WP4 – Agriculture & land-use module documentation

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Main authors	Gino Baudry, Onesmus Mwabonje, Jeremy Woods
Partner in charge	Imperial College London
Contributing partners	
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Short Description
This report describes - *the sources and hypotheses used to build the historical database;* - *The calculation logic and scope of the module;* - *The lever choices and ambition levels.*

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This deliverable contains original unpublished work except where clearly indicated otherwise. Acknowledgement of previously published material and of the work of others has been made through appropriate citation, quotation or both.

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1.Introduction

According to the United Nations, the human population could reach 9.8 billion inhabitants by 2050[1]. The current population represents 7.6 billion inhabitants and consumes the equivalent of 1.7 planets according to the ecological footprint standards[2]. This global ecological footprint measures:

> *'the impact of human activities measured in terms of the area of biologically productive land and water required to produce the goods consumed and to assimilate the wastes generated[3]'.*

In a context of climate change, multiple dynamics may deeply threat the availability and productivity of the Earth's ecological assets, leading to the collapse of ecosystems, and their associated invaluable services without which humanity could not ensure a sustainable future. The land-use and productivity are thus at the forefront of the sustainable development of humanity.

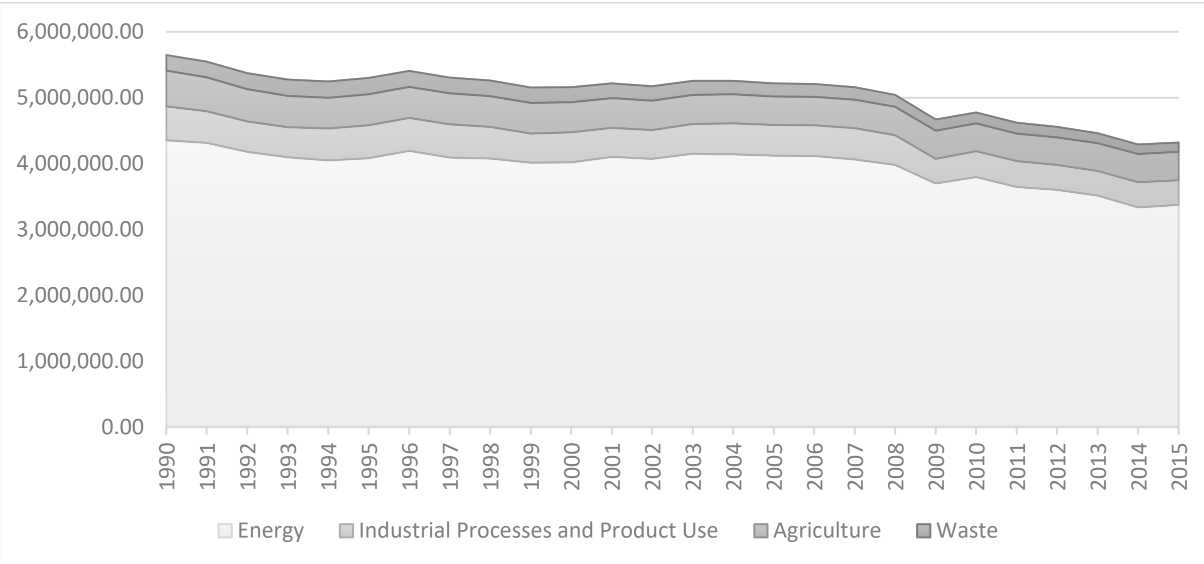

Figure 1 –GHG emissions per sector without LULUCF in the European Union (ktCO₂ equivalent)[4]

The agriculture, land-use, land-use change and forestry modules of the European Calculator (EUCalc) aims at modelling part of these challenges associated with

[1] United Nations, economic and social affairs, World population projected to reach 9.8 billion in 2050, and 11.2 billion in 2100, June 2017; Direct link: https://www.un.org/development/desa/en/news/population/world-population-prospects-2017.html

[2] Global footprint network, Ecological footprint;
Direct link: https://www.footprintnetwork.org/our-work/ecological-footprint/

[3] WWF, Ecological footprint definition; Direct link:
https://wwf.panda.org/knowledge_hub/teacher_resources/webfieldtrips/ecological_balance/eco_footprint/

[4] United Nations Framework Convention on Climate Change (UNFCCC), Greenhouse Gas Inventory Data - Detailed data by Party, Total GHG emissions without LULUCF, European Union (Convention);
Direct link: https://di.unfccc.int/detailed_data_by_party

agriculture, forestry and land activities, including the scope of climate-change and wider sustainability impacts. The objective is therefore to include how were, are and will the agriculture, land-use, land-use change and forestry affecting/affect climate change? And how was, is and will climate change affect the agriculture, land-use, land-use change and forestry sectors in Europe in return.

At the European level, the agriculture sector only represents about 9% GHG emissions, variating by +/- 1% since 1990 (Figure 1). When focusing on land-use, land-use change and forestry associated emissions - usually shorten as LULUCF - (Figure 2), the European carbon sink has been increasing over the year. Nevertheless, the current CO_2 emission level is by far exceeding the biosphere capacity to store carbon, which is challenging the sustainability development of the complex human-based system.

