pay attention to the origin of products, the way they were produced, and other environmental aspects are increasing (being still low in comparison with the general public).

### **Differences from the meat to egg sector**

The organic/sustainable market has more power in the egg sector. Small producers can do the egg production while for the meat sector there are more difficulties for this. In this sense, developing a sustainable approach for eggs seems to have more potential than for meat at the moment.

### **Legislation to a more sustainable sector**

In Spain, the legislation is forcing companies to make more sustainable practices, however, in a limited way. It is true that the nitrates directive and other laws, as well as the different eco-labels, are trying to make the sector more sustainable. However, in practice, no relevant sustainable practices are being implemented by law and this should be improved. It is important to remark that the EU commission Farm to fork strategy (2020), which is adopted as well at a national level, empathizes with the need for the transition towards a more sustainable sector; however, the adaptation process will take time.

In addition, the Next Generation Funds includes several grants to develop a more sustainable farming sector. Nevertheless, not every farm can obtain them and there is not enough resource for this.

The legislation changes should be based on a mixed scheme, in which the public administration, private companies, and consumers, should be part of the solution and not just one actor assumes the cost of the transition to a more sustainable system.

### **Business organizations**

In big groups and more structured companies, there is a clear differentiation between the different actors involved in the supply chain, at the same time they work for the same company. On the other hand, small-scale farmers tend to participate directly in all the stages because of a lack of resources, delegating, in some cases, just the last phase of distribution to specialized companies. In some cases, small companies just participate in one stage.

### Insects' production

Spain follows the EU directives in terms of policies, research and legislation, thus, fomenting the use of insects as food and feed to supply the food chain.

- In terms of policies, EU encourages the use of insects for its circular approach and because it uses triggers two problems in one shoot, the reduction of organic waste and the production of raw materials produced locally. This policy determination reflects in directives, subsidies structures, and legislation.
- From the research point of view, there is an interest to support projects incorporating insects as a source of raw materials and demonstrating the usability in different farm animals like fish, pigs and poultry.
- Legislation that covers insect production has been created, allowing insect farming for food and feed, as far as the feedstock is adequate (vegetables, egg products and milk products) and good management practices are used. The insects produced as such can be used to feed fish, poultry, pigs and pet food. In the case of chickens, the larvae can be used alive, dried or processed into ingredients.

Apart from the commented administration status of insects in Spain, from the commercial point of view, there is a trend in insect production for feed. Main companies to comment, Bioflytech, based in BSF production; Tebrio, based in Tenebrio production (a species of darkling beetle); Bioento, based in BSF production and ENTOMO Consulting as a technology provider for BSF production. Apart from that, many small enterprises are emerging based in the same principle.

Insect production depends on a supply of raw material or feedstock to feed the insects. Fortunately, Spain is an agricultural country and thus with a good source (in quantity and quality) of agricultural by-products to be used in insect production. Overall, Spain has a big potential for insects as feed for farm animals.

### b) Italy

#### Primary sector

Italy is a country with many geographical differences, which are reflected in the primary sector; climate and temperature vary between different areas and allow each region to have peculiar productions. Indeed, in the northern area, which is the most industrialized, many companies over the years have grown considerably in size and production volumes even though some of them are still family-owned.

Moreover, in some of the more marginal territories, there are many small producers, which are dedicated to the conservation of typical products of their area. Italy is, in fact, the European country with the largest number of agri-food products with designation of origin and indication recognized by the European Union (315 products).

Moreover, for the poultry sector, Italy has more than 6,200 poultry farms on its territory divided into fattening, laying and breeding, and weaning farms. The panorama is completed by 400 factories to produce feed, 174 small and large slaughterhouses, and over 500 factories for cutting and processing meat products and preparations (ISMEA).

### Feed producers and farms

Feed producers are mainly big companies. Usually, local and small farmers tend, if possible, to auto produce the feed of the animals, but even on a small-scale farm, it is common to buy the feed from big companies.

Regarding the production of animal feed, among the European countries, Italy with its 9% occupies sixth place (ASSALZOO, 2019). Among the feed sector, we can find in the first place the feed for poultry, chickens, turkeys, laying hens and others, with an overall incidence of this sector of over 40% of the total feed produced. Feed production shows a very slight decline, passing from 5,915 tons to 5,870 tons (between 2018 and 2019) (ASSALZOO, 2019).

On the other hand, 25.8% of total production is destined for pig farming, which marked an increase of 3.5% (from 3,605 in 2018 to 3,731 tons in 2019) (ASSALZOO, 2019).

A more marked growth has instead affected the bovine sector, recovering after years of difficulty, with + 4.6% (from 3,250 to 3,399 tons between 2018 and 2019), which leads it to reach 23.5% of the total (ASSALZOO, 2019).

The small farms are obviously also those that preserve the biodiversity of the ancient poultry breeds, associating the conservation of biodiversity to differentiated agricultural activities and often activities of reception for tourists (agrotourism). The animals are raised outdoors even if unfortunately, the integration to the food found in natural contexts is made with feed suitable for broilers raised intensively, and this makes the nutritional results of the meat not up to what an outdoor farm offers.

Unfortunately, there is not enough awareness of the value of local breeds even as functional crossbred animals. They are less productive in general and therefore it is difficult to get out of the circuit of conservation for its own sake, but some of these breeds can be a very interesting resource for those who want to breed outdoors in sustainable agriculture contexts. Slow Food, with its Presidia, is trying to promote those who preserve these breeds (6 are listed in the FAO database, but there are more in the country).

### Processing and distribution

The processing and distributing stages are strongly correlated to the feed and the farms' stages. In the last 20 years, in particular, the extreme growth of large-scale distribution has led to a significant increase in big companies, in particular regarding distribution, where even the small farmers' and producers rely on these big companies to sell their products.

### Selling stage

Big supermarkets, especially in big cities represent most of the selling stage although in recent years many local farmers markets are growing.

Italy has the largest network of farmers' markets for direct sales in the world, surpassing France and the USA in 2019. Almost 59% of Italian consumers have gone to the farmer's shop at least once a month in 2019 to buy local zero-kilometre products directly from producers (COLDIRETTI, 2018).

### Organic production

Italy is self-sufficient in poultry production, for both meat and eggs. In Italy, organic production has risen significantly in recent years, since 2010, the number of operators has grown by 69%, while the hectares of the cultivated organic surface has increased by 79%. Italians continue to reward organic fresh products [fruit (+ 2.1%) and vegetables (+ 7.2%) and, in some specific categories, which have long been the standard bearer of the sector (eg eggs + 9.7%) (MIPAAF, 2020).

