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# Scenarios developed for the ClinOrg project

Florence Garcia-Launay, Guillaume Martin, Chantal Le Mouël, Thomas Nesme

Version August 2023

## Preamble

Agricultural food production is responsible of roughly one quarter of global anthropogenic greenhouse gas (GHG) emissions. Curbing those emissions is key to achieve the Paris Agreement objectives. Organic farming has good potential to achieve low area emission intensity. However, due to its lower yields, concerns have raised that organic farming expansion may drive land-use change and related CO<sub>2</sub> emissions. Meanwhile, there is life cycle assessment-based evidence that human diets low in animal-sourced products help alleviate agricultural land requirement and GHG emissions. However, very few studies have considered both leverages together and simulated their consequences for land-use change and related GHG emissions at the global scale. The ClinOrg project aims at exploring to what extent an expansion of organic farming in Europe, combined with changes in food and feed consumption, may affect land use worldwide and related GHG emission. First, we develop a set of exploratory (vs normative) scenarios on human diets, livestock production and plant production. Then, we will simulate these scenarios using

- 1 - the GOANIM (Global Organic Agriculture Nutrient siMulator) model, a spatially explicit, biophysical and linear optimization model simulating cropland soil nitrogen (N) cycling in organic farming systems and its feedback effects on food production at the global scale.
- 2 - the GLOBAGRI model, a global agriculture and land-use accounting model that estimates changes in agricultural production, trade, land use over time, and GHG emissions, which result both from changes in uses of agricultural products and changes in agricultural systems.

## System delineation

The current food system is seen as composed of three subsystems: plant production, livestock production and human diets (Fig. 1). All three subsystems interact via biomass flows. Livestock production influences land productivity by providing manure. Plant production influences livestock productivity by providing feed which determines livestock diets. Together with livestock production, it also provides humans with food. Food consumption generates leftovers that can be used as feed for livestock. Human diets and therefore food choices drive food production, and these choices (or lack of choices) are shaped by food production. Main features of human diets that affect food production, and therefore plant and livestock production, include among others, total food intake (quantity of food consumed), share of animal/plant-based food in the diet as well as the amount of organic food eaten (vs conventional).

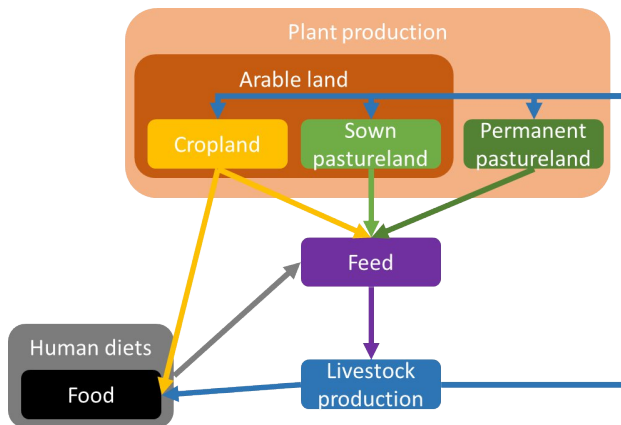


Fig. 1: System delineation used in the ClinOrg project

### Scenario design

Scenario design has been organized in a participatory way and in three steps. At the project kick-off meeting in January 2022, 3-5 options describing likely development pathways were defined by the project scientists for each subsystem, i.e. plant production, livestock production and human diets. Then, during the annual project meeting in November 2022 these options were combined into exploratory (vs normative) food system scenarios (Fig. 2) by the project scientists and discussed the day after with a group of (mainly French) stakeholders with expertise on the organic agriculture sector. In April 2023, these scenarios were presented to a group of European researchers with expertise on organic agriculture and food systems, and further discussed and refined.

