Clever

Bridging the climate neutrality, energy security and sustainability gap through energy sufficiency, efficiency and renewables

Agriculture, forestry, other land-use changes and bioenergy (AFOLUB)

Main assumptions and preliminary trajectory of the CLEVER scenario

March 2022

***Clever** – a Collaborative Low Energy Vision for the European Region*

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Content

This note has been written in collaboration with Solagro for the négaWatt association - as CLEVER project leader - in order to build the AFOLUB trajectory of the CLEVER scenario (a Collaborative Low Energy Vision for the European Region).

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Introduction

The CLEVER scenario

Since 2018, a network of around 24 European partners under the leadership of négaWatt have been engaging in a technical dialogue to ensure the collective development of a European energy and climate scenario.

This scenario is being constructed using a bottom-up approach with national trajectories as a starting point. It assesses all decarbonisation potentials through the main prism of energy analyses based on energy demand reduction (sufficiency and efficiency) and renewable energy development.

It aims at being as ambitious as possible: targeting carbon neutrality and a 100%-renewable energy mix at the European level as soon as possible and by 2050 at the latest, in line with 1.5 degrees pathways. Reaching carbon neutrality by then requires an ambitious and coordinated energy transition strategy supported by concrete and bold policies.

AFOLUB trajectory

The AFOLUB sector is not part of the expertise of the majority of CLEVER partners. To build the AFOLUB trajectory, the network has joined forces with Solagro, expert in agricultural transition. Solagro has previously built a 2050 transition scenario for this sector for France[1]. They defined a trajectory for each European country following their models used for France. The trajectory was then discussed with each country partner.

The current note was written in collaboration with Solagro. It **details the assumptions and the European scenario built in a top-down way by Solagro for CLEVER**. These results were then submitted to the CLEVER partners for bottom-up exchanges. These exchanges led to modifications of the trajectory presented in the note for several countries, notably Sweden and Denmark. This official CLEVER trajectory will soon be available[2].

This note first explains the context and vision of CLEVER for this sector, describes the Agriculture, Forestry and Land-Use trajectory given by Solagro and finally focuses on the modelled contribution of this sector in terms of GHG mitigation and bioenergy production.

Note: *Unless otherwise stated, the various aggregated European data shared in this note are at the EU28 perimeter.*

[1] Solagro, 2016

[2] Link towards the trajectory will be published on CLEVER website.

Context and vision

Context

Climate Change

The need to adapt

Climate change will significantly impact all ecosystems, whether anthropised or natural[3].

This impact could reduce the productivity for agriculture and forestry. For instance, for agriculture, the PESETA project led by the JRC analysed future potential yields for wheat and maize. They predict that significant reductions in yields can be expected, particularly in Southern and Western Europe[4]. Although yield increases can be expected in other regions, the global trends are negative, leading to absolute yield reduction over Europe (for instance for maize[5]).

Therefore, agriculture and forestry will have today to fulfil a new mission to **adapt** to climate change by reducing their vulnerability. In particular because of the lack of water in the most affected regions, which will lead to change the cropping systems throughout Europe as current systems, such as irrigated maize, will no longer be viable[6].

New mitigation missions for agriculture and forestry

Along this adaptation imperative, the **mitigation** of climate change gives three new missions:

- **Substitution:** agriculture and forestry will be needed to replace fossil fuels and materials with a high environmental impact, by bio-energies (such as biogas instead of natural gas) or bio-based materials (such as wood instead of concrete).
- **Sequestration:** it will be needed to raise the carbon storage in forest and agricultural ecosystems (soil, vegetation).
- **Direct mitigation:** the AFOLU sector must also play its part by reducing its own GHG emissions.

Biodiversity loss

A key concern

The collapse of biodiversity is a global concern observable in Europe[7]. It is well considered today by the international community that defined in December 2022 an ambitious Global Biodiversity Framework[8].

[3] IPBES, 2019 – p.16
[4] JRC, 2020
[5] Ibid
[6] Ibid
[7] IPBES, 2018
[8] CBD, 2022

Agriculture and forestry will have to **adapt** to biodiversity loss to manage the loss of ecosystemic services such as pollination and the apparition of new illness and exotic species favoured by this crisis[9].

One of the main causes of the current biodiversity crisis

Agriculture and forestry are key factors of biodiversity loss. They are indeed a trigger of land-use change which is the main cause of biodiversity loss[10].

Agriculture and forestry have then also a key role in the **mitigation** of biodiversity crisis.

CLEVER vision for AFOLUB sector

Rethinking the food system towards a sustainable bioeconomy

Agriculture has therefore a key role to play in adapting and mitigating both the climate and biodiversity crises. It leads to rethink the way humanity uses nature, land and biomass.

The vision of CLEVER AFOLU trajectory is to define a transition towards a sustainable bioeconomy. This means an economy based on renewable resources rather than fossil or geological resources in general and that also preserve the capacity of ecosystems to produce. It maintains by nature the health and functionality of ecosystems for future generations.

Rearticulating different uses of biomass in the economy

Today, there are 6 main types of biomass uses in the economy illustrated Figure 1:

- **Human food**;
- **Animal feed** and fodder;
- **Fibre**, for biomass uses such for building, textiles, paper, chemistry, etc.;
- **Forest**, in its etymological sense (VIIth century): a ban on building or cultivating. This term includes natural biodiversity but also environmental and social amenities of all kinds;
- **Fertiliser**, fertilisation provided by a living soil;
- **Fuel**, biomass used to produce energy.

[9] IPBES, 2018
[10] IPBES, 2019– figure SPM.2

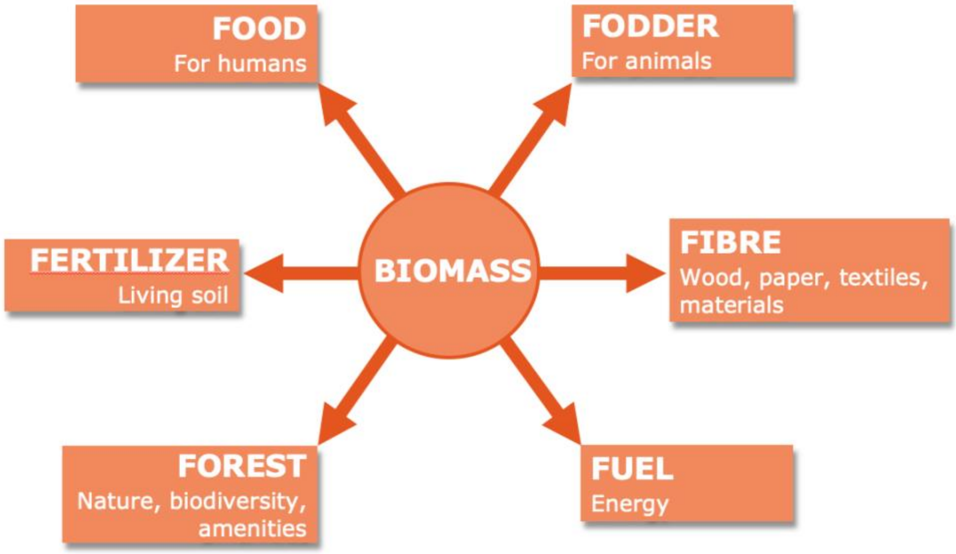

Figure 1: Different type of biomass uses

The distribution between these different uses is fruit of history. The choice in the distribution of these levers will raise different issues:

- First of all, **nutrition** and **health** issues.
- **Climate and biodiversity issues.**
- **Non-renewable resources**, along fossil fuels, agriculture is dependent on phosphorus, which is classified as a critical element.
- Other issues are the effects on **water**, **air** and **soil**.
- **Economic** and **social** issues.
- Finally, land-use planning articulates environmental, social and economic issues through **landscape issues**.

The CLEVER trajectory aims at answering these issues by rearticulating theses 6 biomass uses in a sustainable bioeconomy. Its objective is to answer climate and biodiversity issues by providing **healthy food in a healthy environment and a healthy lifestyle** to all without dependency on non-renewable resources and controlled impacts on water air and soil.

Levers of change available

To face these challenges, two categories of measures could be taken: demand side and production side measures.

On the demand side: diet change is a powerful lever of action

Demand side measures could be defined as everything related to nutritional policies, policies to support the use of bioresources and the issue of exchanges between territories.

In particular, food is a key lever for reorganising the agricultural sector.

A change in diet could have a huge impact on agricultural production needs. Change in diets have major impacts on land and water footprint as well as GHG emissions[11]. For GHG emissions for instance, a vegetarian diet emits 3 times less CO2 emissions than the average European diet[12].

On the supply side: there is a broad panel of agroecological practices available

Supply side measures implies to modify the production systems (plant, animal or forestry).

To answer the CLEVER objective, agroecology is a lever with a very high potential.

Agroecology is a systemic approach, based on the consideration that an agrosystem is first and foremost an ecosystem. This **goes beyond the current paradigm of controlling** an agrosystem. Controlling means considering the soil as a totally controllable growing medium, eliminating pests and weeds, at the cost of increasing recourse to solutions exogenous to the agrosystem: fertilisers, phytosanitary products, genetic techniques, technology. **Agroecology**, on the other hand, **leads to manage the agrosystems**. This means not seeking total control by acting on natural balances and mobilising resources endogenous to the system: integrated biological control, symbiotic fixation, natural pollination.

In such system, biodiversity and soil sustainability are considered as a production factor to be balanced with others.

Agroecology is composed of a plurality of practices well documented[13].

Agroecology is the agricultural practice most used in the CLEVER pathway. It is based in CLEVER on 6 principles:

- **Preserve natural resources and common goods**, water, air, soil, climate, biodiversity.
- **Optimise and balance the flow of nutrients**, mainly nitrogen and phosphorus, in order to reduce the impacts and the consumption of resources.
- **Minimise the use of sensitive resources and inputs**: fertilisers, phytosanitary, products, energy and water.
- **Contribute to the local consumption system**: the food system and the various productive functions assigned to agriculture.
- **Promote ecosystem services** such as pollination, biological control and climate regulation.
- **Promote specific and genetic biodiversity**.