All this has contributed to the building of an extraordinary network, which includes over 130,000 Italian farms that mainly sell directly; in farmers' markets, on the other hand, Italian's spending exceeded 6 billion euros (Ismea, 2015). The reasons why consumers like to buy at farmers' markets are not difficult to outline: high quality products, which are fresher, tastier, and more genuine, are certainly the main reasons

A recent survey carried out thanks to a European project (Ppilow<sup>1</sup>) asked a sample of European consumers about their poultry consumption and their perception of animal welfare. It emerged that citizens view low-input organic and non-organic production more favourably than conventional indoor production, and they declare to be willing to pay a price premium for animal-friendly products. However, a substantial proportion of citizens do not know which farming practices provide better animal welfare. This suggests that there is a lack of knowledge among citizens and that they may have difficulty evaluating complex production practices. Thus, there is a need for more communication between farmers and citizens, and communication that conveys consistent messages through reliable sources of information. It is probably time to implement more informative labelling for consumers because they have become more aware: that the codes used for eggs are not enough.

### Consumer awareness

Italians are increasingly interested in the health and environmental sustainability of food products. Probably, the pandemic situation is having a "positive" impact on eating habits, given that during the lockdown the Italians turned more towards organic and biodynamic foods. Based on a recent survey about modern distribution purchases of organic products grew by + 7% in 2020 compared to 2019, for a total value of more than 4.3 billion totals (ASSOBIO, 2021).

### Differences from the meat to egg sector

Competencies and awareness of the meat sector need to be improved in final consumers; people tend to buy easily broiler meat from supermarket without questioning what they are buying. On the other hand, eggs have seen, especially in recent years, many marketing campaigns and interest from the final consumers, which have led to more conscious shopping regarding eggs even in the big supermarkets (Yeh *et al.*, 2020).

<sup>1</sup> <https://www.ppilow.eu/consortium/>



### **Legislation for a more sustainable sector**

Especially in recent years, with the rising awareness of climate change and environmental pollution, the majority of people are demanding stricter legislation to assure sustainability and animal welfare.

European Union is promoting this trend with the next generation EU plan and the Italian government has received it with the recovery and resilience plan in which the ecological transition is one of the pillars and constitutes an essential guideline for future development.

The Mission, called Green Revolution and Ecological Transition, deals with the major issues of sustainable agriculture, the circular economy, the energy transition, the sustainable mobility, the energy efficiency of buildings, water resources and pollution, aiming to improve the sustainability of the economic system and ensuring a fair and inclusive transition towards a society with zero environmental impact (PNRR, Italian government, 2021).

### **Business organizations**

In big groups and more structured companies, the differentiation between all the actors involved in the supply chain is very structured and diversified. On the other hand, small-scale farmers tend to participate directly in all the stages delegating, in some cases, just the last phase of distribution to specialized companies.

### **Insects' production**

Italy shares with Spain similar conditions in terms of EU policies, legislation and research activities, which could be considered favourable for insect production.

From the feedstock point of view, Italy, like Spain, has a strong agriculture industry with abundant vegetable by-products, which can be used in insect production. Examples of abundant raw materials are vegetable trims proceeding from fruit sorting houses, olive fruit pulp from the olive oil industry, or off quality products produced in the abundant Italian food manufacturing industry (pasta, bread, or cookies among others).

There are no important enterprises producing insects for feed and apparently, little or no product is available to feed the poultry. To mention an insect producer, Cenafly is a start-up that will use BSF to treat vegetables and produce feed ingredients.

In general, it could be considered that feed ingredients are relatively cheap and one constraint in insect operations to produce poultry feed ingredients is to compete with cheap raw materials such as soybean, barley, wheat, or corn. The same applies to Spain.

## **c) Tunisia**

### **Primary sector**

Before the 1960s, industrial poultry farming was non-existent in Tunisia and poultry products were produced from poultry farming. From 1970, industrial poultry farming was promoted due to governmental investments and credits to farmers and the entry of organised entrepreneurs. Currently, the industrial poultry sector (commercial breeds) in

Tunisia provides self-sufficiency in broiler meat and table eggs since the 1980s and turkey meat since the 90's (Karma, 2011). It counts for 33% of the value of the farm, 12 % of the Tunisian agriculture and 200,000 direct and indirect jobs.

It accounts also for more than 60% of the meat supply, and for 100% of table eggs supply. The infrastructure of the poultry sector in Tunisia has 48 broiler breeders' hatcheries, 5-layer breeders' hatcheries, 2 Turkey breeders' hatcheries, 32 slaughterhouses, 6,000 broiler farmers, 620-layer farmers, 320 Turkey farmers and 24 regional cooperatives. Moreover, this sector is very well structured and is characterized by a fast and continuous growth rate (Broiler meat 3%, Turkey meat 5,2 % and Table eggs 2%). At the poultry production level, there are audited poultry farms, professional farmers with membership cards to acquire day-old chicks, integrated companies ensuring the inputs supply as well as the technical support and regional cooperatives (Gannoun, 2019).

On the other side, there are small farmers and rural families, organized /or not, in associations or agricultural development groups. They have small hatcheries and flocks of slow breeds such as local ecotypes or Géant, Génoise, Red-Rhode Island and Fayoum (Egyptian breed). This production in extensive and semi-extensive systems remains very low compared to the industrial sector. By now, within this category, the tutored farmers by l'OEP (office de l'élevage et des pâturages) are about 600 with 58,000 chickens (Jammeli, 2021).

### **Feed producers and farms**

Main commercial animal feed producers are big companies. They import their own raw materials (maize, soybean etc.). However, some feed manufacturers are small family companies and they buy maize and soybean from the big groups of companies.

Small rural farmers of slow breeds feed their flocks with commercial feeds, and due to the high imported raw materials, they mix feeds with local cereal and bakery wastes or canteen wastes.

### **Processing and distribution**

In the industrial sector, the processing and distributing stage is mainly controlled by big companies that have all the linkages of the value chain of industrial production. Before 2007, 40% of broilers were sold in live market and 60% were slaughtered in controlled slaughterhouses (Gannoun, 2019). With the new regulation, all broilers produced in the industrial sector (commercial breeds) are processed in accredited slaughterhouses (belonging actually to big companies).

### **Selling stage**

For the selling stage, in Tunisia big supermarkets chains are the ones which concentrate the biggest share of sales (Gannoun, 2019). Concurrently and besides the new regulation, small farmers commonly sell their live chickens either in local markets or to intermediaries or to small slaughterers.

### **Organic production**

Few farmers tried to rear organic chickens, but they faced many problems at different levels of the value chain of organic poultry production (shortage of organic raw materials and feeds, high feed costs, etc). In the present situation and to our knowledge, there are no organic farmers in Tunisia.