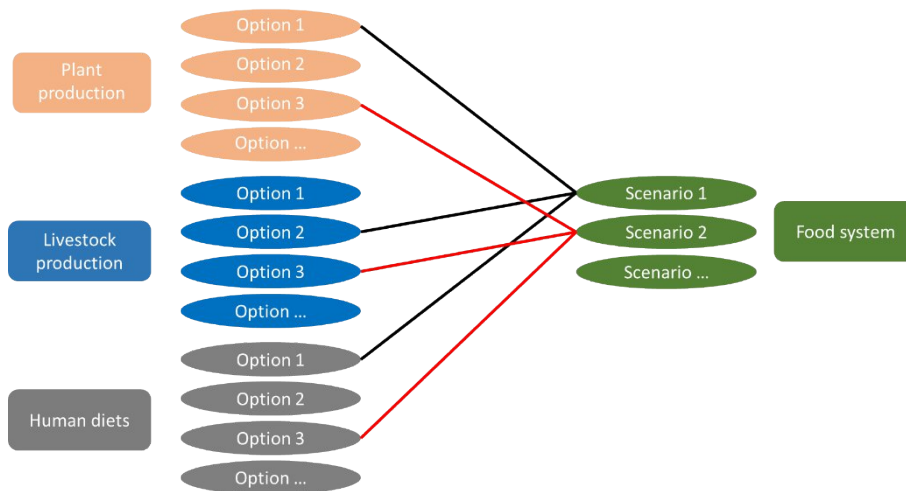


Figure 2: Design principles for food system scenarios in the ClinOrg project

#### Key assumptions applying across scenarios:

For both plant and livestock production, scenarios have been designed for organic production. Conventional production systems remain in the business as usual (BAU) option in all scenarios and human diets for consumers of conventional products remain BAU in all scenarios as well.

For each scenario designed, we vary the share of land under organic management and assume that the proportions of land and consumption of organic agriculture vary together.

Another factor of variation is the possibility to convert permanent grasslands into croplands, shrublands and/or forests (in relation to EU regulation). For each scenario, we will also simulate alternative scenarios which leave possibility to full conversion.

Food wastes are not explicitly considered in the scenarios but will be integrated as a share of the food demand in the simulation modelling.

#### Options for plant production

|                          |  |   |                              |
|--------------------------|--|---|------------------------------|
| <b>Business as usual</b> | <b>Priority to food crops on arable land</b> | <b>Maximising nitrogen and protein autonomy</b> | <b>Priority to bioenergy</b> |
|--------------------------|--|---|------------------------------|

##### *Option 1: Business as usual*

Organic farming systems are modelled similarly to current organic practices. Organic crop rotations – and the derived agricultural land use – reflect the main differences currently observed between organic and conventional arable systems as reported by published meta-analyses. Organic farming is modelled by using a “conservative approach” where differences between organic and conventional farming systems are kept as they are (i.e. ban of synthetic fertilizers, minimum diversification of crop rotations, involving small changes in crop land-use, namely, an increase of pulse as main crops and an increase of temporary fodder crops). Organic farming is thus represented by the current mainstream organic model. Thus, no strategies aiming at maximizing crop-based food production or nitrogen autonomy are hereby considered. In intermediate scenarios where organic farming does not occupy 100% of the European cultivated area, organic farms are allowed to use fertilizing resources from conventional farming systems (both as farm-yard manure and industrial by-products, i.e. blood and bones meals).

##### *Option 2: Priority to food crops on arable land*

Organic farms focus on the production of crop-based food. Since food production is the main objective, pulses are prioritized based on their suitability to be consumed as food (e.g. lentils, chickpeas, and soybeans) while temporary fodders mostly disappear. Cropland use is highly diversified to achieve an optimum in terms of fertility and pest/diseases/weed control while maximizing crop-based food production. To this purpose, the use of N-fixing crops is maximized. In addition, varieties characterized by a lower Harvest Index and/or producing higher amount of biomass are selected, especially to increase crops’ competitiveness towards weeds. Cover crops and undersown crops (on the example of conservation agriculture) are introduced as often as possible in crop rotations both for fertilization purposes (leguminous species) and to prevent nitrogen leaching during winter (non-leguminous species). Thus, livestock animals – mostly ruminant species –, when present (crop-based food is a priority on livestock-based food), are fed on permanent pastures, industrial by-products, eventually, cover crops.