To reach a transition answering all the listed challenges for agriculture and forestry, the CLEVER position is to promote integrated policies, mobilising both demand and supply side measures at the same time. All these levers could include both a technical and a social dimension with questions of organisation of chains and sectors, regulation, price, training and research.

[11] Aleksandrowicz et al., 2016: compared to baseline diet, a vegetarian diet could lead to a reduction up to 70% of GHG emissions; 60% of land needs and 40% of water needs.

[12] Bryngelsson et al., 2016: the average GHG content of EU diet is 1500 kgCO2e/year/cap while a vegetarian diet is 500 kgCO2e/year/cap

[13] Solagro is responsible of a French project (Osaé) listing agroecology practices and its scientific resource. It is available (in French) in the following link. The key practices of agroecology can be listed as follows: associated crops, biological control, agroforestry, eco-grazing, legumes, plant cover, simplified cultivation techniques, direct sowing under living plant cover, pre-orchards, silvopastoralism, farmer seeds, mixtures meadows, organic manure.

AFOLU trajectory

Modelling approach

Properties of the model

The trajectory is based on a model representing the agricultural and food system.

It is a **physical** model that describes mass flows – (mass of matter, food, feed, nitrogen, protein, gas, water, fuels), energy flows and the surfaces used. It analyses the supply and consumption balance of main agricultural and food products.

The model is **normative**: it does not use economic factors such as prices and production costs. But, it is possible to assess the social and economic impacts of the final trajectory.

The model is **recursive** and back-forecasting: it targets several issues at the same time, by gradually adjusting the different levers available. Indeed, since it is not possible to reach all targets at the same time, there are several modelling steps where trade-offs are found for each target in order to reach a feasible trajectory.

Supply side modelling

In the modelling process, there is first a **top-down** phase for the setting of targets. For example, to reach climate neutrality, there is a target to halve GHG emissions in the agricultural sector. In this case, the first step is to set an appropriate target for each Member State based on its own biocapacity.

Then, there is a **bottom-up** phase: the modelling work relies on cropping and breeding systems that are described at the level of elementary units. At this level, new ways of producing are defined with, for example, change in culture rotations and modifications in practices. Each agricultural system is characterised. Then these systems are re-aggregated and resized to the country's agriculture.

Once the agricultural system is re-aggregated, there is a first control whether the targets are achieved. If not, it is then necessary to redefine the target and redistribute the production practices.

Matching supply and demand: systemic land use modelling

The bottom-up phase is based on a modelling tool making the various surface and mass balances consistent to match supply and demand[14]. It allows to test a set of input hypothesis in order to check if the output values fit the targets. The functioning of this tool is illustrated in Figure 2.

Demand is determined primarily by determining the food demand for a given average diet in the population. Supply is determined by affecting in the land area the different plant and animal production systems. Supply balances considers the various items of domestic demand, including processing and industry. External demand can also be the subject of assumptions, for example if one country aims to relocate production or to maintain an export balance.

[14] The base model run by Solagro is called MoSUT (Solagro, 2016 – p.25)

When all the balances are in equilibrium, the results are evaluated according to several indicators: concerning for example the climate, or the impacts of production systems.

The model also makes it possible to calculate the resources available as materials or as energy sources, in order to inject them into models that describe energy systems.

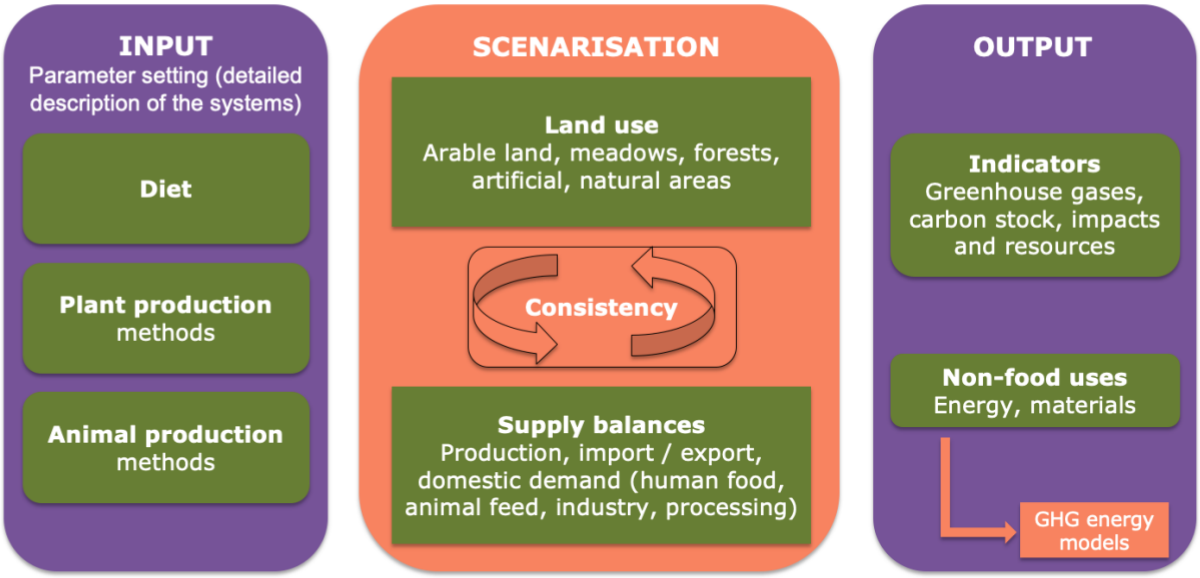

Figure 2: Systemic land use modelling illustration
The modelling tool ensures the consistency of land uses and supply balances for a given input.

Demand side

Demographic trends

It is modelled that the EU-28 population will remain stable at 510 million inhabitants in 2050.

The evolution of individual physiological needs is planned to be as follow:

- First an increase by 12%, taking into account an upward trend in average height and body mass index.
- Then a peak and a decrease due to the success of public health policies, including lifestyle changes such as the increase in active modes of transport in relation to energy transition policies and a healthier way-of-life.

Diet changes

Diet is one of the major drivers for the food system evolution. According to converging recommendations both from a health and environmental perspective, the future diet will be more plant-based[15].

Modelling

The diet change was modelled thanks the FAO Food Balance that provided the historical data and key recommendations. The diet was determined for each European country:

[15] FAO, 2019

- *The food balance sheets, available from 1961 to 2018, have been used as long-term series.*
- *On this basis, future diets for each European country have been built according to a double constraint: achieving an overall target for Europe and taking into account national contexts.*

Details of the diet averages modelled in the trajectory are given in Table 1.

As we can see in Table 1, among the main changes, the proportion of proteins between plant and animal proteins is reversed between now and 2050. In 2050, two thirds of proteins come from plant products and one third from animal products. As a result, the **consumption of pulses is multiplied by almost 3**, while that of **cereals also increases by 10%. Meat is reduced by 40%,** and **milk by 20%**.

For nutritional reasons vegetables, nuts and fruits increase, and alcoholic beverage and sugar decrease. Vegetable oils increase in order to compensate the drop-in lipids from animal products. Fish and seafood decrease due to rarefaction of the resource and a limited compensation by aquaculture. Alternative proteins in this prospective are counted as a marginal fraction.

Over-consumption – expressed on both protein and energy – is also slightly reduced in the 2050 diet.

	2014-2018 consumption (g/day)	**2050** consumption (g/day)
Cereals - Excluding Beer	357	394
Starchy Roots	178	129
Sugar & Sweeteners	114	81
Pulses	7	20
Treenuts	10	16
Oilcrops	10	12
Vegetable Oils	45	74
Vegetable	294	314
Fruits - Excluding Wine	233	360
Stimulants	14	14
Spices	2	2
Alcoholic Beverages	269	173
Meat	218	133
Offals	7	8
Milk - Excluding Butter + Animal fats	736	581
Eggs	33	30
Fish, Seafood	63	52

Table 1: Average daily diet of a European given in FAO Food balance

Loss and waste reductions

In 2050, food waste is reduced by half across the supply chain, offering a global gain of about 6%.

Finally, by adding demographic, diet and losses changes, global food supply is reduced by 11% expressed on a protein basis and by 6% on an energy basis.

Supply side

Overall land-use changes

Modelling

The analysis of land use has been based on Eurostat and FAOSTAT databases. The scenario takes into account past trends for each item and country. The empirical constraint matrix aims to limit, or even prohibit, side effects considered as undesirable – such as the regression of forests, the conversion of meadows to arable land and the conversion of arable land to artificialized areas.

For permanent grasslands, additional bibliography[16] *was used in order to evaluate the grass Net Primary Production. The status of grasslands may vary to a large extend according to pedoclimatic conditions. Here, two kinds of meadows have been distinguished: "Low-productive meadows" producing 1 t DM/ha (Dry Matter per hectare) and "high-productive meadows" where mean yields are 5-6 tDM/ha.*

At the EU28 perimeter, the total area of the European Union is 439 Mha. Its observed used in 2010 and planned for 2050 is shown in Figure 3.