Traditional production was marginalised since 1970 when industrial production increased. Nevertheless, since 2010 the Tunisian office of livestock and pastures (OEP) adopted a strategy to encourage slow-breeds chickens farming, by providing breeders and hatcheries to young farmers and rural women, thus creating opportunities for new jobs and establishing and promoting projects in rural and border areas. The OEP integrated then project promoters into professional structures in order to protect their interests and rights and ensure the promotion of their products and contribute to the rehabilitation of the breeding system and its integration into the organic system in a subsequent phase (Jammeli, 2021).

### Consumer awareness

Consumer awareness depends on his educational and socio-economic level. The majority of consumers are rather concerned by the product cost than by its safety, more than sustainability production or animal welfare.

### Differences from the meat to egg sector

There are no substantial differences in both sectors.

### Legislation for a more sustainable sector

The government established legislations regarding the protection of the environment such as:

- The functioning, effectiveness and efficiency of the discharge treatment or disposal facilities. At this level, wet dropping collection is prohibited and it banned the installation of new poultry farms in “saturated red” declared areas in Tunisia.
- The sources of pollution in all maritime zones subject to Tunisian sovereignty or jurisdiction.
- Observance of the requirements set out in the discharge authorisations granted by the provisions of Chapter II of Decree No 85-56 of 2 January 1985 on the regulation of discharges into the receiving environment.
- Conformity with the legislation relating to the protection of the environment and particularly with Tunisian standards concerning pollution, as well as any violation of the provisions of the abovementioned law n° 88-91 of 2 August 1988.
- There are also grants offered by the national agency for energy management to build infrastructures and purchase specific equipment to guarantee the energy economy.

### Business organization

Basically, big companies and groups of companies are involved in all the different stages: from importing breeders, and raw materials to rearing level, hatcheries, feed production, slaughtering, processing and finally distributing and selling levels.

### Insects' production

As a main difference from the aforementioned countries, Tunisia does not allow the use of animal proteins (with the exception of fishmeal) in poultry farming. It impedes directly the use of black soldier fly larvae as feed ingredients. However, Tunisia can export to Europe those meals for its commercialization, having the potential of being a net exporter of insect meals.

As companies acting, to mention is NextProtein, which produces in Tunisia and export to Europe all the production. Besides that, there is a myriad of small operations that are starting and willing to have a niche in the production market, probably encouraged for the success of NextProtein. Those operations have the potential to have an important role in the future production of this feed ingredient.

#### d) Turkey:

##### **Primary sector**

Today, approximately 85% of the poultry meat and eggs produced in Turkey are produced in integrated facilities. Broiler meat production, which shares 95% of the total poultry meat production, is well integrated in Turkey. The integration model consists of breeding flocks, hatchery, broiler producers, feed mill, slaughterhouse including rendering, and marketing. The chicks, feed, vaccine, and technical support are delivered to the broiler producers by the integration system under a written contract. There are more than 15 000 broiler producers under contract farming. Companies in the poultry sector have successfully implemented the contract production model, enabling many small producers to join the supply chain.

Small family producers usually produce free-range eggs and broiler chickens. There is no integration between organic egg and meat production. The share of free-range and organic production in total production is very low.

##### **Feed producers and farms**

Feed producer is a part of an integrated broiler breeder company. The feed mill of the integrated company supplies the feed to their contracted broiler producers.

There are also independent feed producers that supply feed to small producers. It is not common for small broiler producers to prepare their feed. While some egg producers produce the feed themselves, some buy it from the independent feed mill.

##### **Processing and distribution**

The integrated big companies also undertake the processing and distribution business. Small family producers slaughter their birds in small slaughterhouses that operate independently of integration. They sell their products at local small markets.

##### **Selling stage**

At the sales stage, large supermarket chains take the biggest share of sales. Local markets are effective in selling the small producer's products in small cities and villages.

##### **Organic production**

Organic poultry production has become popular over the last 15 years; however, the market share is less than 5 %. The number of organic broilers and laying hens was 94,585 and 749,736, respectively, in 2019. Agricultural support for organic agriculture and animal production was completely abolished at the end of 2019 in Turkey (the transition period support ended at the end of 2018). Organic producers are independent of integration. There is no contracting production for organic products. There are organic egg and broiler

meat producers' cooperatives in which small producers united, but do not play a crucial role in promoting efficiency of production (e.g., Tire Organic Egg Producers Cooperative).

There is a small amount of traditional production in small villages. It is estimated that 42 of the 214-egg consumption per capita per year is provided by backyard poultry.

### **Consumer awareness**

The vast majority of consumers know that ethical and biosecurity rules must be followed in egg and meat production. However, in egg and chicken meat consumption, the price often determines the choice. Consumers tend towards more affordable ones. Mostly in big cities, there is a group of consumers who prefer village chicken, enriched eggs, organic or free-range eggs, even if it is expensive.

### **Differences from the meat to egg sector**

There are structural differences between egg and poultry meat production in Turkey. The integrated production structure, which is widely seen in chicken meat production, is uncommon in egg production.

### **Legislation for a more sustainable sector**

Although there are regulations issued by the government regarding poultry meat and egg production, there is no legislation for the sustainability of the sector.

### **Business organization**

Integrations play a role in the supply chain at every stage of production; chick, feed, vaccine, transport, slaughtering, and marketing. The poultry housing equipment industry, feed additives, and vaccine suppliers are not included in the integrations. The actors involved in the supply chain for small producers include chick producers, feed ingredients suppliers, feed mill, and slaughterhouses.

### **Insects' production**

This country does not have a specific regulation on insect production nor a policy supporting the insect industry and it hampers enterprise's creation and expansion, since public bodies might be against new enterprises or restrict their development apparently caused by the lack of knowledge on how to deal with them. However, Turkey's regulations in food and feed production normally follow European directives and could be expected to be aligned at any time in the short term.

For insect feedstock, Turkey produces many vegetables, thus by-products are abundant to feed the insects.

In favour of the future use of insects as feed, is the price crisis (due to currency issues), which make the importation of raw materials rather expensive and consequently, favourable to locally produced feed ingredients as could be insects. There are few small enterprises offering BSF and the industry could be considered at a very early stage.