##### *Option 3: Maximizing nitrogen and protein autonomy*

In this option, organic farms aim at maximizing their autonomy in both nitrogen – for crop production – and protein – for animal feed. Off-season green manures, leguminous temporary leys and cereal-legume intercropping are maximized as much as possible. Temporary pastures are an important

component of organic crop rotations, that can be valued both for livestock feed and for providing N-inputs to agricultural soils. At the same time, pulses do not disappear from crop rotations, as they represent a protein source for feeding monogastric livestock species (peas, soybeans). Thus, leguminous crop species characterized by high rates of N-fixation and high potential as livestock feed (e.g. broad-beans) are prioritized. Because livestock based-food are likely to have high importance compared to crop-based food in human diets, technology innovations allowing the extraction of proteins from fodder crops to be used as feed for monogastric livestock species are authorized.

*Option 4: Priority to food crops and bioenergy*

In this option, all farms or territories have installed a biogas production facility. All (or most of) temporary fodder leys and cover crops are used as substrate for the anaerobic plants. All feed crops have been replaced by food crops (including a share of pulse production to guarantee the required protein production for the population) and by biogas/energy crops (mostly non-leguminous crop species, despite the inclusion of a small share of N-fixing plants may be necessary to guarantee a sufficient quality of the mix substrate for the anaerobic plants). The biogas plants substitute livestock animals in their role of fertility transfer from grasslands to croplands. Indeed, crop residues and part of the permanent pasture biomass is used to feed the anaerobic digester. Most industrial by-products are also used as substrate for the anaerobic digestion. Similarly to the option “Priority to food crops on arable lands”, livestock animals are maintained only on permanent pastures.

|   | <b>BAU</b>                        | <b>Priority to food crops on arable land</b> | <b>Maximizing N and protein autonomy</b> | <b>Priority to food crops and bio-energy on arable land</b> |
|---|-----------------------------------|--|--|---|
| <i>Type of cropping systems</i>               | Integrated crop-livestock systems | Mostly crop-based                            | Integrated crop-livestock systems        | Mostly crop-based   |
| <i>Type of crop rotation</i>                  | Currently observed                | Food-focused (no temporary fodders)          | Diversified                              | Diversified with a food/energy focus                        |
| <i>Frequency of pulses</i>                    | Intermediate                      | Very high                                    | Very high                                | Intermediate  |
| <i>Type of pulses</i>                         | Currently observed                | Food-target pulse crop species               | Feed-target pulse crop species           | Food-target pulse crop species                              |
| <i>Frequency of oil-crops, industrial ...</i> |                                   |  |  |   |
| <i>Frequency of temporary fodders</i>         | Intermediate/High                 | None   | High                                     | Intermediate  |
| <i>Type of temporary fodders</i>              | Mixed                             | /  | Leguminous-based                         | Mixed (energy-focused)                                      |
| <i>Frequency of off-season crops</i>          | Not implemented                   | High   | High                                     | High  |
| <i>Type of cover crops</i>                    | /                                 | Mixed grass-legumes                          | Mostly leguminous crops                  | Mixed grass-legumes   |
| <i>Straw returned to soils</i>                | Currently observed                | Always                                       | Most of the time                         | Never   |

## Options for livestock production

|                          |   |  |  |                             |
|--------------------------|---|--|--|-----------------------------|
| <b>Business as usual</b> | <b>Livestock Farming Systems (LFS) to value non-edible feedstuffs</b> | <b>LFS to provide services to cropping</b> | <b>Patrimonial LFS for biodiversity conservation</b> | <b>Disappearance of LFS</b> |
|--------------------------|---|--|--|-----------------------------|

### *Option 1: BAU*

Organic livestock farming systems apply current organic practices. Feedstuffs and animal genotypes, and the derived efficiency of feed to production reflect the main current differences between organic and conventional livestock systems as reported by published meta-analyses. Organic farming is modelled by using a “conservative approach” where differences between organic and conventional livestock farming systems are kept as they are (e.g. ban of synthetic amino acids in the feed formulas). For ruminants, LFS are mainly based on grass resources, in particular in highland areas. For monogastrics, organic feedstuffs resources are similar to the ones used in conventional production, with a low share of by-products and forages resources, and therefore a relatively high level in feed/food competition (based on the share of kcal and proteins for feed and food), and associated land use. There are no specific strategies applied to reduce the level of feed/food competition or to improve the services provided by LFS to cropping systems. The organic LFS are consistent with the current mainstream organic model.