[16] Especially Billen et al., 2021

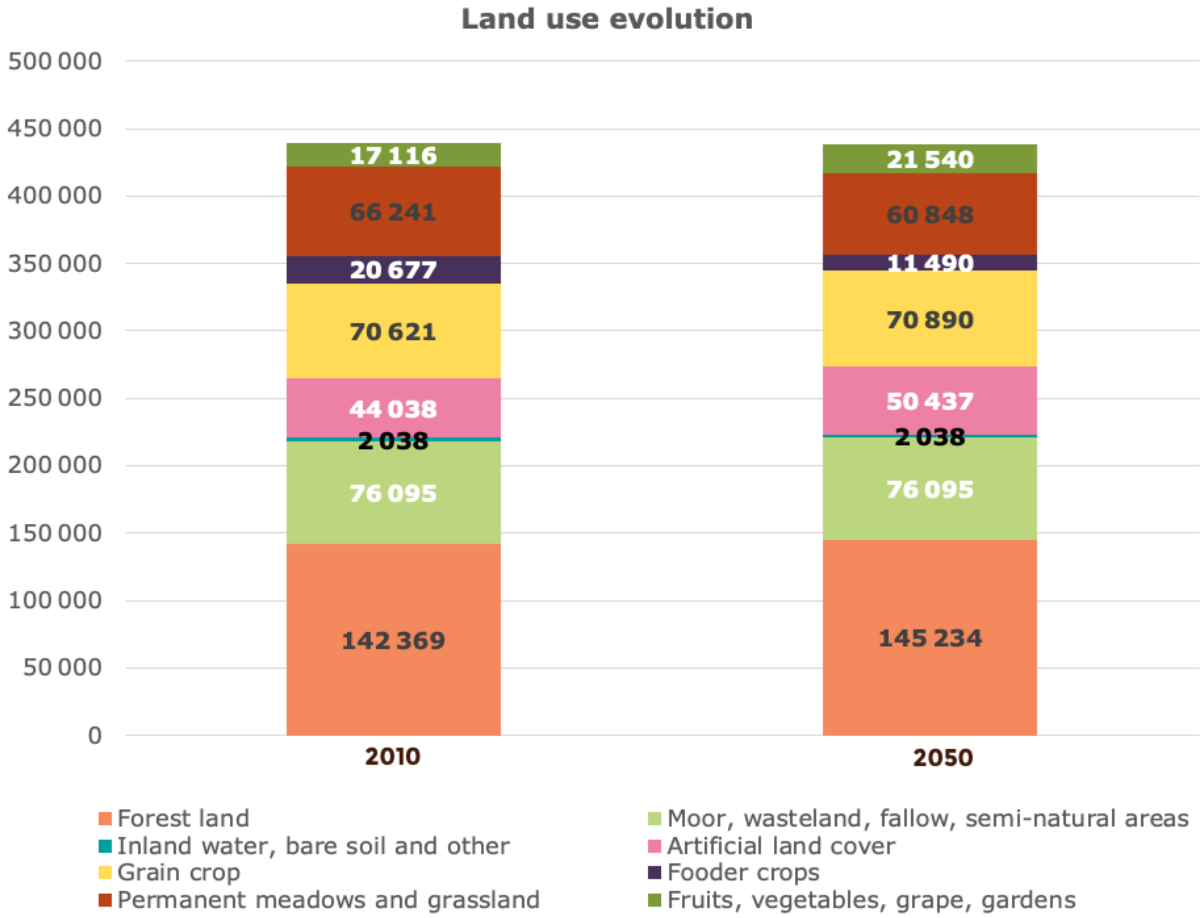

Figure 3: Planned evolution of land use in the European Union (EU28, thousands of hectares)

In 2050, due to ambitious urban planning policies, **urban sprawl is limited** and the net increase in artificial areas is only 3 Mha. The main losses come from arable land and, to a lesser extent, from meadows.

A mix of renaturation policies, ecological restoration, land abandonment trends, spontaneous afforestation on former fallow land, and afforestation policies on arable land, lead to an **increase** of **natural and semi-natural areas** (2 Mha) **and forest** (3 Mha). Policies to conserve and protect permanent meadows and grassland limit their loss to only 1 Mha, to the benefit of moorland and new forest areas.

The **agricultural area decreases** (from 174 to 167 Mha). The main evolution is the **sharp reduction of fodder crops on arable land** (from 21 to 9 Mha). Grain crops slightly decrease, and vegetable and fruit crops increase. No gain is counted from highly anthropized areas, as renaturation policies will affect semi-natural areas and not agricultural areas.

From a qualitative point of view, these evolutions expressed in terms of surfaces are to be considered in a more global view: wide extension of "green and blue" infrastructure in order to restore ecological functions of ecosystems, creation of vast renatured areas, including areas in most anthropized regions such as large cereal plains, and not only in mountainous regions where biodiversity is already rich.

More details for agricultural area are shown Figure 4.

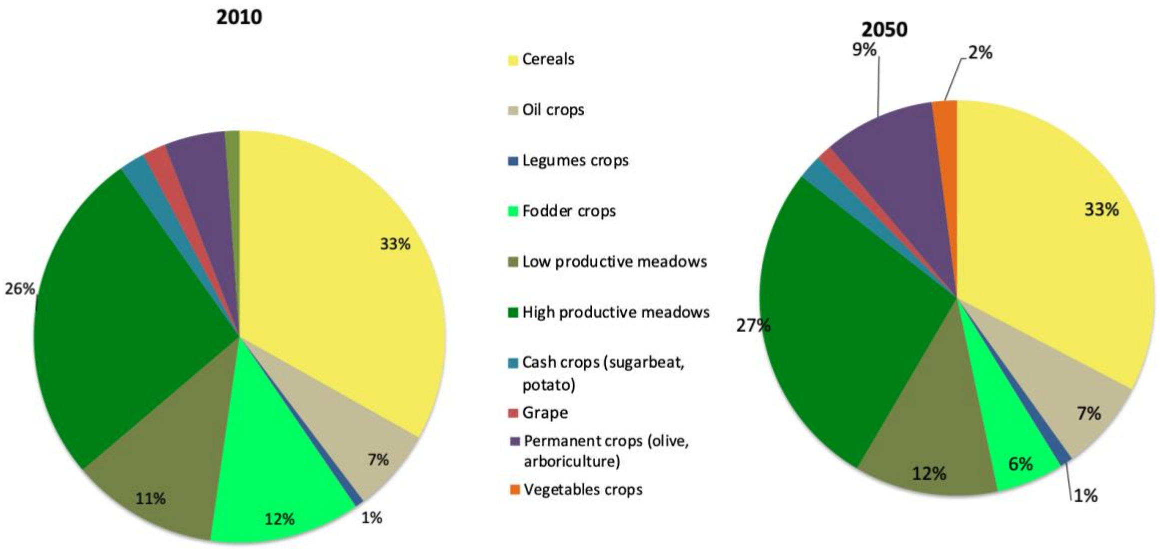

Figure 4: Planned evolution of the repartition of crop in agricultural lands

There is a slight decrease for cereals, sugar-beet, potato and a strong decrease in fodder crops and grape. Whereas there is an increase for oil crops, legumes crops, arboriculture and vegetable crops.

The loss of highly productive meadows, which are the most likely to be converted to arable land, is limited to 1 Mha, much less than the trend. These developments in the different agricultural areas are in line with the changing needs for food and feed. Fodder crops are resized to satisfy the fodder requirement for ruminants, after deducting grass from permanent meadows.

Vegetables and fruits surfaces increase to reduce the importations. Cereals surfaces are used as an adjustment variable.

Evolution of plant production

A 100% agroecological cropping system in 2050

Modelling

The analysis of cropping systems has been based on Eurostat and FAOSTAT data. The description of crop production is based on a detailed description of 22 main crops, and broader information on 100 other crops is also taken into account.

The 22 main crops represent 90% of agricultural land: 8 cereals, 2 oil crops, 3 legumes crops, 2 cash crops, 3 fodder crops, 2 types of meadows and 2 permanent crops.

Each crop is described in terms of yield of products (grain, forage...) and by-products (crops residues), soil carbon storage, inputs (NPK, energy, water, pesticides).

For the 22 main crops several systems are described (organic / soil conservation / conventional) with some variants. The scenario-building exercise consists of choosing a proportion of each system and variant

In 2050, crop systems are 100% agroecological, their progressive modification is illustrated for cereal crops in Figure 5. The global evolution leads to diversified systems with low or very low inputs.

In a simplified representation, the 2050 systems are shared between organic farming and soil conservation agriculture. The choice of a 50% organic farming and 50% soil conservation system balance in 2050 stems from the desire to reduce the environmental impact while ensuring a level of exports deemed necessary as Europe's fair contribution to global food security.

In 2050, in each family, 10% of the farms are managed in agroforestry, and 10% in combined crops, i.e. legumes with cereals. All systems are also managed with cover crops and include agroecological infrastructure (hedges, grass strips, groves, etc.). In order to compensate for the decrease in fodder crops, crop rotations are extended by greater diversification, including legumes, field vegetables and some perennial grasses.

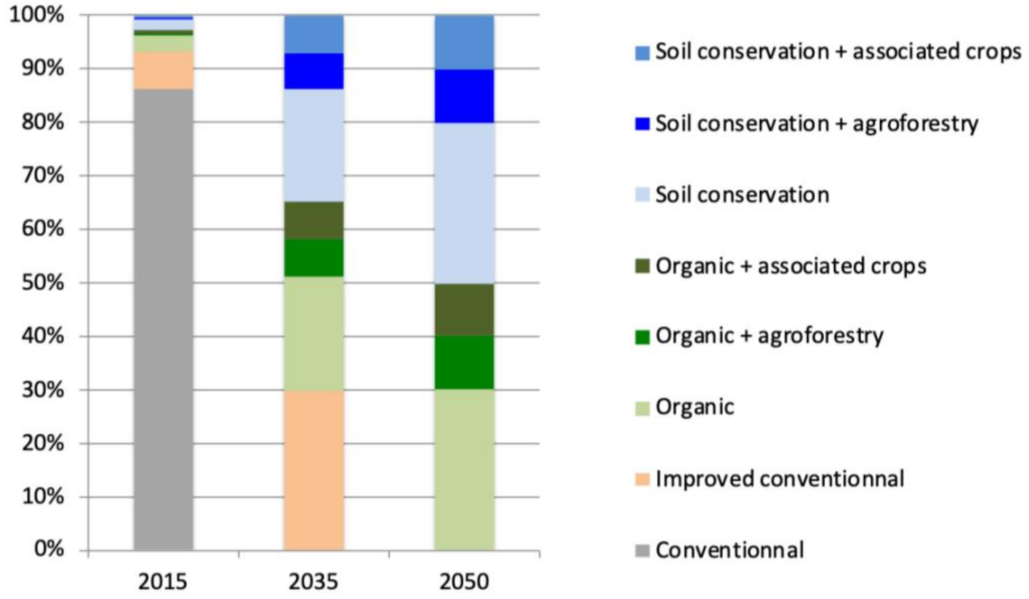

Figure 5: Cropping systems evolution in Europe towards 2050

This evolution towards agroecology leads to the broad reduction of the agriculture impact:

- **Water consumption for irrigation in summer is reduced** by 80% compared to 2015 levels. However, irrigation throughout the year is maintained. Indeed, crops that require a lot of water in summer are limited, such as corn in the more southern regions, but water is needed for vegetable crops and in some regions for cereals and legumes.
- **Inputs are reduced:** 60% less N fertilizer and 70% fewer pesticides are used in 2050 compared to 2015.
- **Energy needs are reduced:** 40% less energy is needed to power the systems.