### **Main outcomes**

It is clear that, even though there are several differences between the countries, there are clear and important similarities that make the project objective relevant in a similar way:

- **Primary sector, feed producers, farms, processing and distribution:** in all the pilot areas, big groups control the whole supply chain in a major way. Despite the existence of small companies and smallholders, big groups and intensive practices are the majority in all the studied regions. In the case of Tunisia, this is a most recent situation, however, at the moment is similar to the other study cases.
- **Selling stage:** similarly, even though local markets have a presence in all the studied regions, big supermarkets chains own most of the sales of eggs and meats.
- **Organic production:** it represents a low share; however, it is gaining importance in the last few years and maybe even more important in the future. The organic market represents an opportunity in the future.
- **Consumer awareness:** In all the countries, consumer awareness is increasing, although they do not represent a majority of the population. It is also associated with the socioeconomic levels, the higher, the bigger consumer awareness, especially in Turkey and Tunisia, although also important in Italy and Spain.
- **Differences between the meat to egg sector:** there are differences in most of the regions, as it is easier to develop a sustainable approach in eggs production, rather than broiler chickens. The organic market in the egg sector is bigger nowadays and is growing even more and smallholders are more used to producing eggs than meat. This also applies to consumer awareness; there is a bigger market for eggs than for meat in this field.
- **Legislation to a more sustainable sector:** legislation and policies are fostering the change towards a more sustainable sector. However, its impact is still limited in comparison to the needs of the sector and the objectives to mitigate and adapt to climate change and the ecological crisis.
- **Business organisation:** as already explained, big groups integrate different companies or actors within the same company in all the different steps of the supply chain, due to the number of resources they have. They are the most important actors in the supply chain, while smallholders and small producers have a limited impact.
- **Insects' production:** The main difference here is the legislation that differs among countries that allow insects to be included in feeds or not. In all cases but in Tunisia, this is possible. On the other hand, all the different countries have an agriculture sector which makes it possible to develop an insect farm at different levels. Spain is the most advanced country in terms of companies working in the field.

As a general remark regarding the sustainability of the sector, it is important to highlight that big groups (and especially multinational companies) have the possibility of leading the change of the farming sector towards a more sustainable one, as they control the different steps of the supply chain, have a big market share and a lot of power regarding marketing issues. This can be positive, but also tricky in some cases, as the sustainability of these companies could be just a minor adjustment in their procedures and not a real change. To this aim, consumers and small producers will have a big role in pushing the sector in the right direction.

### 3 THE CIRCULAR ECONOMY APPROACH OF THE SUPPLY CHAIN

Once the supply chains, resource flow and business interactions have been analysed, it is time to propose a circular economy approach for closing the loop of the poultry supply chain and promoting its sustainability.

The possibilities have been classified by each step of the supply chain and are described below:

#### - Primary production

According to Pinto *et al.* (2022), agriculture and livestock production are the beginning of the FSC and are responsible for about one-third of the world's food loss and waste. The main causes are overproduction, problems in the manufacturing process, which lead to irregularly sized products being trimmed to fit or discarded entirely, or technical malfunctions that lead to product damage. The retail sector also has an influence on agriculture and livestock production due to its high-quality standards for fresh products. These standards concerning size, shape, weight, colour and appearance lead to the rejection of some products that will not be harvested, contributing to the food waste problem.

The primary production has a great opportunity to be more circular through the valorisation of agro-industrial by-products for animal feeding.

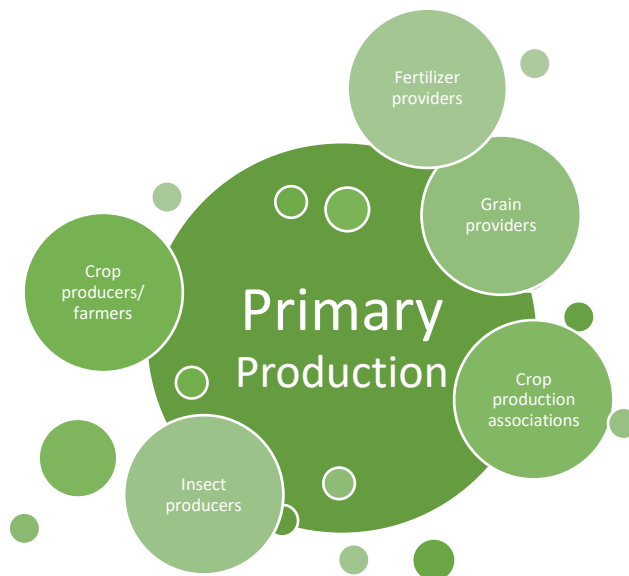


Figure 10. Stakeholders involved in the primary production stage

Main outputs produced in this stage:

Table 1. Main outputs produced in the primary production stage and possible next uses

| Primary Production  |  |  |
|---|--|--|
| Outputs   | Next use                                       | User group   |
| Crops surpluses   | Composting to use for agricultural production  | Some could be used as a biomass or for animal feeding, depending on the product. |
|   | Biomass  | Biorefineries  |
|   | Animal Feeding                                 | Farmers  |
| Fertiliser, pesticide, insecticide or herbicide containers or bottles | Re-cycle the plastic into appropriate end-uses | Plastic recyclers  |
| Damaged irrigation plastic equipment                                  | Re-cycle the plastic into appropriate end-uses | Plastic recyclers  |
| Packaging items   | Re-cycle the plastic into appropriate end-uses | Plastic recyclers  |
| Phytosanitary products  | They don't have a reuse                        |  |

#### - Insect farming

Insect farming is a circular model itself, as the insects are fed with outputs from other sectors. It allows to incorporate the animal manure into new products via insects, and food and beverages producers to incorporate their by-products into another process as insect farms.

Food services can be also a provider in this model. In order to take full advantage of the food leftovers, it is necessary to segregate the organic fraction from the non-organic and furthermore vegetables and bread from the meat (since meat cannot be used in insect feeding). An improved system to separate those categories will be significantly beneficial to this circular approach.