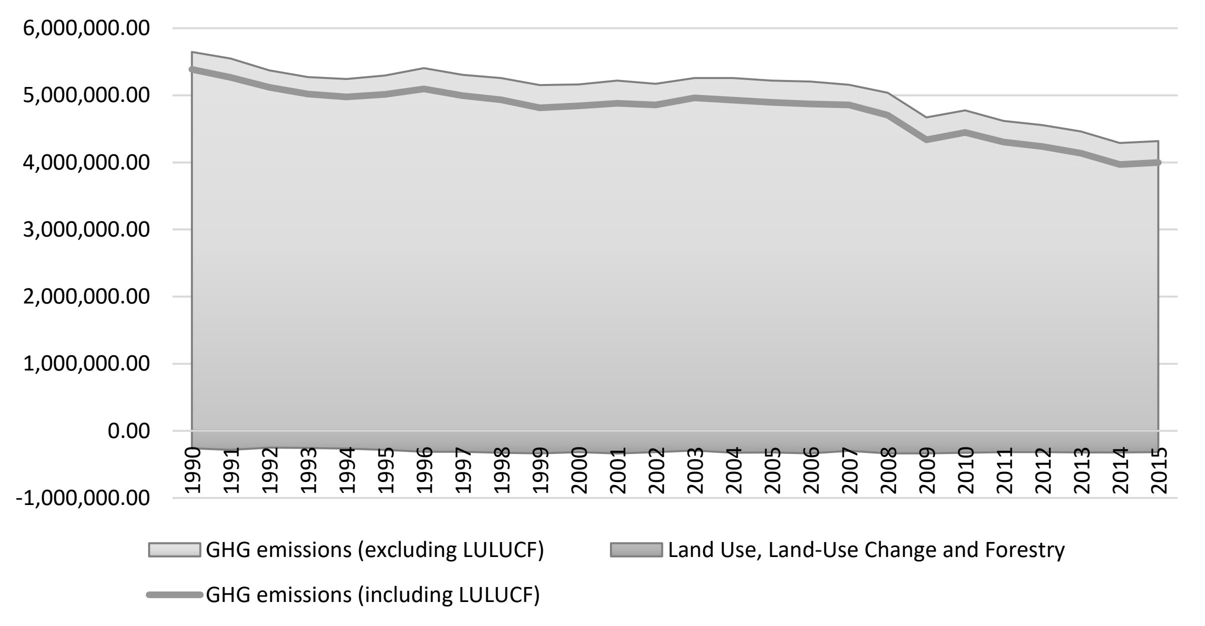

Figure 2 –GHG emissions from LULUCF in the European Union (ktCO₂ equivalent)[5]

Although Figure 2 present the total LULUCF carbon pool, it does not picture the highly heterogeneous European landscape. For example, the LULUCF carbon sink potential has been divided by 2 in Germany whereas Italy's was multiplied by 10 between 1990 and 2015. The LULUCF sector has a critical role to play to reach net-zero pathways. The extent of the LULUCF carbon sink potential mainly dependents on the land-use and land-use change dynamics and land management (e.g. agricultural practices, land allocation) that leads to store or free carbon from the soil.

[5] United Nations Framework Convention on Climate Change (UNFCCC), Greenhouse Gas Inventory Data - Detailed data by Party, Land Use, Land-Use Change and Forestry, European Union (Convention);
Direct link: *https://di.unfccc.int/detailed_data_by_party*

1.1.Trends and evolution of the sectors

The section presents in brief the trends and past evolution of the agriculture and LULUCF sectors.

1.1.1.Agriculture

The main drivers of GHG emissions in the agriculture sector (Figure 3) consist of the livestock production through the enteric fermentation emissions (i.e. CH_4 emissions, methane) that stems from the livestock digestion process; the manure management (CH_4 emissions and N_2O emissions, nitrogen dioxide); the use of fertilizers which emits N_2O emissions through the oxidation of nitrogen inputs. And in a lower extent in Europe, the rice cultivation process that involves CH_4 emissions; and the management of crop residues that lead to CH_4 emissions and N_2O emissions.

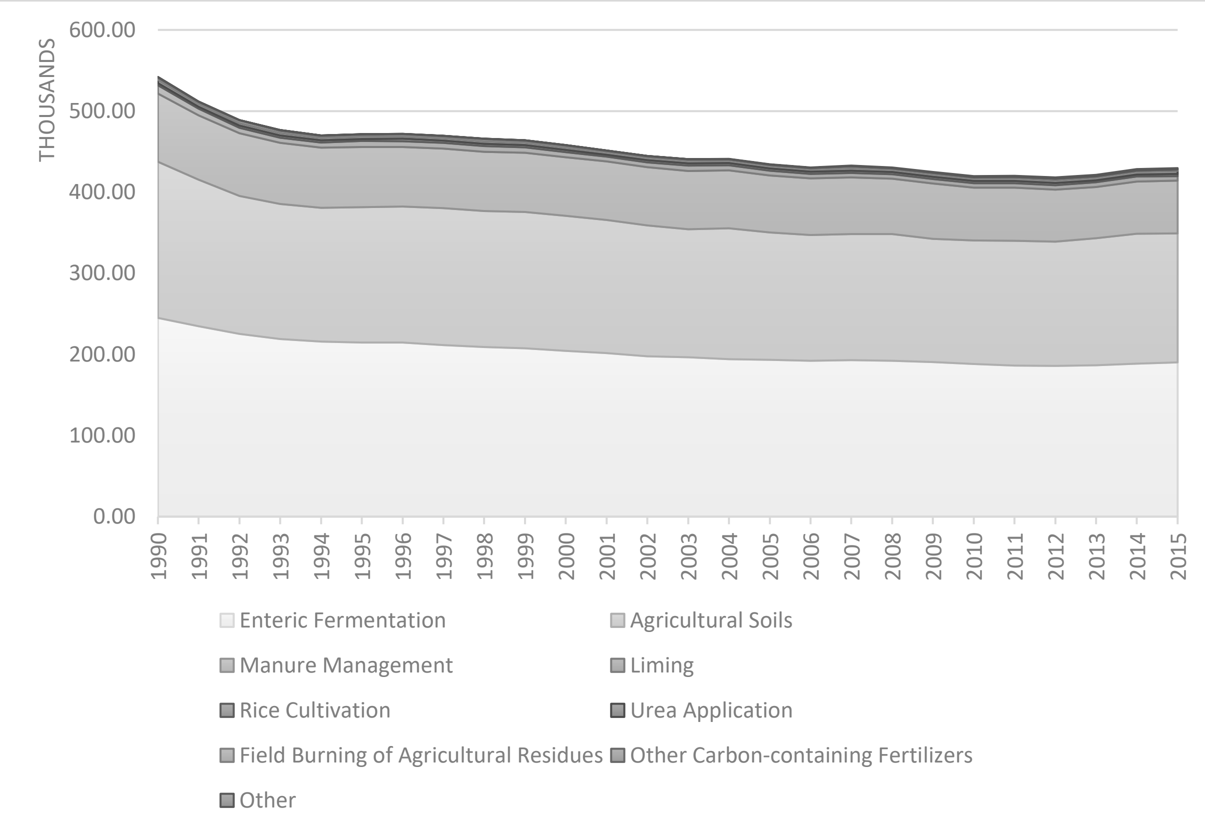

Figure 3 – GHG emissions in Agriculture in EU28 (2015)[6]

As shown by Figure 3, the agriculture associated GHG emissions decreased by about 18% since 1990. According to the European Union, the two main drivers

[6] EUROSTAT, Agri-environmental indicator - greenhouse gas emissions
Direct link: https://ec.europa.eu/eurostat/statistics-explained/index.php/Agri-environmental_indicator_-_greenhouse_gas_emissions

explaining this trend[7] consist of the decrease of the animal products production, the evolution of the practices, especially in terms of fertilizer-use, and the increasing share of food and drink imports. Imports contribute to GHG emissions leakages through the consumption of goods produced outside of the EU, but which are not considered in the official GHG inventory (Peters and Hertwich, 2008).