Evolution of animal production

Smaller herds

The **overall livestock population is reduced**, with differences between dairy cows and other livestock (Figure 6):

- The number of dairy cattle is reduced by 35% (from 23 million heads to 15 million)
- Suckler cows (adults) is divided by 3 (12 to 4 million heads).
- Fattening pigs are divided by 2,
- Laying hens and broilers are reduced by a third.

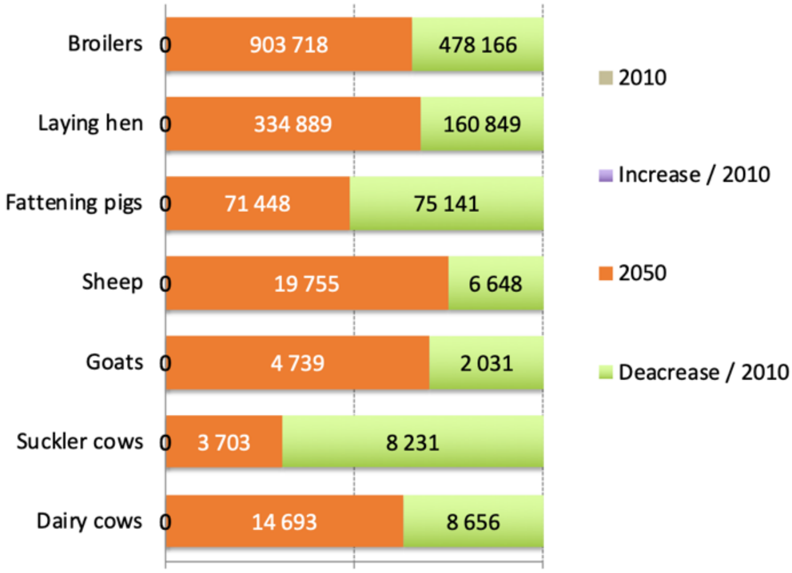

Figure 6: Herds size in 2050 comparatively to 2010 levels (thousands of heads)

These evolutions adapt to the new diets in 2050 while answering self-sufficiency (for cattle) and exporting capacity (for pork and poultry) imperatives. The size of the monogastric population (broilers, hens, pigs) was limited by the grain balance.

Ruminants: less maize-soya, more grass

First, the breed of dairy cattle is shifting towards multi-purpose of cross-bred dairies: e.g. cows able to produce both milk and good quality meat, for example Normande, Jersey or crossbreds Jersey x Holstein. Hence, multi-purpose livestock is largely replacing the suckler cow's livestock. Specialised suckler cowherds are maintained in specific contexts, especially where quality signs and labels already exist.

As suckler cattle have a small place, the following focuses on dairy systems.

Modelling

Dairy systems are characterised by a level of milk production in accordance to feed strategy: the higher productivity is achieved with a high intake of concentrates (grains, oilseeds cakes and agroindustry by-products), highly digestible forages (maize silage) and low grazing duration.

The conservation of high natural value areas such as natural permanent grasslands requires long grazing duration which implies lower milk productivity, especially with rustic breeds that are able to stay outdoors, even under adverse weather conditions. The categories used in the CLEVER scenario to differentiate the systems (Figure 7) have no official definition. Thus, the distribution of the current livestock between these different categories are extrapolated from different bibliographical sources[17] *and not from statistics.*

In the modelling dairy cattle breeding systems are largely moving towards more grass-based systems in order to conserve as much natural permanent grassland as possible and to use as little concentrates (cereals and by-products) as possible.

The majority of current dairy systems can be qualified mostly as "moderately intensive" and "predominately grazing systems" (Figure 7). In the scenario, the heads bred in grazing systems are maintained but move towards highly or even full grazing systems. These systems have lower

[17] Especially Billen et al., 2021

productivity and lower concentrates and fodder crops intake. The heads bred in systems qualified as intensive are reduced and systems without grazing disappear completely.

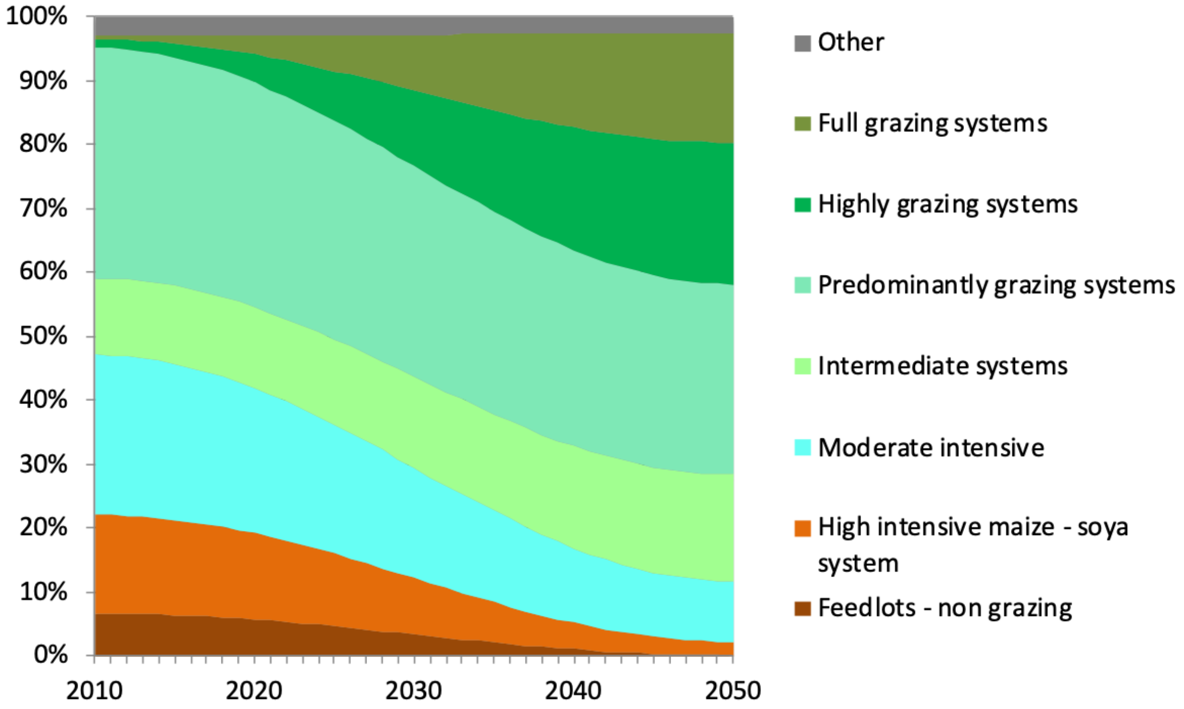

Figure 7: Evolution of the dairy cows feeding systems (share of heads)

Ruminants: evolution of the forage balance

Modelling

The cattle feed balance is described here as a use / resource balance sheet. The resources are the production of grass and fodder on naturel permanent meadows and on arable land, including temporary meadows of gramineous and legumes grasses and fodder crops, mainly maize for silage. These resources are used in two ways: grazed at the field or conserved as hay, silage, or alfalfa pellets

The evolution of cattle balance is shown Figure 8. Ruminant feed requirements in Europe are estimated at around 360 Mt of dry matter today and modelled at 200 Mt in 2050 due to the reduction of herds.

The remaining herd in 2050 is composed of hardier breeds, and the share of field grazing has increased while retained forage (hay and corn silage) has decreased.

Finally, permanent natural meadows are able to supply a large part of the needs. This allows to reduce the surface of fodder production on arable land.

This modelling achieves the objective of keeping as much permanent grassland as possible under grazing and reallocating arable land to the production of food rather than feed.

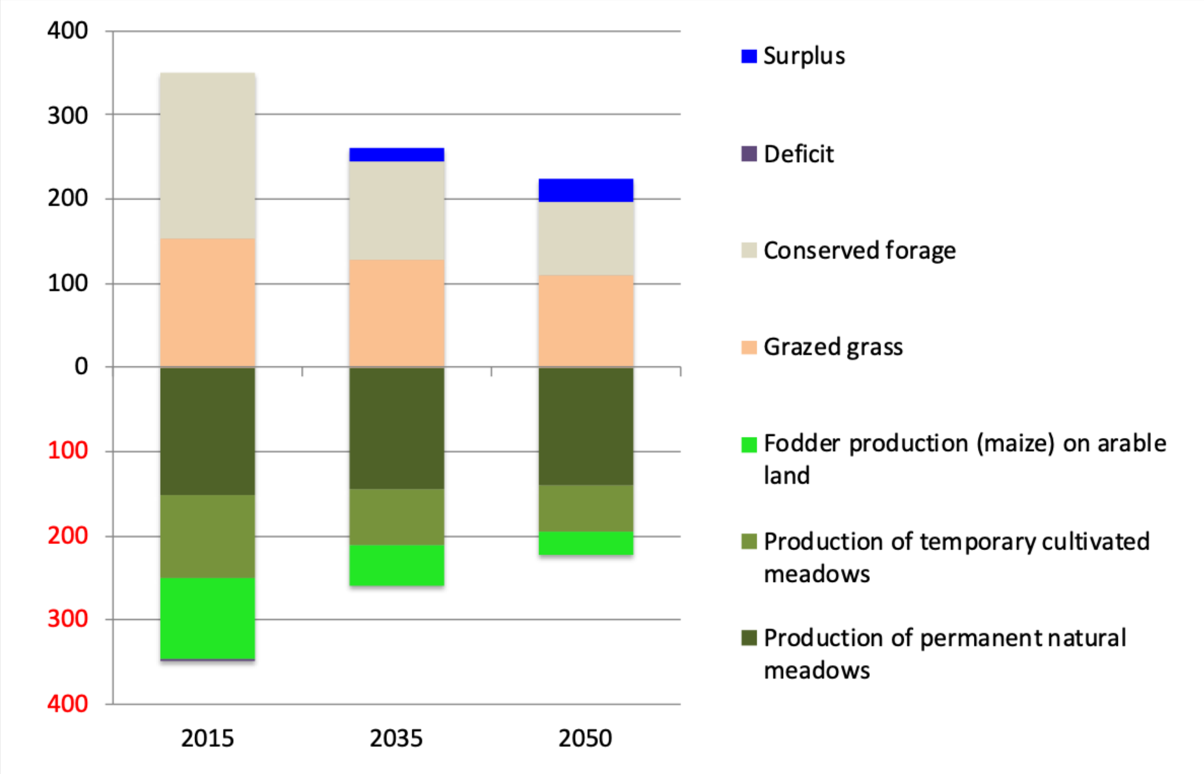

Figure 8: Evolution of ruminants' forage balance (Mt of dry matter)

Monogastric: towards animal welfare and quality production

Monogastric breeding systems are driven by animal welfare consideration and not by the search for a certain "climate efficiency" at any cost. The main parameters are slaughter age, feed conversion ratio and available space for the individuals.