### *Option 2: Livestock farming systems (LFS) to value non-edible feedstuffs*

In this option, food provision from livestock farming systems remains central, but at the lowest possible cost in terms of land use and feed/food competition. Therefore, livestock are fed with various types of low-cost opportunity feedstuffs, like by-products issued from the food industry, food waste and grazing resources. For ruminants, this option results in a high share of grass resources in the diet (grazed grass, conserved grass as silage, hay...) and a small amount of other low-cost opportunity feedstuffs, in particular in the winter period to supplement the diet. For monogastrics, this option results in feed formulas based on various by-products from crop production, processing and consumption. Pigs and poultry are also fed with innovative feedstuffs, which result from waste-to-nutrition processes that provide feed ingredients obtained from residual biomass (e.g. insects larvae meal from insects fed on residual biomass, food waste, manure...). In this option, the nutrients available in the diets do not necessarily cover the requirements of highly producing genotypes. Therefore, animal types (breeds, genotypes) with intermediate productivity levels are preferred. For beef production, early maturing breeds are chosen, to make fattening possible on grass resources. For monogastrics, some specific breeds and crossed genotypes are also favored, that have lower requirements in digestible amino acids than the current animal types.

### *Option 3: LFS to provide services to cropping*

In this option, the main role of livestock farming systems is to provide services to crop production (i.e. both crop fertilization, elimination of weeds, passage of shredders avoided...). In this situation, two very contrasted ways of conducting livestock farming systems co-exist. First type are small ruminants (light cows, sheep and goats) grazing directly on fields to consume residual biomass from crops, in order to eliminate weeds. They are also used on grasslands to avoid the passage of shredders. Second

type are monogastrics providing organic fertilizers that can be easily transported to arable lands for crops. Since livestock are fed with various types of low-cost opportunity feedstuffs like in the previous option, which are usually feed resources with high content of fibres, manure has high methane production potential for biogas production.

*Option 4: Patrimonial LFS for biodiversity conservation*

The central aim is the conservation of biodiversity (including local breeds) and of cultural heritage associated to high-quality animal products. Human food production from livestock is marginal. In this option, biodiversity conservation is targeted both for landscape biodiversity and biodiversity of livestock (local breeds). Biodiversity conservation is mainly performed through permanent grasslands conservation. In this option, only local and hardy breeds with low production potential remain. Livestock animals are kept outdoor at very low stocking density. Ruminants are fed only with grassland resources, on permanent pastures. For monogastrics, only free-range systems remain with both consumption of resources available on the ground and of local leftovers and by-products, with minimum or no processing before distribution. In this option, excreta from free range and grazing animals go directly to the fields. When animals are kept indoor (winter and/or night period), they are kept on straw-based systems and solid manure is used for fertilization of local crops.

*Option 5: Disappearance of LFS*

No livestock farming systems remain.



|                                 | <b>BAU</b>   | <b>Livestock Farming Systems (LFS) to value non-edible feedstuffs</b>                           | <b>LFS to provide services to cropping</b>  | <b>Patrimonial LFS for biodiversity conservation</b>   | <b>Disappearance of LFS</b> |
|---------------------------------|--|---|---|--|-----------------------------|
| <i>Animal type</i>              | Main breeds and genotypes used nowadays in European organic production | Early-maturing breeds for beef production   | Early-maturing breeds for beef production   | Hardy local breeds   | /                           |
| <i>Individual productivity</i>  | Medium   | Medium  | Low   | Very low   | /                           |
| <i>Reproductive performance</i> | Medium   | Medium  | Medium  | Low  | /                           |
| <i>Culling age</i>              | Medium   | Medium  | High  | High   | /                           |
| <i>Age at slaughter</i>         | Medium   | Medium  | High  | High   | /                           |
| <i>Feed efficiency</i>          | Medium   | Medium  | Low   | Very low   | /                           |
| <i>Feedstuffs</i>               | Current practices applying organic specifications                      | Based on low-cost opportunity feedstuffs, with innovative processed feedstuffs for monogastrics | Based on low-cost opportunity feedstuffs, with innovative processed feedstuffs for monogastrics                         | Based on local low-cost opportunity feedstuffs, with minimal to no processing – free range resources | /                           |
| <i>Type of housing</i>          | Current organic specifications   | Current organic specifications  | Mainly pasture for ruminants and technologies to keep nutrients in manure when animals are kept indoors (winter, night) | Free-range - outdoor (animals kept sometimes indoors during winter)                                  | /                           |
| <i>Manure management</i>        | On-farm use of manure as organic fertilizer                            | On-farm use of manure as organic fertilizer   | Biogas production and composting and transport of coproducts  | On-farm use of manure as organic fertilizer  | /                           |