1.1.2. Land-use, land-use change and forestry

European lands are mostly shared between forests (38%), cropland (22%), grassland (21%). Artificial lands account for 3% of the total European lands (Figure 4).

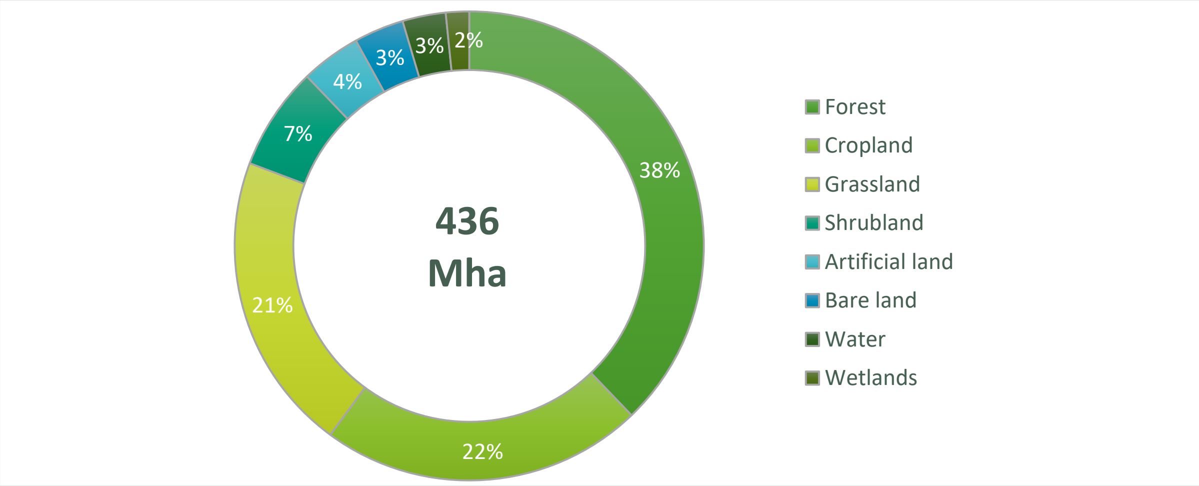

Figure 4 –Land cover overview in the EU in 2015 (ha)[8]

Given the land dynamics in Europe, the LULUCF carbon sink has increased thanks to the expansion of the forest lands and the harvest of wood products. At the opposite, the cropland and the extension of settlements areas led to increase GHG emissions (Figure 5), but while the LULUCF balance remains negative (i.e. remains a carbon sink).

Nevertheless, the land management and other climate smart approaches could foster widely the LULUCF carbon sink potential, including climate smart production systems for livestock, crops and forestry (FAO, 2013; Nabuurs et al., 2017). For instance, according to the initiative 4 for 1000 proposed at the 21st Conference of Parties in Paris (COP-21), good practices would lead to increase the natural carbon pool of the agriculture lands by 4 ‰, i.e. the equivalent of the yearly CO_2

[7] EUROSTAT, Agri-environmental indicator - greenhouse gas emissions
Direct link: https://ec.europa.eu/eurostat/statistics-explained/index.php/Agri-environmental_indicator_-_greenhouse_gas_emissions
[8] EUROSTAT: land-cover (dataset: an_lcv_ovw), Direct link: https://ec.europa.eu/eurostat/data/database

emission[9]. These good practices include[10] grassland advanced management practices that could increase the carbon soil storage ability by 0.1-0.5 tC/ha/year; the deployment of hedges could also add an extra 125kgC/year for each 100 meters; Agroforestry practices could also massively contribute to enhance the agriculture land carbon storage; and so on.