This approach is illustrated in this section for poultry.

Modelling

Poultry systems are described with 4 families:

- *"Standard" is the main system today with a slaughter age of about 4 to 7 weeks and 25 birds /m2 and a feed conversion ratio (FCR) of 1,7 kg grain/kg gain.*
- *The label "56 days" is intermediate 18 birds /m2, no outdoor space, FCR=2,2*
- *The "label 81 days" corresponds to 11 birds /m2, 2 m2 outdoor/bird, FCR = 3,1*
- *The "organic" label is 10 birds /m2 and 4 m2 outdoor/bird, FCR=3,3.*

In the scenario (Figure 9), the **"standard" production completely disappears** as there is no more public acceptancy for cage. The remaining systems are monitored by **labels guarantying minimum outdoor space** (80% of the production).

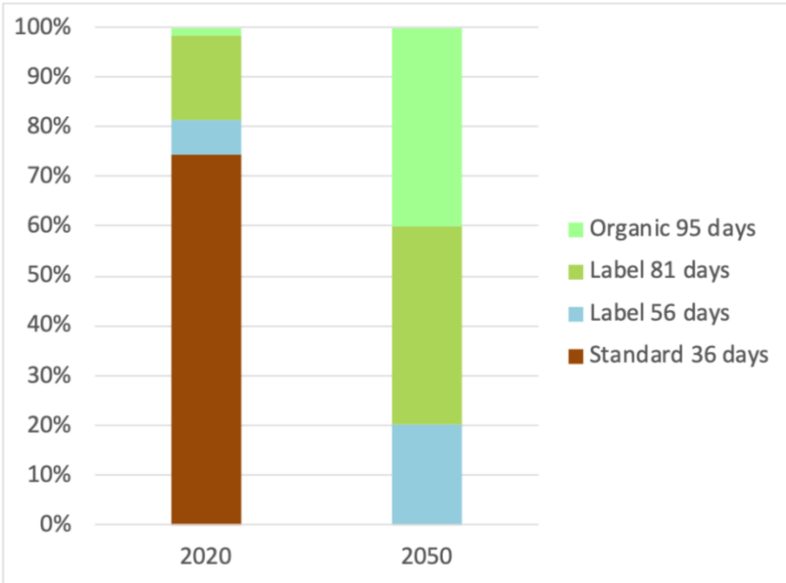

Figure 9: Evolution of broilers production type (share of heads)

Evolution of feed coverage and international trade

In 2050, the main balances of international trade are maintained overall, with significant changes for some commodities (Figure 10).

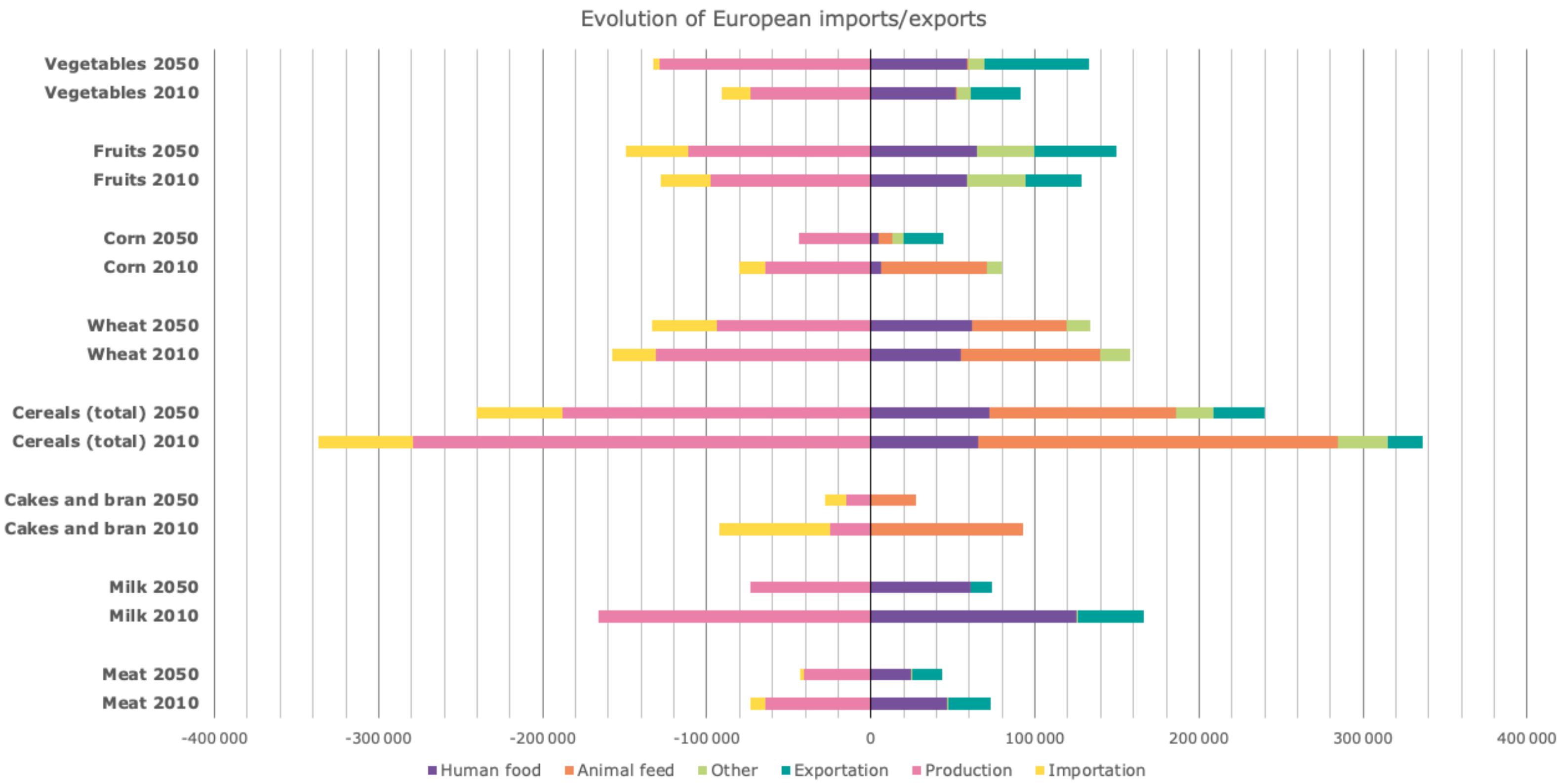

Figure 10: Evolution of European imports/exports (Mt of products)
This figure shows the resources on the left (production + importation) and the use on the right (export + domestic demand divided into food, feed and other uses). Exports and imports are expressed as net flows. Single items such as "wheat" or "sugar" are either exported or imported. Aggregated categories such as "cereals" and "fruits" may include import flows for some items and exports flows for others.

Agriculture, forestry, other land-use changes and bioenergy: main assumptions and trajectory

For cereals, there is a decrease in production due to water scarcity (especially for corn) and change of land-use and practices. On the use side, food consumption increases while feed for cattle decreases. As a result, the net export is maintained at the same level in 2050 compared to 2010.

Milk balance is close to equilibrium, as for meat and sugar.

Europe becomes net exporter of vegetables and remains net importer of fruits.

Finally, imports of soya cakes drop to nearly zero.

Climate mitigation and bioenergy production

The previous part detailed the key changes in land uses and agriculture and forestry practices modelled for Europe by Solagro. In an energy and climate perspective, an improvement of climate change mitigation and the provision of bioenergy resources was among the objectives of the modelling. This section gives the first results of the modelling of these two parameters.

Climate change mitigation

GHG emissions of agriculture

The GHG emissions of European agriculture can be estimated to 619 $MtCO_2eq$ today, including direct and indirect emissions.

Modelling

The measure of greenhouse gases includes direct and indirect emissions from agriculture:

- *"Direct" emissions include enteric fermentation, manure management and soil emissions. It also includes CO_2 emissions due to the combustion of fossil fuels by the agriculture sector.*
- *"Indirect" emissions are due to the production of inputs such as nitrogen fertilisers. Feed is not counted in the calculation.*

In the modelling, the GHG emissions drops by 62% between 2015 and 2050, to 230 $MtCO_2eq$/year, thanks to 3 main drivers (Figure 11):

- the **reduction of enteric fermentation** (in green) proportionally to the herd of ruminants;
- the **reduction of N_2O emissions** (in blue) from the soil due to the reduction of inputs through the generalisation of agroecological practices;
- the **reduction of CO_2 emissions** (in orange) with energy savings and substitution of remaining needs by renewable sources.