Figure 11. Stakeholders involved in the insect farming stage

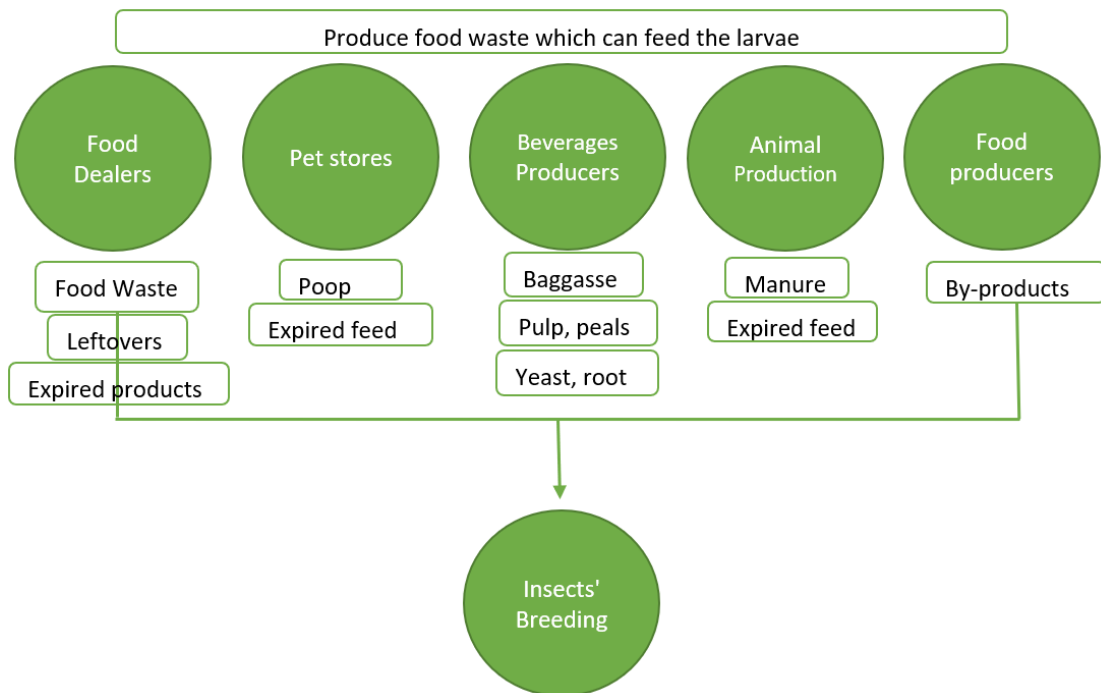


Figure 12. Main sources of by-products utilized in insect feeding

Insect production produces near to zero waste and has different possibilities for circularity: Insect frass can be used as fertiliser. Chitosan is produced out of larvae exoskeleton. There is also an effluent of chemicals that can be used in soap production.

Table 2. Main outputs produced in the insect farming stage and possible next uses

| Insect's farming   |                    |                                 |
|--------------------|--------------------|---------------------------------|
| Outputs            | Next use           | User group                      |
| Larvae exoskeleton | Chitosan           | Bioplastics<br>Food producers   |
| NaOH effluent      | Soap production    | Cosmetics and cleaning products |
| Frass              | Compost/Fertiliser | Farmer                          |

- **Animal feeding**

In this stage, sustainability can be addressed through the increase in the use of alternative raw materials, and food waste may be taken into account as an alternative feed source

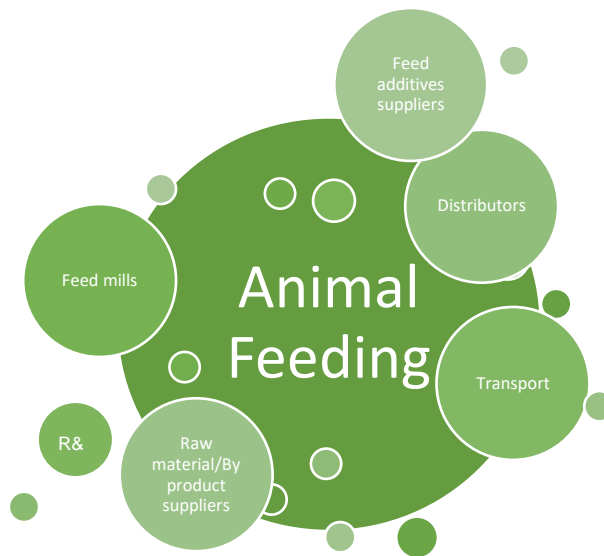


Figure 13. Stakeholders involved in the animal feeding stage

By-products, instead of being directly returned to the soil or landfilled, could be used as inputs for new production. Nowadays, the use of by-products in feeds is becoming increasingly important but is still necessary to continue researching its use, as is expected to increase over time. It is also necessary to create adequate processes and networks of factories to collect the materials and bring them back to the process.

Some examples are fruits and vegetable by-products, such as tomato pomace, brewery yeast, grape pomace, and dairy processors such as whey powder. The drying process is insufficient, highly energy-consuming, and requires to be improved, this is the case of tomato pomace and grape pomace.

Some of the raw materials used such as soybean, corn, vitamin, and minerals are imported mainly from Russia, Brazil, Ukraine, and Germany for animal-feeding manufacture.

Soybean is one of the elements of the whole process with the highest environmental impact. One of the factors related to this impact is the transportation stage. The vehicles used are mainly ships and lorries. The use of alternative ingredients is expected to reduce the environmental impact of the existing diet to reduce the need for transportation, it is necessary to encourage the use of the nearest raw materials in order to improve the use of regional production.

Table 3. Main outputs produced in the animal feeding stage and possible next uses

| Animal feeding  |   |                   |
|---|---|-------------------|
| Output  | Next use  | User group        |
| Rejected final product (feed spoilage) and feed Leftovers | Feed  | Feed manufactures |
| Vitamins & mineral containers                             | Re-cycle the plastic into appropriate end-uses      | Recyclers         |
| Packaging   | Re-cycle the plastic into appropriate end-uses      | Recyclers         |
| Bio-waste   | Biogas  | biorefineries     |
|   | Bioproducts (Proteins, sugars, plastics, medicines) | biorefineries     |

### - Breeding and poultry farming

As in other stages, in this one, the optimisation of the use of wastes is the key to improving the circularity.

The alternative production systems are going to increase over time. The commercial breeds are monopolised by a few producers. The improvement of sustainability goes through the valorisation of autochthonal breeds and the promotion of their use. The production of autochthonous breeds is very small or familiar, low technician and the number of breeds and animals are also very limited.