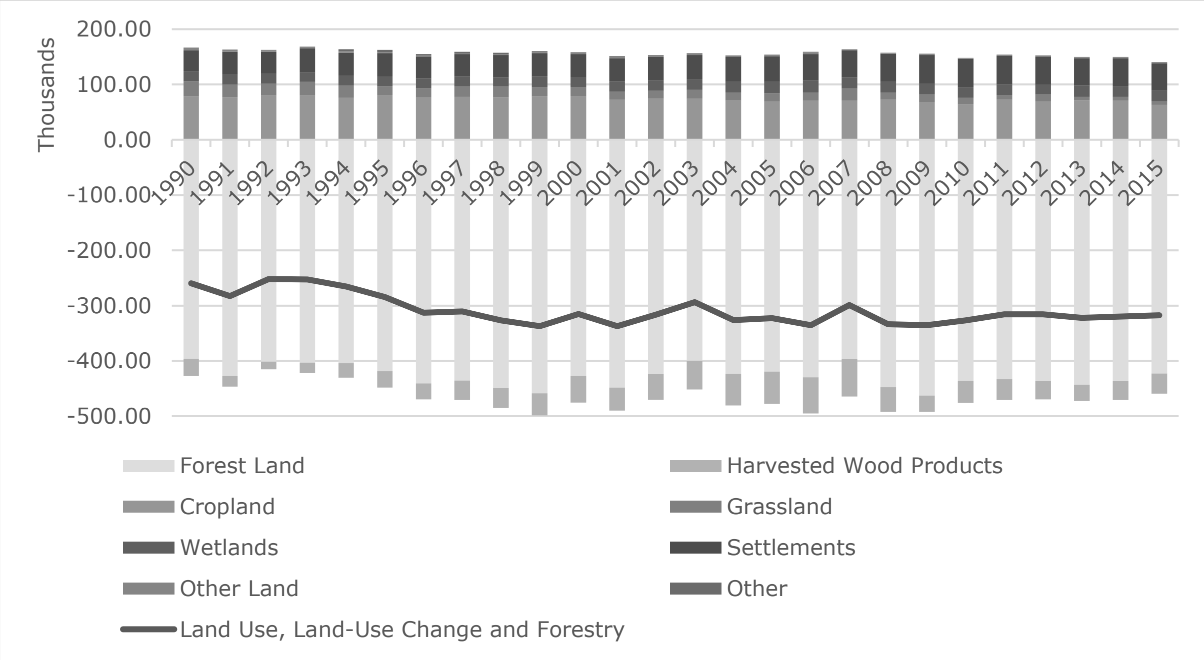

Figure 5 –GHG emissions from LULUCF by source in the European Union (ktCO₂ equivalent)[11]

1.2. Objective of the document

The present document aims at presenting the agriculture, land-use, land-use change and forestry modules included in the European Calculator framework by detailing: the questions that we aim at addressing (Section 2); the logic of the EUCalc modelling framework (Section 3); the scope and the calculation of the agriculture, land-use, land-use change and forestry modules (Section 4); and finally, the input data that have been used across the model (Section 5) and the references (Section 6).

[9] What is the 4 per 1000 initiative? Direct link: https://www.4p1000.org/

[10] INRA (French national Institute for Agricultural Research), Contribution à la lutte contre l'effet de serre : stocker du carbone dans les sols agricoles de France ?, 2013 ; Direct link: http://institut.inra.fr/Missions/Eclairer-les-decisions/Expertises/Toutes-les-actualites/Stocker-du-carbone-dans-les-sols-agricoles-de-France

[11] United Nations Framework Convention on Climate Change (UNFCCC), Greenhouse Gas Inventory Data - Detailed data by Party, Land Use, Land-Use Change and Forestry, European Union (Convention); Direct link: https://di.unfccc.int/detailed_data_by_party

2.Questions addressed by the module

The following Table presents the main questions addressed by the agriculture, land-use, land-use change, and forestry modules.

Table 1 – Type of impacts tackled in the model

Impact	Short description	Status
Impacts of agricultural practices (crop)	Assessing the impacts of shifting towards climate smart crop production practices in terms of GHG emissions, biodiversity, water-use, energy-use, fertilizer-use, land-use, carbon storage in the soil	Advanced
Impacts of agricultural practices (livestock)	Assessing the impacts of shifting towards climate smart livestock production practices in terms of GHG emissions, biodiversity, water-use, energy-use, fertilizer-use, land-use, carbon storage in the soil, manure management, grassland management	Advanced
Impacts of alternative feed ration (livestock & aquaculture)	Assessing the impacts of deploying microalgae and insect-based meals in terms of GHG emissions, biodiversity, water-use, energy-use, fertilizer-use, land-use, use of the resulting freed lands, and the availability of feedstock for bioenergy and biomaterials	Advanced
Impacts of fishery practices	Assessing the impacts of shifting towards climate smart fishery and aquaculture production practices in terms of GHG emissions, biodiversity, energy-use, inland-water use, fish stocks, manure management	Still to implement
Impacts of sustainable land management	Assessing the impacts of allocating lands towards various uses such as afforestation, energy-crops, grassland, or leaving land unmanaged in terms of GHG emission factors and carbon stock dynamics.	Advanced
Impacts of bioenergy & biomaterials	Assessing the impacts of bioenergy use, including biomass availability associated with the agri-food industry and agricultural climate smart practices, in terms of GHG emissions, biodiversity, water-use, energy-use, fertilizer-use, land-use, carbon storage in the soil	Advanced
Impacts of sustainable forest management	Assessing the impacts of improving forest management practices in terms of GHG emissions, biodiversity, fertilizer-use, carbon storage in the soil & biomass, and availability of cellulosic feedstock for bioenergy and biomaterial	On going
Energy consumption of the agriculture system	How the combination of the agriculture, fishery, livestock climate smart practices may affect the energy demand and mix?	Advanced
Emissions of the agriculture system	How the climate smart practices may affect the direct emissions of the sector? How the climate smart practices may affect the indirect emissions of the sector?	Advanced
Impacts of import/export of agri-food products	Assessing the impacts of imports and exports of agri-food commodity in terms of GHG emissions, biodiversity, land-use, and resources-use.	Advanced
Employment	What are the employment impacts of agriculture system?	On going
Land-use & carbon dynamics	How the land-use dynamics affect the soil carbon storage	On going

Table 2 – Main questions addressed in the agriculture and land-use modules

Themes	Sub-themes		Status
What are the existing solutions to decarbonize agriculture and land-use?	Avoid	Food waste	Advanced
		Land-use change of rich carbon lands (no deforestation, in Europe and outside)	Advanced
		Mechanical work of soil, fertilizer over-use	Advanced
	Shift	Move towards climate smart practices for food, feed, bioenergy, biomaterial Move towards new feedstuffs for livestock	Advanced
	Improve	Efficiency of the current and new practices	Advanced
		Land-management	Advanced
Can we identify some potential breakthrough (technologies or societal) that could have an impact?	Technology & practices	Microalgae / Insect based feed may drastically reduce land demand for food, enabling to produce more sustainable bioenergy in larger amount	Advanced
What are the impacts of agriculture on the other sectors?	Power	What is the impact of climate smart agriculture on sustainable bioenergy supply?	Advanced
	Land	What is the impact of climate smart agriculture on land use (carbon storage) and availability (biomass potential for bioenergy and biomaterial)?	Advanced
	Industry	What is the impact of climate smart agriculture on fertilizer demand?	Advanced
What are the impacts of other sectors on agriculture & land-use?	Lifestyle	What are the impacts of lifestyle changes on the diets?	Advanced
	Transport	What are the impacts of biofuel demand on the agriculture sector?	Advanced
	Building	What are the impacts of bioenergy and biomaterial demand on the agriculture sector?	Advanced
	Industry	What are the impacts of bioenergy and biomaterial demand on the agriculture sector?	Advanced

3. EU Calculator logic

Calculators share a common Philosophy, which is (1) being fully open source and transparent; (2) simple and engineering-based architecture; (3) ensuring the web-based interface user-friendliness (for not expert and non-expert audiences); The Calculator approach has been adopted by more than 30 countries or regions to support policy-makers and increase public knowledge and understanding. For example, India, Nigeria, Colombia and Vietnam are using their Calculators to develop and report on their Intended Nationally Determined Contributions (INDCs); South Africa and Belgium are using a simplified Calculator for education purposes. The European Climate Foundation funded the development of a Calculator to explore net-zero emission pathways at the aggregated European level; and so on.