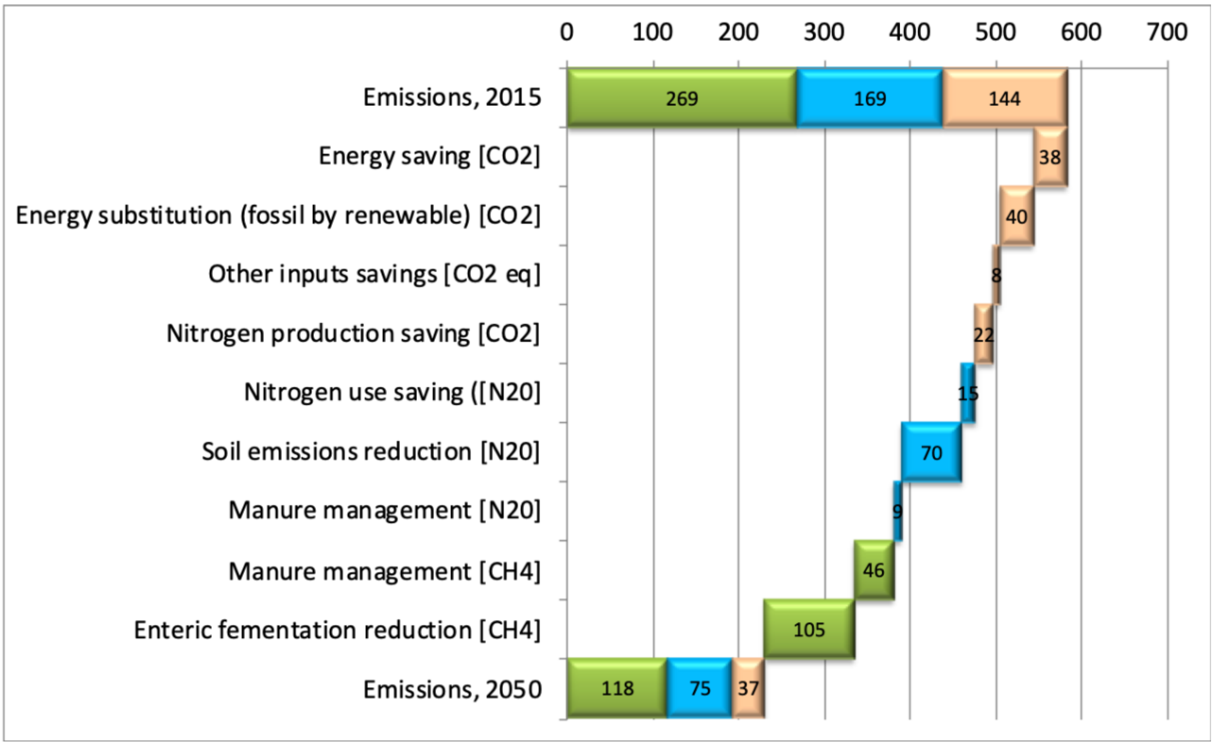

Figure 11: GHG emission reductions from the agricultural sector in 2050 compared to 2015 levels (MtCO2eq)

Carbon storage potential of Land Use, Land Use Change and Forest (LULUCF)

Definition and historical evolution

There are 2 factors of variation of carbon stocks:

- *Land use change effect:* when forest is converted into meadows, or a meadow into ploughed cropland, or into settlement, carbon is emitted. In the opposite direction, carbon is stocked.
- *Land use effect:* depending on the land management method: some practices favour accumulation, for example the growth of existing forest, organic matter in meadows or arable land. Others, on the contrary, contribute to destocking carbon: ploughing, excessive export of organic matter. This is the land use effect.

Today, the land sector in Europe (EU28) constitutes a net carbon sink. In 2019 it represented 243 million tons of CO2 equivalent[18]. Sinks represented 418 MtCO2eq and sources 174 MtCO2eq. By far, the largest sink is the forest, which continues to accumulate carbon through: increased density per hectare, expansion of forest area and storage in harvested wood products (mainly long-life timber). These 3 sectors together captured 393 MtCO2eq in 2019, the main part being the increase of the existing forest.

Regarding carbon sources, the main source is the artificialisation of land and the conversion of meadows and forests into cropland. It is important to note that meadows along wetlands and ploughed lands are considered to be slight carbon emitters, not net sinks.

Since 2000, the European sink has tended to decrease. Emitting sources have decreased slightly, mainly from agricultural land, but land artificialisation is increasing. Carbon sinks have also been decreasing for several years. Storage in forest has decreased, as well as in wood products[19].

[18] Source: EEA data

[19] See EEA data

EU modelling and potential levers and brakes

The ambition of the European Union is to move from a net sink of 240 MtCO2eq/year to a net sink of between 310 MtCO2eq by 2030[20]. The scenarios built for the European Commission envisioned a net sink in 2050 between 343 MtCO2eq/year (1.5 TECH scenario) and 455 MtCO2eq/year (1.5 LIFE scenario)[21].

This level of ambition can be achieved through three strategies:

- **Reduce sources of emissions**: emissions from land-use change are still significant. They can be reduced or even reversed by reducing urban sprawl and infrastructure, preserving natural areas such as marshes and peat bogs and avoiding the conversion of grassland to cropland.
- **Improve the carbon sink of the current forest**: it is a very uncertain possibility due to uncertainties of the impact of climate change. There are today signs of a slowdown of carbon storage of European forest due to climate change[22].
- **Afforest**: massive afforestation. This is the key lever used in the EC models[23]. It implies massive conversions of agricultural land into forest. This therefore presupposes a significant reduction in food demand as envisioned in this trajectory.

LULUCF trajectory

In this trajectory, the following hypotheses have been retained (illustrated Figure 12):

- **The forest carbon sink will not increase** under any harvesting scenario. It is assumed that the annual loss of 60 MtCO2eq/year between 2015 and 2019[24] will be partially recovered by 2050.
- **Land use change will decrease**: artificialisation is greatly reduced, grasslands are no longer converted to ploughed land, peatlands are preserved and restored, as well as wetlands. The trajectory is on that point very ambitious, it supposes bold objectives of no net land take by 2050 taken in the different EU Member States.
- **Afforestation will play a role comparable to that of today**. There is no acceleration of the increase in forest area because the trajectory does not model conversions of agricultural land to forest (see Figure 3).
- Finally, **agricultural practices will play an increasing role thanks to agroforestry**, hedges and cover crops: this is the main origin of the raise of LULUCF carbon storage between now and 2050.

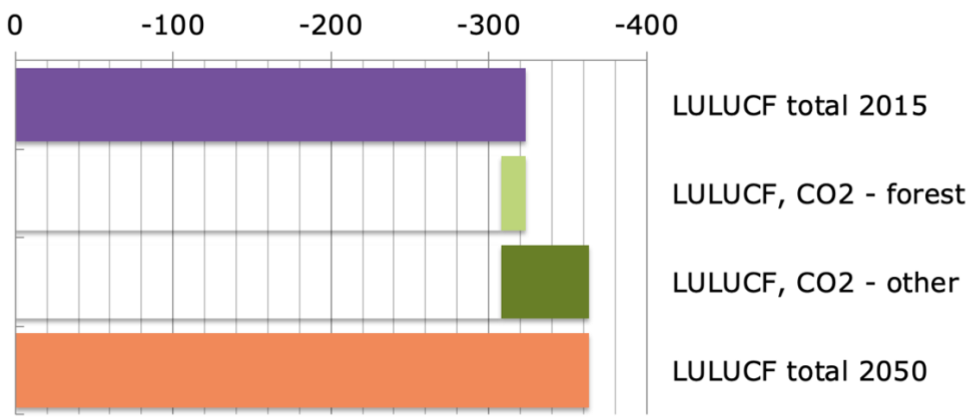

Figure 12: Change in LULUCF carbon storage (EU28, MtCO2eq/year)

[20] See the EC target proposal, validated in 2022 in trilogue.
[21] EC, 2018
[22] See EEA data and analysis
[23] EC, 2018
[24] See EEA data and analysis

The net balance of these different measures, excluding forests, adds a carbon sink of 50 MtCO2eq/year in comparison to the 2015 level, obtaining a carbon storage of 364 MtCO2eq/year in 2050. It is more ambitious than the EU Commission 1.5 TECH scenario trajectory, but it is far from the 1.5 LIFE scenario because of less ambitious assumptions on afforestation[25].

Bioenergy production

Challenges of the bioenergy production

Bioenergy provides a way to produce carbon neutral combustion fuels through photosynthesis. The climate change mitigation potential of bioenergy is therefore very important. However, its production has to compete with other uses of biomass (Figure 1).

This competition raises three main families of challenges with bioenergy:

- The first concerns **food security** and more generally social and societal issues.
- The second concerns **climate issues**.
- The third concerns **biodiversity issues**.

Food security and societal issues

Regarding food security, some scenarios mobilise large agricultural areas for the production of bioenergy[26]. It could be a problem if the mechanisms that ensure food security are insufficient. A progress has been seen in the revision of the REDII directive with the addition of new sustainability criteria to avoid using edibles for energy, and also to avoid cultivating high nature value land for energy.

Bioenergy production could also raise societal issues through a confrontation between territorial logics and market logics. The bioenergy production put the risk on local populations to lose control of their production to the benefit of major food and energy companies. However, in some cases, it could be integrated in practices that gives more autonomy to communities and territories. Parallels can be drawn on these issues of loss of community autonomy with other local resources exploitation (minerals, fossil resources, renewable electricity). In all cases, size and complexity are factors that contribute to this risk.

GHG balance

The second family of issues concerns the actual climate balance of bioenergy. There are three issues:

- The measurement of the complete GHG balance from production to end use.
- The land use change impact.
- The concept of carbon debt.

Complete GHG balance

In GHG balances, Life Cycle Assessments (LCAs) are carried out taking into account all stages, and when there are co-products, the emissions are allocated on a pro-rata basis.

The GHG balance of bioenergy is sometimes contested on the grounds that the fossil fuels spent on agricultural production and the various processing stages are energy intensive, and that the use of inputs such as fertilisers also generates large amounts of GHGs.

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[25] The final CLEVER trajectory is slightly more ambitious than the following results with a carbon storage around 385 MtCO2/year in 2050.

[26] The EC 1.5 TECH scenario for instance

This argument however is weak, there is significantly more energy recovered than what was used. It is possible to produce bioenergy that has a favourable GHG balance and meets the REDII criteria. With a complete LCA, the worst bioenergy pathway emits less than 50 g CO_2 e/MJ (without taking ILUC into account).

Land use change

On the other hand, as underline by the EU Commission[27] LCAs have difficulty in considering its indirect land-use change (ILUC) impact. There are two positions on the accounting of the bioenergy impact on land-use change:

- Considering that any dedicated crop that is transformed into energy requires an equivalent area elsewhere in the world, e.g. 1 ha of biofuel implies 1 ha of deforestation.
- Considering that a change in demand leads to a change in production systems, and that the efficiency gains largely offset this increase.