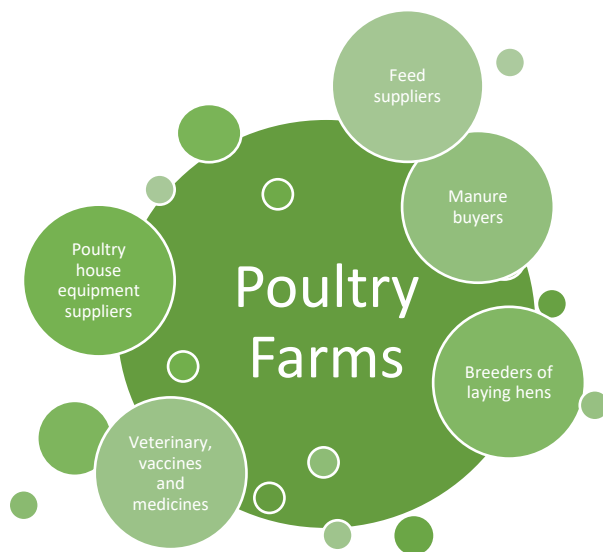


Figure 14. Stakeholders involved in the poultry farm stage

Table 4. Main outputs produced in the breeding and poultry farm stage and possible next uses

| Poultry farms                         |   |  |
|---------------------------------------|---|--|
| Outputs                               | Next use                                    | User group   |
| Manure/Slurry                         | Fertiliser                                  | Farmers  |
|                                       | Organic fertiliser                          | Fertiliser's producers   |
|                                       | Vermicompost production                     | Fertiliser's producers   |
|                                       | Dietary ingredients for fish                | Animal feed manufacturers  |
|                                       | Insects' breeding                           | Animal feed manufacturers  |
|                                       | Biogas production                           | Energy/Industry Sector   |
| Damaged equipment (feeders, waterers) | Scrap metal recycling and plastic recycling | Recyclers  |
| Dead birds/Deceased animals           | Animal food (Reptile, etc.)                 | Zoos   |
|                                       | Composting                                  | Fertiliser's producers   |
|                                       | Biogas production                           | Energy/Industry Sector   |
| Downgraded eggs                       | Liquid egg products                         | Liquid egg products factories; industrial bakeries and ice cream manufacturers |
|                                       | Egg powder products                         | Industrial bakeries and ice cream manufacturers                                |
|                                       | Pet food formulas                           | Animal feed manufacturers  |
| Spent Hens                            | Composting                                  | Fertiliser's producers   |

| Poultry farms |                          |                                    |
|---------------|--------------------------|------------------------------------|
| Outputs       | Next use                 | User group                         |
|               | Soup chicken             | Food industry                      |
|               | Processed for cheap meat | Meat industry<br>Pet Food Industry |

In the case of egg production, a good example of circularity is the case of irregular sized or downgraded eggs, which do not go to waste, instead, they have moved to process plants that produce liquid egg and egg powder products for food industry clients such as industrial bakeries and ice cream manufacturers.

### - Slaughterhouse

Every year, 70 billion land animals are slaughtered for food worldwide. But a significant proportion of these products never flow into the human food supply. Bones, sinew, organ meats, fats, and many other animal parts that are inedible to humans or undesirable in certain cultures end up as animal feed for farm animals and house pets (Pullman and Wu, 2021).

Pinto *et al.* (2022) estimate that in the case of chickens, 25% of the live weight of the chicken is lost or wasted in the slaughter stage.

Table 5. Main outputs produced in the slaughterhouse stage and possible next uses

| Slaughterhouse |                              |  |
|----------------|------------------------------|--|
| Outputs        | Next use                     | User group                                 |
| Bones          | Collagen                     | Pharmaceutical industry                    |
|                |                              | Cosmetics industry                         |
|                | Flavouring production        | Food industry                              |
|                | Composite production         |  |
| Feathers       | Low grade animal feed        | Animal Feed industry,<br>pet food industry |
|                | Feather-based raw materials  |  |
|                | Biodegradable plastic        | Packaging industry                         |
| Blood          | Development of food products | Food industry                              |
|                | Protein recovery             | Pharmaceutical industry                    |

Feathers contain nearly 90% keratin, a valuable protein and potential source for biodegradable materials, feathers are likely to produce plastics that are stronger and more tear-resistant compared to those using modified starch or plant proteins for example due to its high keratin content. The EU-funded Projects UNLOCK and KARMA2020 initiatives, develop efficient conversion techniques for feather processing, enabling large-scale manufacturing of feather-based raw materials. At present, the researchers are looking at how to make food packaging from feathers, although they are also developing other applications such as slow-release fertilisers, composite materials and flame-retardant coatings, depending on economic and technical feasibility.

Regarding other animal by-products, there are food safety rules for the processing of residues. In the case of bones, all residues from slaughterhouses must be disposed of by rendering, this represents an expense for the industry. After rendering, part of this output is usually reused as meat and bone meal for animal feed, fertilisers and bulk pet food ingredients. There are claims to flexibilize these rules and explore new to improve utilisation of bone ingredients, in other to take full advantage of the nutritional value of the bones (good source of collagen protein, fat and other minerals), and make gull use as an ingredient for nutritious foods, pet foods, pharmaceutical and cosmetics well as biodiesel and fertiliser industries.

### - Processing: Meat elaborates/Egg packing plants/Liquid egg industry

It is estimated that 15% of the live weight of the chicken is lost or wasted in meat processing and wholesale, and an additional 10% in retail and preparation. If this is added to the 25% from the slaughterhouse stage, means that only 50% of the live weight of the chicken is consumed meat (one 1kg of consumed meat for 2kg of live weight) (Pinto *et al.*, 2022).

Table 6. Main outputs produced in the processing stage and possible next uses

| Meat elaborates/Egg packing plants/Liquid egg industry |                                     |  |
|--|-------------------------------------|--|
| Waste  | Next use                            | User group                                   |
| Downgraded eggs  | Fertilising plants and feeding hens | Farmers                                      |
| Dried and crushed eggshells                            | Feeding of the laying hens/Chicken  | Farmers                                      |
| Meat leftovers   | Personal care products              | Pharmaceutical industry<br>Cosmetic industry |
|  | Pet food formulas                   | Animal feed manufacturers                    |
| Grease/fats  | Personal care products              | Pharmaceutical industry<br>Cosmetic industry |
|  | Food formulations                   | Food industry                                |
| Muscle   | Protein recovery                    | Food industry                                |
|  | Adhesive and glue                   |  |

### - Distribution and selling point

As logistics and transport are one of the stages with the greater impact in the process, the possibilities to make the process more circular are mainly related to the design of distribution strategies between the points of production and distribution chain to improve the use of regional products.



Figure 15. Stakeholders involved in the distribution stage

The current geographic distances can be the result of market mechanisms related to proximity and availability of resources, the future plans have to be related to optimising the distance between the origin points of raw materials and their destiny points.

Geographic dispersion of stakeholders is a potential limit for the overall implementation of circular models, if one industry wants to make use of the wastes from another, geographic situation could be a handicap, since emission from trips depending on distance and transport means, may be in conflict with the principle of sustainability.

However, on the other hand, the transportation cost in the supply chain may also encourage the use of alternatives.

The innovation of insect farming containers from ENTOMO, which could be installed in situ is a great example of how to close the loop efficiently.