The modelling framework enables one to explore a wide range of (un)sustainable futures given potential shifts in behaviour, technology, and practices patterns via a set of action levers. The action levers and the extent of the GHG mitigation efforts in the agriculture & LULUCF sectors are explicitly based on an extensive and interdisciplinary literature review, complemented by multiple expert consultations, and a 2-days stakeholder workshop (Baudry et al., 2018b).

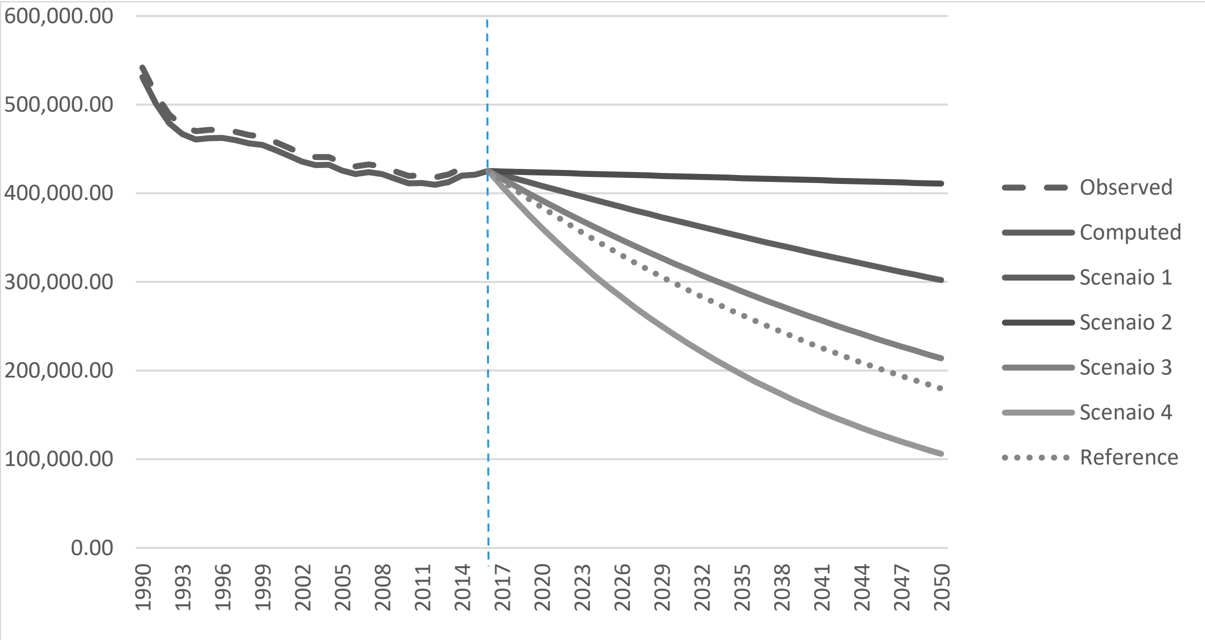

Figure 6 – Overall model logic (illustration graph, made by the authors)

The modelling framework is calibrated based on the observed data for the period 1990-2015, referred as Original Time Series (OTS). Using the same computation pathways, namely the calculation trees in Calculators' terms, the framework computes the scenarios for the period 2016-2050, but while considering eventual behavioural, technological, and practices shifts. The extent of the shift(s) is made explicit through the lever setting which ranges between low and high ambition levels in terms of GHG emission mitigation effort (Strapasson et al., 2016).

Traditionally, 'state of the art' pathways are also implemented through specific lever settings in the framework to enable one to compare the Calculator's output pathway with existing reference scenarios that shape the current state of the art in the context of climate change. For example, the IPCC or else the IEA carbon mitigation scenarios (Figure 6)[12].

The next sections are presenting the scope of the agriculture module (Section 3.1), and the land-use, land-use change and forestry module (Section 3.2).

3.1. Definition of ambition levels

Across the model, each lever provides 4 settings to enable the users to explore the impact of various ambition levels, associated to GHG mitigation efforts:

[12] See the Global Calculator tool; Direct link: http://tool.globalcalculator.org/

The 1-4 scale ambition levels (Table 3): represents 4 scenarios that express the range of effort between the least ambitious (1) to the most ambitious (4) in terms of GHG mitigation. Nevertheless, in a complex and dynamic human system, one cannot always express such a linear scale given feedback loops or else carbon leakages. Thus, the Calculator offers an alternative scale:

The A-D scale ambition levels presents 4 options that express 4 distinguished scenarios to tackle climate change and sustainability impacts but without an established ranking in terms of GHG mitigation efforts. For example, A-D scale is used for population, considering 4 trends of population demographics.

Depending on the lever setting, i.e. on the context, some ambition levels could be either best or worse in terms of GHG emissions. For example, increasing bioenergy share may either be positive or negative in terms of GHG emissions whether it affects direct and indirect land-use change. In other words, the user may increase the ambition level for bioenergy while the impact remains negative in terms of GHG emissions. Consequently, A-D scale can be more relevant to avoid misleading the user. For these reasons, the agriculture and land-use sectors use mainly A-D ambition levels settings.

Table 3 – General definition of ambitions levels

Level	Definition
1	This level contains projections that are aligned and coherent with the observed trends. Possibly, minimum effort can possibly involve a scenario that is less ambitious compared to the historical trends.
2	This level is an intermediate scenario, more ambitious than level 1 but it is not reaching the full potential of the available solutions.
3	Very ambitious change: This level is considered very ambitious but still realistic given the current technology evolutions and the best practices observed in some geographical areas.
4	Transformational changes: This level is considered as transformational and requires large additional efforts such as strong changes in the way society is organized, a very fast market uptake of deep measures, an extended deployment of infrastructures, major technological advances and breakthroughs (but without relying on new fundamental research), etc.