Deforestation is not a mechanical effect, it is also possible to put fallow, wasteland or degraded land back into cultivation. However, deforestation emits very large amounts of CO_2, so if this indirect effect is to be attributed to biofuels, the GHG balance of bioenergy produced on arable land is severely altered or even becomes negative compared to fossil fuels.

When the ILUC is taken into account, the values of GHG emissions of bioenergy production is much higher. The net loss of carbon per hectare of forest converted to arable land is about 20 tCO_2 per year for 20 years. With an energy yield of 55 GJ/ha, this means that the ILUC could represent 360 g/MJ. If the deforestation ratio of bioenergy production is 10%, 36 g/MJ of bioenergy is emitted for ILUC alone. With this accounting, most fuels reach almost the same level of GHG emissions as petroleum fuels, some even exceed it, and only a few do not exceed half of the emissions[28].

These considerations paved the way for policy promoting low-ILUC bioenergy in REDII[29]. May be considered as low ILUC-risk biomass, a biomass using new feedstock that is additional to current production levels, so that displacement of food production is avoided. This can be achieved through improved yields of existing crop systems, or through new crop production on formerly unused land, abandoned agricultural land or severely degraded land.

Carbon debt

Finally, the concept of carbon debt is mainly about forests and solid biomass uses. Forests act both as a carbon sink and as a source of bio-based materials that can replace fossil fuels and materials with a high GHG impact.

However, these two effects – the sequestration effect and the substitution effect – may be negatively correlated. Wood cannot be stored in living trees and buildings at the same time. The question is to what extend these effects are negatively correlated.

There are two extreme positions:

- Substitution effects generally cannot compensate for any sequestration effect, so forest harvesting must be reduced.
- On the contrary, active forestry is capable of offering a higher overall balance because the additional substitution effects more than compensate for the loss of the sequestration effect.

In a **sequestration strategy**, the growth of living biomass will therefore be favoured. In the end, a maximum level is reached, which corresponds to the climax, i.e. the stage where a new natural balance is reached which depends on local pedoclimatic conditions. When the climax is reached, the carbon stock is maximum, and the net annual flows are reduced to zero.

In a **substitution strategy**, there is an initial effect of destocking living biomass which is partially offset by the substitution of fossil fuels, and then recovering the initial stock of biomass. The previous

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[27] EC, 2019 part II.

[28] That's the conclusion of a key study made for the EU Parliament in 2011: EP, 2011

[29] See the EC strategy in the following website.

balance is regained, so there is no destocking and a benefit from the substitution effect can be reaped.

But the latter strategy is true in the very long term, and the whole question is to know when the balance is reached.

Two strategies hence exist in the modelling, one of sequestration and the other of substitution. There are two intersection points (Figure 13):

- *C debt repayment:* when the substitution scenario made it possible to compensate for the initial effect of destocking.
- *C offset parity point:* when the substitution scenario compensated not only the initial destocking effect, but also the additional storage effect of the sequestration scenario: when this point is reached, the wood used at the beginning could be considered as carbon neutral.

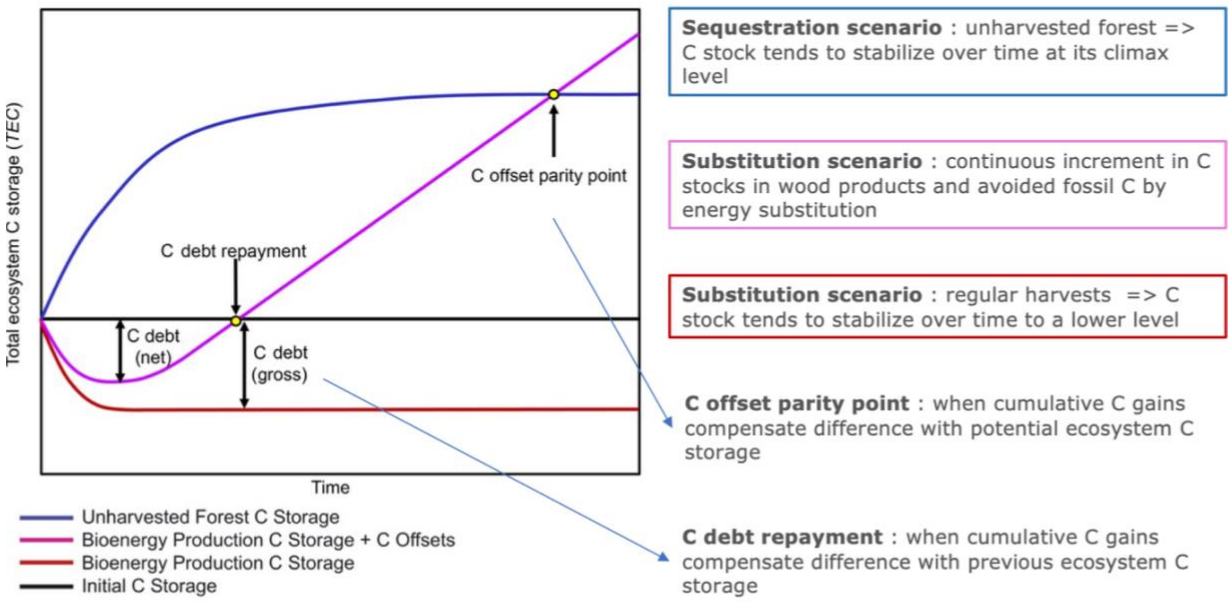

Figure 13: Illustration of the theoretical carbon debt

The challenge of modelling is to determine when these intersections or parity levels are reached, whether they are reached.

Biodiversity impact

Finally, biodiversity is strongly impacted by deforestation, ILUC are hence a huge risk. Furthermore, in the case of carbon debt, the biodiversity could be reduced after the carbon destocking in the substitution scenario.

CLEVER's vision for bioenergy

It is clear from the IPCC and IPBES reports on land[30] that, given the interdependence of all the issues, only a systemic approach can provide solutions compatible with the SDGs (Sustainable Development Goals). Bioenergy in a modelling couldn't be added to the current agricultural production system or forestry as an additional demand. The challenge is therefore to support the development of bioenergy through practices that offer co-benefits.

[30] IPCC, 2019, IPBES, 2018

Hierarchy of uses: cascading use of biomass

To comply with these guidelines, the CLEVER trajectory will respect as much as possible the principle of cascading or prioritisation of uses (Figure 14):

- **Biomass production** must be **used primarily for high value-added productions**, food, but also fibres and sustainable materials.
- The second priority is to **reuse and recycle** as much as possible, as is done today with paper.
- **Residues, co-products and wastes** for which there is no better use could be **used for the production of energy**.
- Energy production is the final use of biomass because the atomic bonds are destroyed. The **direct production of biomass for energy use should be avoided**.

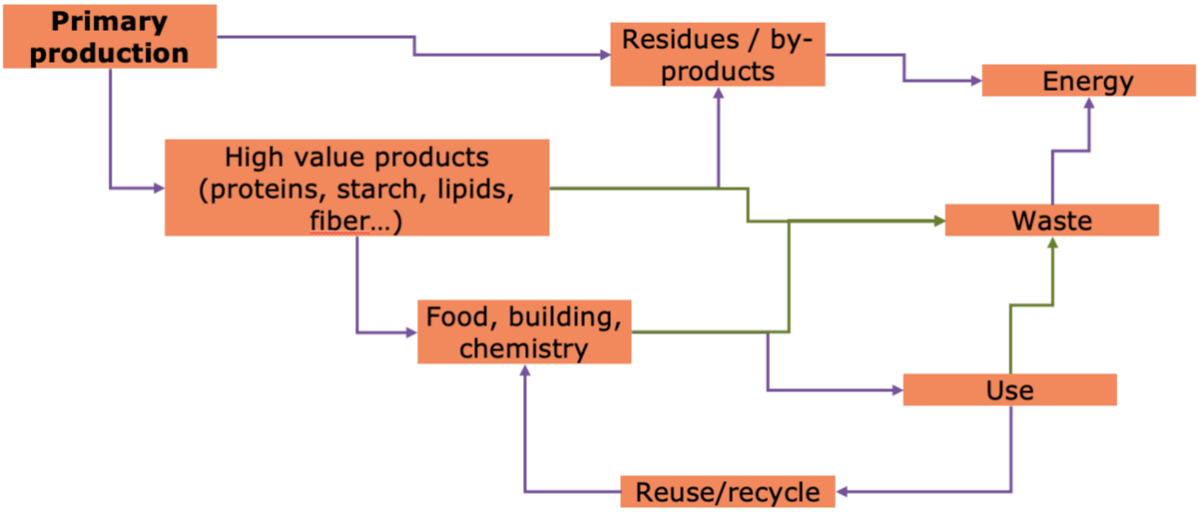

Figure 14: Illustration of the principle of cascading biomass use

The principle of cascading is one that has been followed by the wood industry for a long time. By-products are generated at the various stages of processing, bark, black liquors, paper sludge, shavings, and it is these materials that are used to produce energy.

Biogas production

For biogas, the main resources mobilised are manure, intermediate coverings, crop residues and grass. Dedicated cultures are completely ruled out by 2050. The different biogas resources, their considered advantages and drawbacks and relative use in CLEVER are detailed Table 2. The advantages and drawbacks exposed are fundamental, the cost, or difficulty of implementation was considered in the scenario but not in this table. The trajectory was limited to techniques that have already been proven.

Resource	Advantages	Drawbacks	Use in CLEVER
Manure	Improvement of the fertilizing value, no C loss, reduction of GHG emissions during storage	No	+++
Cover crops	Good agroecological practices : N & P recovery, positive impact on erosion, soil organic carbon, biodiversity, pesticide use	Competition for water, reduction of main crop yield, inputs (fuel, N)	++++
Residues (straw)	Low input by-product	Low digestible	++
Dedicated crops	High potential	High competition	0
Grass and fodder	Diversification of outlets in grassland areas as livestock decreases	Competition for feed	++
Municipal and commercial biowaste	Waste treatment	No	+
Wastewater and sludge	Waste treatment	No	+

Table 2: Consideration of the use of biogas resources in CLEVER

Wood and solid energy

Solid bioenergy is defined as wood and more generally lignocellulosic materials. They come from the forest but not only. 3 origins can be distinguished:

- Primary resources extracted directly from ecosystems, the forest, agriculture with hedges, agroforestry, vine shoots and orchard pruning, but also trees in towns, on the roadside or from maintenance of green spaces and gardens.
- Secondary resources, obtained in the primary wood processing industries, sawmills and paper mills.
- Tertiary resources: waste from wood products (materials recovered at the end of the consumption cycle).