## Options for human diets

|            |                         |                        |                   |
|------------|-------------------------|------------------------|-------------------|
| <b>BAU</b> | <b>Flexitarian diet</b> | <b>Vegetarian diet</b> | <b>Vegan diet</b> |
|------------|-------------------------|------------------------|-------------------|

The options are defined based on usual diets of French adults who are volunteers in a nutritional cohort, therefore not representative of the French population. However, the very large size of the cohort (app 30 000 individuals) allows to cover a wide variety of dietary practices including vegetarianism.

Diet comprises 264 standard food and beverage items in organic and conventional. It should be noted that fish is not considered as it is not linked to land use in the scenarios. Novel foods such as insect cell-based meat are excluded and that food waste is not considered. Of note, all the diets are supposed to be fully organic.

### *Option 1: BAU*

BAU-diets follow the current trends, i.e. they are Western dietary patterns, characterized by high calorie intake, ultra-processed food intake. The ratio of animal/plant protein is high although it has been slightly decreasing over years. This high-calorie diet is characterized by a high contribution of high energy-dense foods such as processed foods, refined cereals, sweet and fatty products, animal fat, fruit juices and sauces.

### *Option 2: Flexitarian diet*

This dietary pattern (or low-meat diet, total meat intake <50g/d) is characterized by a moderate amount of meat and animal-based foods. This is a relatively balanced diet which includes both healthy plant-based products and a small amount of animal-based products.

### *Option 3: Vegetarian diet*

This diet does not include meat but include any dairy products and eggs. This diet is rich in plant proteins. The share of fruit and vegetable is also high.

### *Option 4: Vegan diet*

This plant-only diet excludes any food of animal origin, dairy products and eggs. The share in the diet of wholegrain cereals and legumes is very high.

|   | <b>BAU</b>         | <b>Flexitarian diet</b> | <b>Vegetarian diet</b> | <b>Vegan diet</b>        |
|---|--------------------|-------------------------|------------------------|--------------------------|
| <i>Energy intake</i>                        | High               | Medium                  | Medium                 | Medium                   |
| <i>Share of plant/animal-based products</i> | Very low           | Low to medium           | High                   | Entirely plant-based     |
| <i>Fruit and vegetables</i>                 | Low                | Medium                  | High                   | Very high                |
| <i>Cereals</i>                              | Refined/<br>medium | Low to medium           | High                   | Wholegrain/<br>Very high |
| <i>Legumes</i>                              | Low                | Low to Medium           | Medium to high         | Very high                |
| <i>Milk and dairy products</i>              | Very high          | High                    | Medium                 | Absent                   |
| <i>Poultry meat</i>                         | High               | Medium                  | Absent                 | Absent                   |
| <i>Red meat</i>                             | Very high          | Medium                  | Absent                 | Absent                   |
| <i>Sweet and fat foods</i>                  | High               | Medium                  | Medium                 | Low                      |

## Scenario narratives

### 0 Business as usual

| Subsystem       | Plant production | Livestock production | Human diets |
|-----------------|------------------|----------------------|-------------|
| Option selected | <b>BAU</b>       | <b>BAU</b>           | <b>BAU</b>  |

In this scenario, plant production, livestock production and human diets remain as they are.

### 1 Circular food system

| Subsystem       | Plant production                         | Livestock production  | Human diets             |
|-----------------|--|---|-------------------------|
| Option selected | <b>Maximizing N and protein autonomy</b> | <b>Livestock Farming Systems (LFS) to value non-edible feedstuffs</b> | <b>Flexitarian diet</b> |

European consumers have a flexitarian diet based on very diversified sources of proteins, from both plant and animal production. The amount of meat and animal-based foods is moderate compared to plant-based products but it still includes meat, dairy products and eggs. Food production is achieved within a close perimeter around food consumption areas.