4. Calculation logic and scope of the modules

The present section is presenting the calculation logic and scope of the agriculture, land-use, land-use change and forestry modules. The later technically consists of 2 distinguished modules in the KNIME modelling framework environment, namely the agriculture module, and the land-use, land-use change and forestry module.

The EUCalc agriculture, land-use, land-use change, and forestry modules architecture has been developed following these principles:

- ✓ *Which aggregation offers the highest level of information in the available database across the different items and elements?*
- ✓ *Which aggregation offers the highest level of information in the agriculture, land-use, land-use change and forestry modules?*

- ✓ *Which aggregation offers the required level of information regarding the other modules' needs?*
- ✓ *Which items/elements can be aggregated without compromising on the quality of the modelling framework results to limit the computation time?*

The next sections will present and detail the inputs and outputs of the agriculture, land-use, land-use change and forestry modules. Section 5.1 presents the agriculture module's calculation logic and scope, Section 5.2 focuses on the land-use, land-use change and forestry module. Both sections include the detailed interactions with the other modules of the modelling framework, as well as the lever and ambition levels of the agriculture, land-use, land-use change and forestry modules.

4.1.Scope of the agriculture module

The agriculture module is mostly demand-driven and enables the modelling framework to compute the resources requirement to supply food, bioenergy, and biosourced materials (Figure 7).

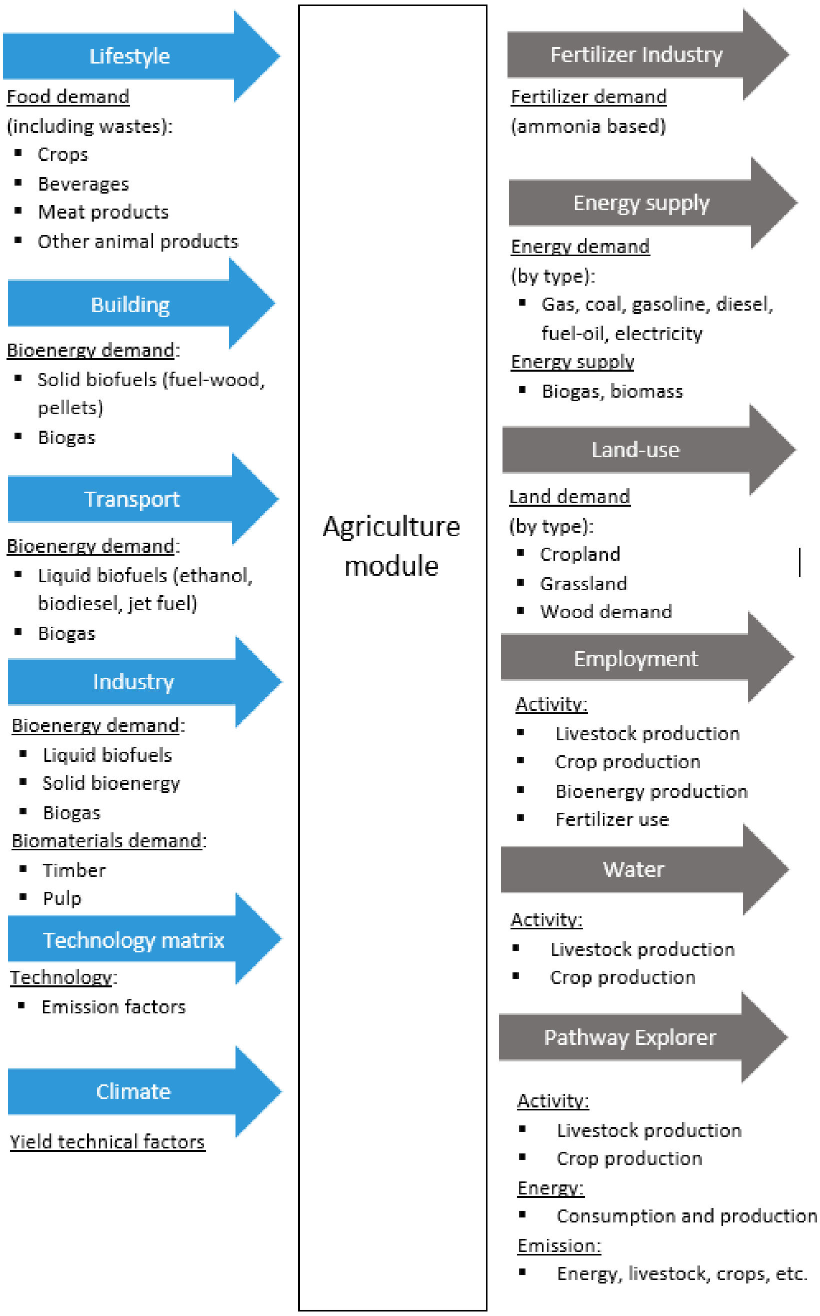

Figure 7 – Agriculture module in brief

4.1.1.Input from the other modules

As shown by the Figure 7, the diet patterns are driving the demand for food by 2050 expressed as crop & livestock primary equivalent in kilocalories (kcal)[13]. The transport, industry and building sectors are driving the demand for bioenergy, expressed as liquid, solid and gaseous bioenergy expressed in terawatt per hour (TWh). The demand for biosourced materials is driven by the industry sector, which is considering shifts from fossil based to biosourced based feedstocks, expressed in tons (t).

4.1.1.1.Lifestyle's inputs

The lifestyle module provides agriculture with the calorie requirement aggregated by country and by food group, accounting for consumer's and distributor's wastes, expressed in kcal/year[14].

The calorie requirement is computed from the amount of daily calories demand for an individual to maintain its metabolic rates and comes expressed in kcal/cap/day. The total calorie requirement is based on FAOSTAT database for the period 1990-2015[15], and the possible range of calorie demand for future scenarios is determined by extending the country-specific Body Mass Index (BMI) & income dependence observed between 1990 and 2013 for each country. The calorie requirements for the higher ambition levels are assumed to be those resulting from a decline in BMI so that overweight levels of a country are, respectively, a quarter of that observed in 2015 and half of that observed in 2015[16].