Table 7. Main outputs produced in the distribution stage and possible next uses

| Distribution and selling point     |  |                   |
|------------------------------------|--|-------------------|
| Outputs                            | Next use                                       | User group        |
| Expired/Non-consumed eggs and meat | Fertilising plants and feeding hens            | Farmers           |
| Packaging Material                 | Re-cycle the plastic into appropriate end-uses | Plastic recyclers |

The selling points play an important role in the conscientization of the consumer about sustainability and circularity. In this stage, the main waste is the expired and unsold eggs, although the big groups have developed different strategies to prevent the waste of eggs

not acquired by individual consumers, in order to sell them to companies before the expiration dates.

**- Consumers**

Consumer's possibilities to make the process more circular: Increase their own knowledge about the traceability of the consumed meat and eggs. It is expected that the final consumer will increase their interest in alternative and more sustainable production systems. The key to hastening this cultural change is to encourage consumers to become responsible for the end-life of products and make changes in their habits.

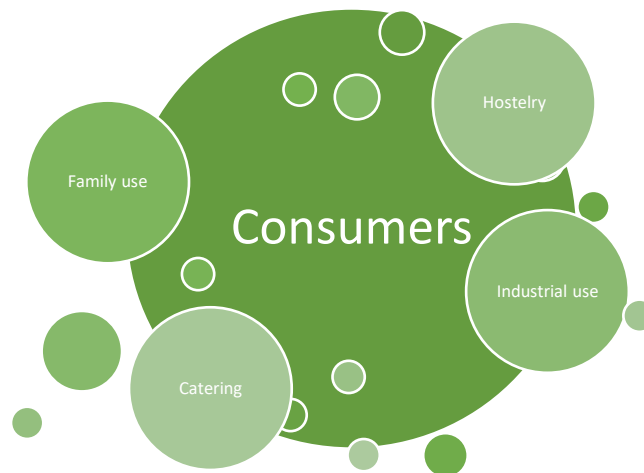


Figure 16. Final uses of poultry products

Table 8. Main outputs produced in the consumer stage and possible next uses

| Consumers          |  |                                  |
|--------------------|--|----------------------------------|
| Outputs            | Next use                                       | User group                       |
| Expired Eggs       | Fertiliser                                     | Consumers/ manufactures Breed    |
| Expired meat       | Fertiliser                                     | Consumers/ manufactures Breed    |
| Eggshell           | Fertiliser                                     | Consumers/ manufactures Breed    |
| Leftovers          | Recipes  | Consumers                        |
| Packaging Material | Re-cycle the plastic into appropriate end-uses | Plastic recyclers/ Manufacturers |

Consumers should experiment with household reuse and recycling, for example, the eggshells are rich in calcium that may benefit garden plants or chickens that consumers raise on their own, another way is to recommend appealing recipes to use leftovers.

Reverse logistics is an interesting approach to involving consumers. Borello *et al.* (2016) propose a system structured to collect bread leftovers and packaging from the consumers



and ship them to insect breeders and packaging manufacturers taking advantage of the established transportation routes, setting-up reverse logistics, using return trips after delivering products to return materials.

To involve the consumers in this collection system, it has to be accessible and consumer-friendly. Consumers should be incentivised to return materials through a system that is neither energy-intensive, costly nor time-consuming for them. Also, specialists should be involved to guarantee the preservation of the materials.

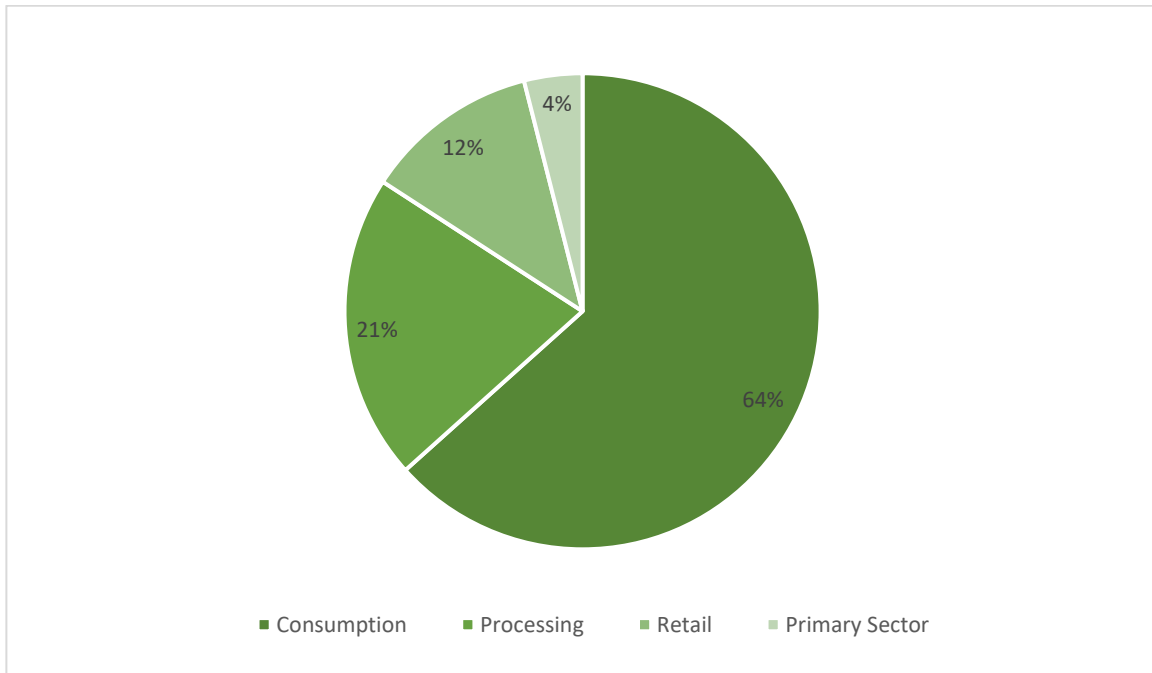


Figure 17 . Share of European meat waste by stage of the supply chain 2011.  
Source: Adapted from Pinto *et al.* (2022)

## Summary

The emphasis continues to be on obtaining raw materials and by-products from industries located as close as possible. Regular waste management is important as well, in order to achieve the circular economy model. Plastics, bio-waste, paper and cardboard and others should be appropriately collected and managed. Reverse logistics is a key to the implementation of new uses for the outputs of each stage of the supply chain.