Meeting this demand for animal products while achieving enhanced circularity in food systems has led to some de-specialization of the territories and possibly to the reintroduction of livestock farming in arable cropping regions. Animal production has reduced competition with human food for land use. Ruminant livestock feeding is mainly based on grasslands. Ruminant production has been redistributed in lowland areas, but not in the most arid regions (Greece, Spain, etc.) where establishing temporary grasslands has become too difficult. Genetic selection has been oriented to reduce methane emissions by ruminants, and the preferred genetic types are early breeds to facilitate grass finishing of animals. Monogastric production is based on different sources of biomass that cannot be used by humans, such as crop residues and by-products from the agrifood industry. This reduction in competition between monogastric livestock feed and human food has been made possible by the development of innovations to convert different biomasses (grassland-based, or catering and agrifood industry waste) into highly digestible ingredients, and to produce pure amino acids authorized in organic production. Nevertheless, supplying farms with these innovative products poses problems of proximity to remain consistent with circularity goals.

In order to maximize nitrogen autonomy on farms, crop rotations are diversified and pulses, green manures, leguminous temporary leys and cereal-legume intercropping are sown whenever possible. Such leys are valued both for livestock feed and for providing N-inputs to agricultural soils.

**2 Circular vegetarian food system**

| Subsystem       | Plant production                         | Livestock production                       | Human diets            |
|-----------------|--|--|------------------------|
| Option selected | <b>Maximizing N and protein autonomy</b> | <b>LFS to provide services to cropping</b> | <b>Vegetarian diet</b> |

European consumers are vegetarian, meaning their diet does not include meat but include dairy products and eggs. Plant proteins also represent a large share of protein intake. The share of fruit and vegetable is also high. Food production is achieved within a close perimeter around food consumption areas.

Meeting this lower demand for livestock products while achieving enhanced circularity in food systems has led to both a reduction of livestock farming and a de-specialization of the territories and possibly to the reintroduction of livestock farming in arable cropping regions. Animal production is present above all for the services it provides to cropping: recycling of nutrients, biological control of weeds, shredding interventions avoided, etc. These services include the recovery of nitrogen through solid organic fertilizers, which can be easily moved when it comes to fertilizing crops. These developments have been made possible by regulations allowing to keep animals indoor for at least 50% of their life. Animal production has also reduced its level of competition for land use with human food. Egg production is based on different sources of biomass that cannot be used by humans, such as crop residues and by-products from the agrifood industry. This reduction in competition between monogastric livestock feed and human food has been made possible by the development of innovations to convert different biomasses (grassland-based, or catering and agrifood industry waste) into highly digestible ingredients, and to produce pure amino acids authorized in organic production. Nevertheless, supplying farms with these innovative products poses problems of proximity to remain consistent with circularity goals. Ruminant production is mainly oriented towards dairy cattle production supported by light cows located 1) in mountainous grassland-based areas and 2) in

territories of intermediate productivity in which it is possible to introduce temporary grasslands in the crop rotations. The other ruminants left are dairy sheep and goats for their ability to move around the diversity of available resources and to provide services by avoiding shreeding interventions e.g. for cover crop termination.

In order to maximize nitrogen autonomy on farms, crop rotations are diversified and pulses, green manures, leguminous temporary leys and cereal-legume intercropping are sown whenever possible. Such leys are valued both for livestock feed and for providing N-inputs to agricultural soils.

**3 Diversified food system**

|                 |  |  |                         |
|-----------------|--|--|-------------------------|
| Subsystem       | Plant production                             | Livestock production                       | Human diets             |
| Option selected | <b>Priority to food crops on arable land</b> | <b>LFS to provide services to cropping</b> | <b>Flexitarian diet</b> |

European consumers have a flexitarian diet based on very diversified sources of proteins, from both plant and animal production. The amount of meat and animal-based foods is moderate compared to plant-based products but it still includes meat, dairy products and eggs.