The specific diet composition is expressed in kcal/year and is computed from the daily calories demand shared in 26 food groups. The lowest ambition levels are considering a continuation of the current trends, based on FAOSTAT observed data, keeping the country heterogeneous diet composition trends. The higher ambition levels assume health-oriented scenarios which implies the diet composition to converge to typical rations in which all meat does not go over 90g/day; sugars & sweeteners are kept below 10% of calorie consumption; fruits & vegetables consumption represent at least 400g/day. For the most ambition level, a general improvement of all the above calories so that countries meet the best dietary standards (Springmann et al., 2018). This implies red meat to be kept at no more than 42g/day; sugars & sweeteners at below 5% of calorie intake; and

[13] Food and Agriculture Organization (FAO), FAOSTAT, Food Supply - Crops Primary Equivalent / Livestock Primary Equivalent;
Direct link: http://www.fao.org/faostat/en/#data/CC / http://www.fao.org/faostat/en/#data/CL
[14] See: EUCalc Lifestyle documentation; Direct link : https://drive.google.com/open?id=1OftuGqv2ML3WM09qGRQNkltaSrGkhoUo
[15] Food and Agriculture Organization (FAO), FAOSTAT, Food Supply - Crops Primary Equivalent / Livestock Primary Equivalent;
Direct link: http://www.fao.org/faostat/en/#data/CC / http://www.fao.org/faostat/en/#data/CL
[16] See: EUCalc Lifestyle documentation; Direct link : https://drive.google.com/open?id=1OftuGqv2ML3WM09qGRQNkltaSrGkhoUo

fruits & vegetables consumption to be over 600g/day. The 26 food groups have been aggregated by the lifestyle modules following the patterns presented in the following Tables:

Table 4 – Meat demand categories in EU28+1

	EUCalc	FAOSTAT category	Aggregation rationales in brief
Livestock-based products	Meat, bovine	Meat, non-dairy cattle Meat, buffalo	Cattle meat represents nearly 17% of the overall meat production in the EU28+1. Cattle is a significant GHG emitter and requires large amount of feed and lands. Buffalos are aggregated with cattle as they only represent 0.04% of meat production.
	Meat, poultry	Meat, chicken Meat, duck Meat, goose and guinea fowl Meat, turkey Meat, bird nes	Chicken meat represents nearly 30% of the meat production, shared between 82% of chicken meat. Added up together, the other poultry represent 5% of the meat production Thus, the other poultry have been aggregated with chicken in a unique poultry meat category.
	Meat, pig	Meat, pig	Pig is the most produced and consumed meat in the EU28+1, representing half of the meat production.
	Meat, sheep & goat	Meat, sheep Meat, goat	Sheep and goats are only representing 2% of the overall meat production, but as small ruminants, they are using pastureland and are thus considered as a dedicated meat category.
	Meat, other animals	Meat, rabbit Meat, game Meat, horse Meat, mule Meat, ass Meat, nes	Added up together, the other meat types represent less than 2% of meat production in tons in EU28+1. Thus, they have been gathered together as a unique meat category other animal.
	Milk, dairy (all)	Milk, dairy-cow Milk, dairy-goat Milk, dairy-sheep Milk, dairy-buffalo	The level of data for milk consumption and production is not homogeneous in FAOSTAT. Thus, EUCalc only considers an aggregated category 'milk dairy' in the agriculture model. Nevertheless, the split of dairy-animals is considered in the yields in terms of kcal/animal.
	Eggs hens	Eggs, laying hens	No aggregation required, EUCalc uses the FAOSTAT most important level of detail.
	Animal fats	Animal fats	No aggregation required, EUCalc uses the FAOSTAT most important level of detail.
	Offal	Offal	No aggregation required, EUCalc uses the FAOSTAT most important level of detail.

The animal-based food products have been aggregated in 9 groups including bovine, sheep, pig, poultry and other animals, which basically corresponds to the typical aggregation level used by EUROSTAT[17] and FAOSTAT[18]. Adding higher

[17] Eurostat, statistics explained, Agricultural production - livestock and meat (2018); Direct link: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Agricultural_production_-_livestock_and_meat&oldid=427096

[18] Food and Agriculture Organization (FAO), FAOSTAT, Food Supply - Crops Primary Equivalent / Livestock Primary Equivalent;

levels of details would have been possible although the implied complexity would not have added significant result improvement. Nevertheless, the FAOSTAT level of details is preserved at the production side, i.e. in the agriculture module considers the split of animal types through the pre-processing of the data. For instance, the bovine yields have been computed given the population of non-dairy cattle and buffaloes.

Table 5 – Food crop-based products demand categories in EU28+1

	EUCalc	FAOSTAT category	Aggregation rationales in brief
Food crop-based products	Cereal	Wheat, Maize, Barley, Rye, Oats, Sorghum, Brans, Millet, Other cereals	Cereals are aggregated in a unique food group (excluding rice) for simplification and computation time issues. A compromise would be to consider wheat, maize and barley separately as the 3 main produced cereals in EU28+1. Nevertheless, we considered a better compromise to gain in computation time than maintaining a higher level of information in the present case.
	Rice	Rice	Rice is considered separately as its cultivation involves direct and significant CH4emissions.
	Oil crops	Rapeseed, Olives, Sunflower, Soya beans, Groundnuts, Cottonseed, Sesame, Other oil crops	Oil crops are aggregated in a unique food group for simplification and computation time issues. We considered a better compromise to gain in computation time than maintaining a higher level of information in the present case.
	Pulses	Beans Peas Other pulses	Pulses are aggregated in a unique food group. we considered a better compromise to gain in computation time than maintaining a higher level of information in the present case.
	Starchy roots	Cassava, Potatoes Sweet potatoes, Yams Other roots	Starchy roots are aggregated in a unique food group. we considered a better compromise to gain in computation time than maintaining a higher level of information in the present case.
	Vegetable oil	Rapeseed, Olives Sunflower, Palm Soybean, Maize germ, Groundnuts, Cottonseed, Sesame Coconut, Palm, Other oils	Vegetable oil are aggregated in a unique food group for simplification and computation time issues. We considered a better compromise to gain in computation time than maintaining a higher level of information in the present case.
	Sugar & Sweeteners	Sugar & Sweeteners	No aggregation required
	Fruits	Multiple fruit variety	FAOSTAT offers a two-aggregation level for fruits and vegetables, a detailed one, and an aggregated one. We considered a better compromise to gain in computation time than maintaining a higher level of information in the present case.
	Vegetable	Onions Tomatoes and products Vegetables, Other	FAOSTAT offers a two-aggregation level for fruits and vegetables, a detailed one, and an aggregated one. We considered a better compromise to gain in computation time than maintaining a higher level of information in the present case.
	(Stimulants) Tea Coffee Cocoa	(Stimulants) Tea Coffee Cocoa	Although stimulants are mainly imported from outside of Europe, the agriculture module will estimate the embedded GHG emissions associated with the stimulant's consumption.