As an example of the circularity approach Incorporated into the supply chain, an adaptation of the schematic of FAO (2016) for the egg supply is included in Figure 18

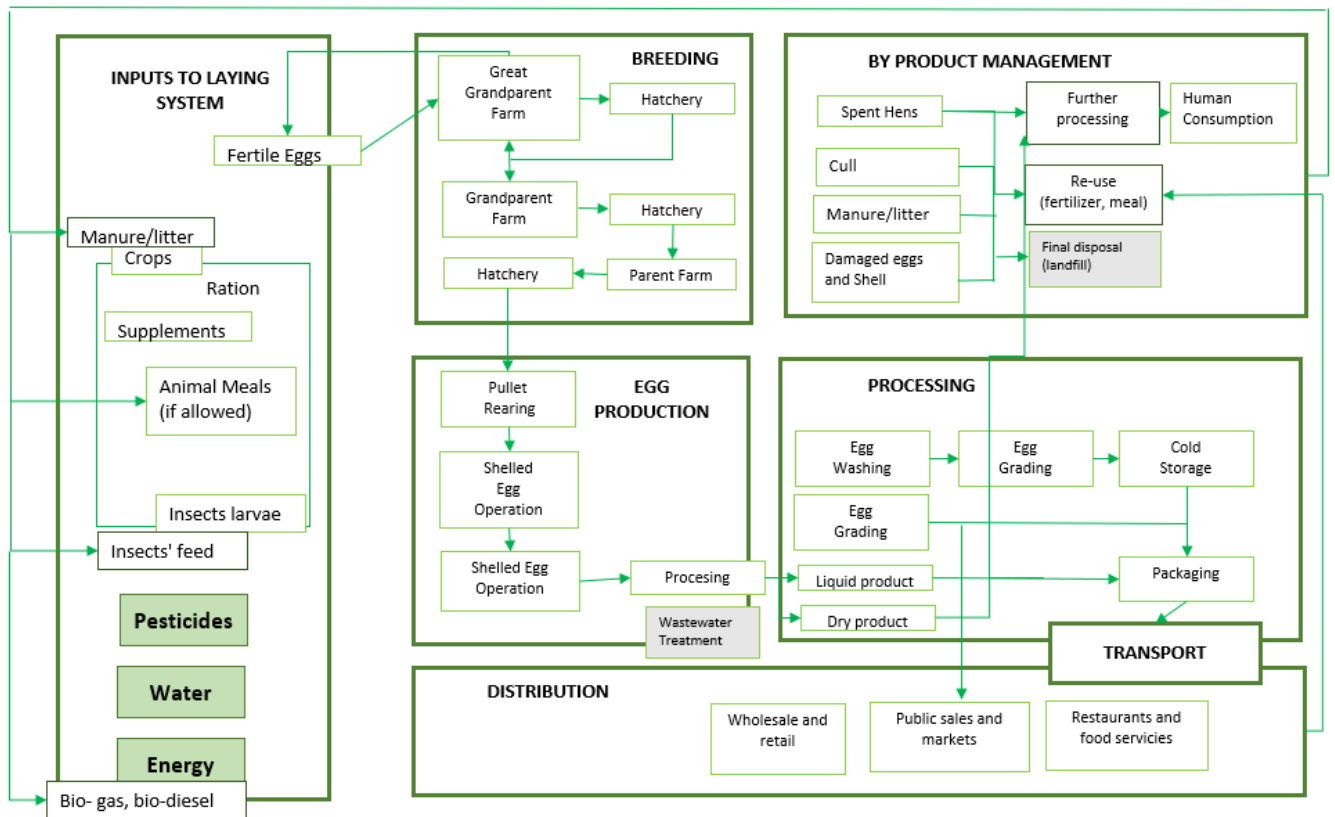


Figure 18. Schematic of eggs supply chain including circular economy approach  
Adapted from FAO (2016)

## 4 SUSTAVIANFEED'S LARGE-SCALE IMPLEMENTATION

Until now, we have studied the possibilities of making the process more circular and the need to change the poultry supply chains in more circular ones. It has been analysed that there are main principles which will make this possible and also some specific ones depending on the location of the activities.

Once this has been done, it is time to identify which are the pillars for a sustainable approach as SUSTAVIANFEED one, large-scale implementation. In future implementation steps of the project guidelines for Circular Economy Business Models (task 4.3) will be developed as well as an economic analysis of pilot activities (task 3.6). However, after the analysis done in this report, a few aspects have been already identified which will be crucial for real large-scale implementation over the next few years in the society:

### Change in our consumption habits

During the whole document, it has been clear that it is necessary to change our consumption habits towards more sustainable ones. This does not mean that animal-based products should be removed from our diet, however, eating less but more quality products should be a priority.

By changing this, it would be possible to develop a more extensive and sustainable sector in which the environmental impact would be reduced, the animal welfare promoted and the quality of the products increased. For this, awareness campaigns, information sessions and day-to-day work with the citizenship should be done.

### Consumer's empowerment

In line with the change in consumption habits, the consumers' power of changing industrial patterns should not be underestimated. Even though sometimes is difficult to think that just one single person can contribute to modifying patterns. However, individual decisions and especially when they are included in a movement or association, can definitely achieve this. Industries and big groups will adapt to more sustainable practices if there is a demand for it, despite the sustainability is not a priority for them.

### Resilient systems

The raw material, energy, climate, and geopolitical crisis make it especially important to increase the food systems' resilience and the short cycles, in order to ensure quality food available to all the population. By doing this, the dependency on external events will be reduced and prices and food availability will be more stabilized.

### R&D for the development of sustainable diets

Another key element for the transition towards a more sustainable sector is the investment in R&D. We have seen that there are different possibilities of obtaining and valorising valuable resources from by-products, insects, and other non-common ingredients.

The R&D investments will make it possible to introduce more alternative ingredients in the diets and also to increase the efficiency along the whole supply chain. In addition, it will reduce the costs of these processes and make them more scalable for a different context. The insect's production and its inclusion in sustainable diets is one major example of this practice.

### **Policy changes**

Nowadays, there are existing constraints barriers and difficulties that make the transition towards sustainability a challenge for the policy sector. Globalization and the different environmental and animal welfare requirements in countries around the world make it necessary to promote sustainable practices from the national governments and the European Union, so products with fewer requirements (and with lower costs) do not compete with an advantage in the market.

In this sense, policy makers should assume larger roles in creating a sustainable food supply chain in two senses: limiting unsustainable practices and supporting environmentally friendly practices.

### **Stakeholder collaboration**

And, finally, developing an integrated approach in which all the different stakeholders involved are included would be the most important pillar in order to achieve this goal. This applies from big groups of the sector to smallholders and small companies, as well as social organizations, science & technology sectors, policy makers, markets, and the whole citizenship.

In the SUSTAvianFEED project, the LL activities are working in this line, involving actors from the academia, private sector, public administration, and general public in order to develop the project approach. This should be also applied when considering the large-scale implementation of it. Just one actor by itself, will not make the difference. However, collaboration among a group can achieve great results.

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