The consideration of solid bioenergy in CLEVER are given in Table 3.

Origin	Resources	Advantages	Drawbacks	Use in CLEVER
Primary	Fuel wood from wood-material oriented forestry	Complementary with construction wood	Risk of nutrient depletion in case of excessive take off	+++
Primary	Fuel wood from dedicated forestry (traditionnal coppices)	Traditional method	Possible negative carbon balance	++
Primary	Short rotation coppice	Use of fallow land or water protection areas	Land use	+
Primary	Agroforestry	Good agroecological practices, C storage in soil and wood, favourable to biodiversity	Slight impact on crop yield ; no harvest before 10-15 years	+
Primary	Hedges		No	+
Secondary	Sawmills by-products (bark, etc)	Available and low-impact by-products	Competition with other uses (pulp, mulch, compost)	+
Secondary	Papermills by-products (black liquor, sludge)			e
Secondary	Agricultural by-products			
Primary	Urban trees, garden and green spaces			+
Tertieary	Wood waste, incl. waste paper, packaging, furniture, carpentry			+
Tertiary	Wood from deconstruction		Emerging practice	+

Table 3: Consideration of the use of solid bioenergy in CLEVER

Biofuels

Classification

There is a very wide variety of biofuels. They can be classified according to their form and their origin.

These can be oil-based fuels, alcohol-based fuels, methane-based fuels and other less used forms. Within each family there are also variants, for example methyl esters or hydrogenated oils and ethanol can be mixed in gasoline or combined to produce MTBE-like forms.

Fuels can come from agriculture, forests, waste or the sea. Each family can be referred to according to its origin, e.g. agrofuels.

The agrofuels can be distinguished in 3 generations:

- First generation fuels are fuels produced from dedicated crops (also biogas from excreta). They generally correspond to fuels that began to be produced from oil or grain in the 1990s.
- Second generation fuels are produced from straw.
- Third generation fuels are produced with algae.

Biofuels use in CLEVER

Biofuels are overall little used in CLEVER, the estimated potential for 2050 are 150 TWh for 1st generation (slight reduction compared to current level due to a ban on high risk ILUC), 50 TWh for 2nd generation and 20 TWh with huge uncertainties for 3rd generation.

The consideration of solid bioenergy in CLEVER are given in Table 4.

Resource	Advantages	Drawbacks	Use in CLEVER
1st generation biofuels	Easy substitution to fossil fuels	High risk ILUC	+
2nd generation biofuels	Low risk ILUC (under condition)	Technical difficulties	+
3rd generation biofuels	Low risk ILUC (under condition)	Low TRL	(+)

Table 4: Consideration of the use of biofuels in CLEVER

Bioenergy trajectory

Overall results and country breakdown

Overall results

In total in this scenario, the role of bioenergy increases by about 50% from 1,500 TWh currently to 2,200 TWh in 2050 (EU28 - Figure 15):

- Wood energy from the forest remains at its current level, neither decreasing nor increasing.
- The other solid biomass sources increase, this is mainly due to the use of wood by-products and waste and agroforestry installation (see Figure 5).
- Biogas production increase and represent 2/3 of the overall increase.
- Finally, for biofuels, it is rather a slight decrease.

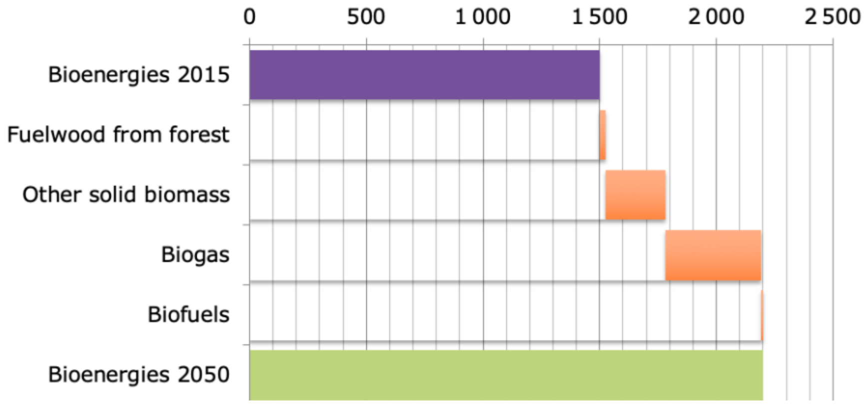

Figure 15: Overall change in bioenergy production (EU28, TWh)

Country breakdown

Figure 16 shows a breakdown of bioenergy production and imports by country.

The amount of bioenergy that each country can produce is directly related to its forest area and its agricultural area. France and Germany are in the lead because both countries have extensive forests and significant agriculture. Other countries such as Poland or Italy have a similar structure. Some such as Finland, the United Kingdom or Austria are rich in forests but have a smaller share of bioenergy from agriculture.

The productivity of agricultural and forest ecosystems also plays a role.

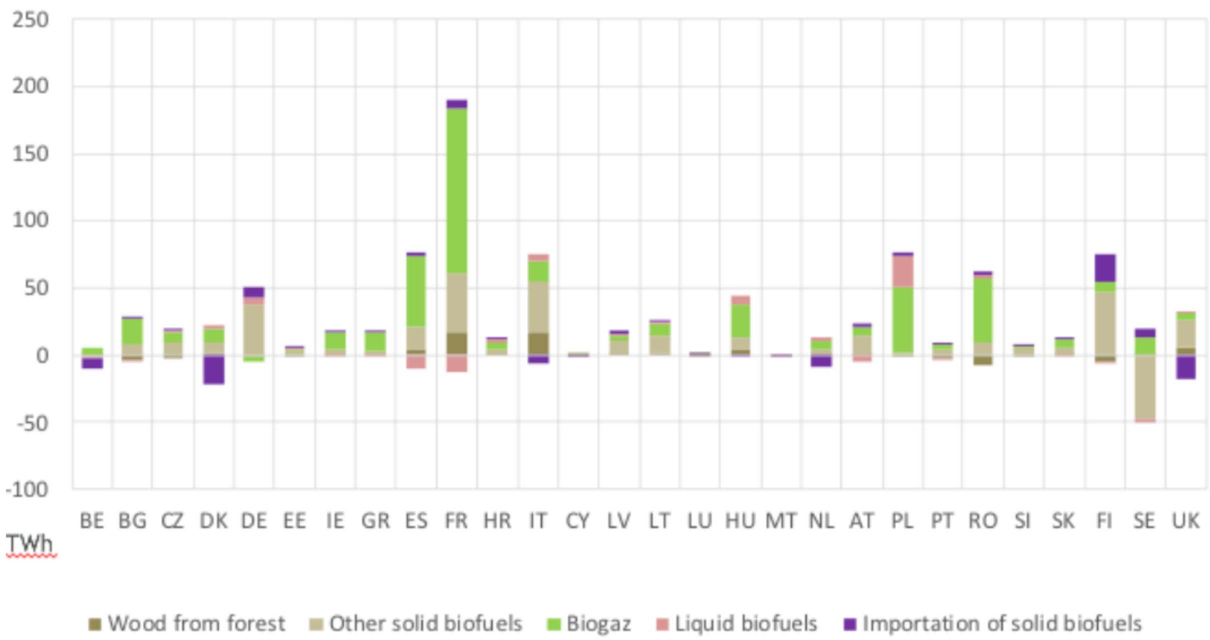

Figure 16: Country by country bioenergy production and imports breakdown in 2050 (TWh)

There are different national trends following each country context.

Biogas is set to develop a lot in France, Spain, Poland and Romania. In Germany, there is no variation, which means that all crops used for biogas can be replaced by intermediate crops.

For wood, the variations are more uncertain. No country would see significant variations in wood energy from forests.

Agriculture, forestry, other land-use changes and bioenergy: main assumptions and trajectory

There would be an increase in other solid biomass in France, Germany and Italy, mainly wood waste and agroforestry.

References

Aleksandrowicz, L., Green, R., Joy, E. J., Smith, P., & Haines, A. (2016). The impacts of dietary change on greenhouse gas emissions, land use, water use, and health: a systematic review. *PloS one*, *11*(11), e0165797.

Billen, G., Aguilera, E., Einarsson, R., Garnier, J., Gingrich, S., Grizzetti, B., ... & Sanz-Cobena, A. (2021). Reshaping the European agro-food system and closing its nitrogen cycle: The potential of combining dietary change, agroecology, and circularity. *One Earth*, 4(6), 839-850.

Bryngelsson, D., Wirsenius, S., Hedenus, F., & Sonesson, U. (2016). How can the EU climate targets be met? A combined analysis of technological and demand-side changes in food and agriculture. *Food Policy*, *59*, 152-164.

European Commission (2018). A Clean Planet for all: a European long-term strategic vision for a prosperous, modern, competitive and climate neutral economy. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52018DC0773

EU Commission, (2019). Report on the status of production expansion of relevant food and feed crops worldwide. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52019DC0142

FAO (2019). Sustainable healthy diets. Guiding principles. https://www.fao.org/3/ca6640en/CA6640EN.pdf

IPBES, (2018). Summary for policymakers of the assessment report on land degradation and restoration of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. https://zenodo.org/record/3237411#.Y-tfvcGZPaq

IPBES, (2019). Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services.

IPCC, 2019: Summary for Policymakers. In: Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems. https://doi.org/10.1017/9781009157988.001

JRC (2020). Analysis of climate change impacts on EU agriculture by 2050. https://joint-research-centre.ec.europa.eu/system/files/2020-05/pesetaiv_task_3_agriculture_final_report.pdf

Solagro, (2016). The Afterres2050 scenario. https://solagro.org/images/imagesCK/files/publications/f94_afterres2050-eng.pdf