To meet the growing demand for plant-based food without entirely eliminating animal proteins, permanent grassland areas have been converted to cropping. Elsewhere, priority is given to plant production on arable land that is occupied by food crops. These crops are very diversified and include a significant share of pulses to satisfy human needs for plant proteins, and cover crops as soon as possible for their provision of services such as nitrogen supply or weed control. Crops are fertilized with both livestock manure discharged directly into the field (grazing of cover crops and stubbles, winter grazing on cereals) or spread, and with sewage sludge, the regulations having evolved to allow their use.

Animal production does not compete for land use. In mountainous areas, it relies on permanent grasslands. In arable areas, it relies on biomass that cannot be used by humans: crop residues, cover crops, and by-products of the agri-food industry, and is present above all for the services it provides to crops: recycling of nutrients, weed control, avoidance of mechanical interventions for cover crop termination, etc. Ruminants are light cows, sheep and goats because of their ability to move easily towards this diversity of resources, while monogastric animals are fed from by-products and transformed forage resources (e.g. alfalfa proteins). As the animals are free-range, most of their effluents are discharged directly into the field.

This scenario relies on significant progress in the selection of minor plant species such as pulses and on progress in animal selection to have animals that are able to value a diversity of feed resources richer in fiber rather than a high feed conversion efficiency or a high individual productivity.

**4 Extensive and low-livestock food system**

|                 |   |  |                         |
|-----------------|---|--|-------------------------|
| Subsystem       | Plant production  | Livestock production                                 | Human diets             |
| Option selected | <b>Priority to food crops and bio-energy on arable land</b> | <b>Patrimonial LFS for biodiversity conservation</b> | <b>Flexitarian diet</b> |

Social norms towards livestock production have considerably changed and the pressures on animal welfare and the environmental impacts of livestock farming have increased. Europe has undergone major socio-cultural changes and is now populated by low-meat eaters whose diets are flexitarian, mainly relying on plant-based foods.

As a result, only a few livestock farms remain in marginal areas (e.g. mountains) that are less suitable for cultivation. These are very extensive farms, based on hardy breeds and using local feed resources: grass, acorns, tree biomass, etc. Their function is above all cultural heritage, open landscape conservation and biodiversity conservation in permanent grasslands and rangelands. Productivity levels are very low but of high quality. The main control exercised over the herds is to regulate populations to avoid environmental damage that could be caused by too high a stocking rate and to guarantee the closure of biogeochemical cycles on a local scale. To satisfy the consumption of animal products, imports are necessary.

Everywhere else, livestock farming has disappeared to make way for a maximum of crops for human consumption and energy production. A wide variety of crops is grown to satisfy the diversity of foods needed for balanced diets: cereals, crucifers, polygonaceae, solanaceae, etc. As proteins for humans are mainly of plant origin, these crops frequently include pulses. In order to control weeds and fix a maximum of atmospheric nitrogen, annual or semi-perennial forages are planted as soon as possible. One fertilization option is even based on the transfer of biomass from these forages to fields sown with cash crops. Another option is the anaerobic digestion of these fodder crops and the use of digestates, which facilitates the closing of biogeochemical cycles. Crop residues, part of the biomass of permanent grasslands, and most of the co-products of the agri-food industry are also used to feed biogas plants.

**5 Plant-based food system**

| Subsystem       | Plant production  | Livestock production        | Human diets       |
|-----------------|---|-----------------------------|-------------------|
| Option selected | <b>Priority to food crops and bio-energy on arable land</b> | <b>Disappearance of LFS</b> | <b>Vegan diet</b> |

Social norms towards livestock production have considerably changed and the pressures on animal welfare and the environmental impacts of livestock farming have increased to an unprecedented level. Europe has undergone major socio-cultural changes and is now populated by vegan consumers fully relying on plant-based foods and synthetic food supplements.

Livestock farms have disappeared and are replaced by biogas plants for their function of valorization of biomass not consumable by humans, and by pulses for their function of protein production. Marginal areas (e.g. mountains) that are less suitable for cropping are rewilded.

To counter the fall in yields due to the disappearance of livestock farming, permanent grassland areas have been converted to cropping. The arable land is occupied by crops for human consumption. These crops are very diversified and include a significant proportion of pulses to satisfy the need for plant proteins. Urban sludge is used to fertilize the crops. Cover crops are also introduced as soon as possible in the rotations for their provision of services such as nitrogen supply or weed control.