Direct link: http://www.fao.org/faostat/en/#data/CC / http://www.fao.org/faostat/en/#data/CL

The crop-based food products have been aggregated in 13 groups including cereals, rice, oil crops, pulses, starchy roots, sugar, sweeteners, vegetable oil, fruits, vegetable and stimulants (coffee, tea, cocoa). Alcoholic beverages accounts for another 4 extra food groups that includes wine, beer, distilled and fermented alcohol. Adding higher levels of details would have been possible although the implied complexity would not have added significant result improvement. Such as the livestock-based products, the highest level of details is preserved at the production side, i.e. in the agriculture module considers the split of crop types in all computation for the period 1990-2015 and assumes fixed split by 2050.

Alcoholic beverages have been taken separately in order to properly modelling the possible byproducts supply that can be use as bioenergy, animal feed, fertilizer and other aggregated uses (Table 6).

Table 6 – Alcoholic beverages demand categories in EU28+1

	FAOSTAT category	EUCalc	Aggregation rationales in brief
Alcoholic beverages	Wine	Wine	Wine is significantly requiring lands and yields significant amount of byproducts such as marc and lees that can be used as bioenergy and agronomy feedstock.
	Beer	Beer	Beer is significantly requiring cereals and yields significant amount of byproducts such as cereal meals and yeast that can be used as animal feed.
	Distilled alcohol	Distilled alcohol	No aggregation required, EUCalc uses the FAOSTAT most important level of detail.
	Fermented alcohol	Fermented alcohol	No aggregation required, EUCalc uses the FAOSTAT most important level of detail.

Finally, the lifestyle module is providing the assumed amount of food waste that is coming from the consumers and distribution, for each food group, also expressed in kcal/year. The average fraction of food waste in Europe per food group are taken from (Gustafsson et al., 2013) and are assumed to be the same across the EU members, given the lack of a more detailed database. Thus, the absolute value of waste varies from country to country given the different dietary compositions and population.

For the least ambition level, food waste at the consumer level evolves following historical patterns of more food demand leading to more food waste. This implies an average increase of 25% in relation to the food waste in 2015 in the EU28+1. For the most ambitious levels, it is assumed that countries achieve food waste reductions at the consumer level of 50% by 2050, which means complying with the SDG target 12.3 (originally set by 2030). This translates to an average food waste for EU28+Switzerland of 410 kcal. For the highest ambition level countries achieve food waste reductions at the consumer level of 75% by 2050, thus overcoming the SDG target 12.3 by 2030. This translates to an average food waste for EU28+Switzerland of 200 kcal.

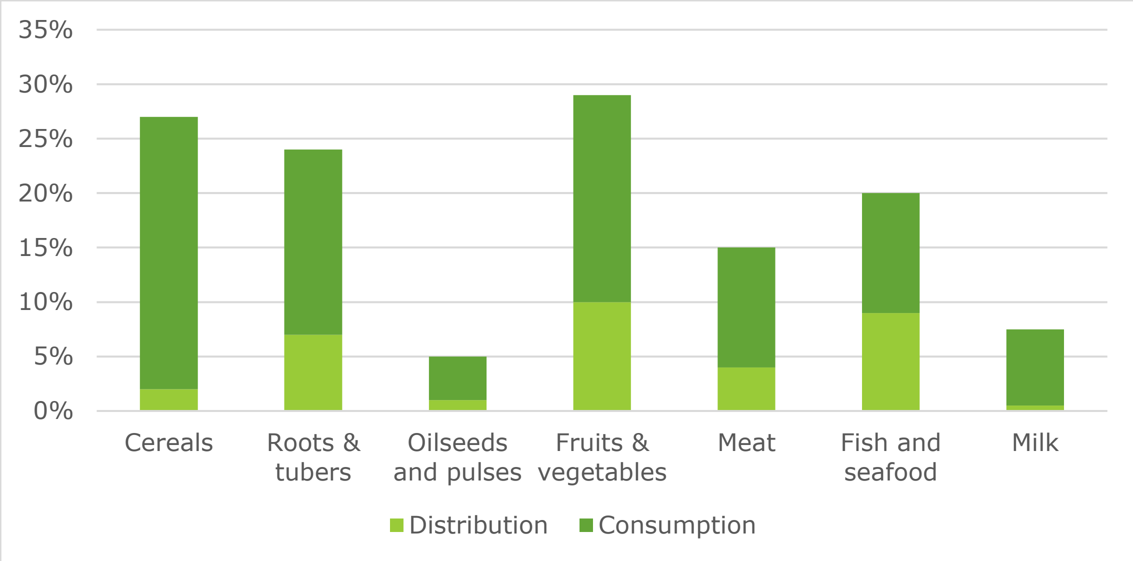

Figure 8 – Food wastes by food group in Europe in 2012 (Gustafsson et al., 2013)

It is worth mentioning that the food-waste from the production side is considered as an agriculture feature, included in the Climate-Smart Cropping and livestock production systems levers, following a similar approach.

4.1.1.2. Building's inputs

The building module provides agriculture with the bioenergy demand by type expressed in TWh, coming from the heating demand, excluding the district heating share. The heating demand in the building sector relies on the living space demand per person, the insulation quality, the average indoor temperature, the district heating share, the heating systems efficiency and finally the switch from fossils towards renewable energy, such as solar hot water systems and bioenergy.

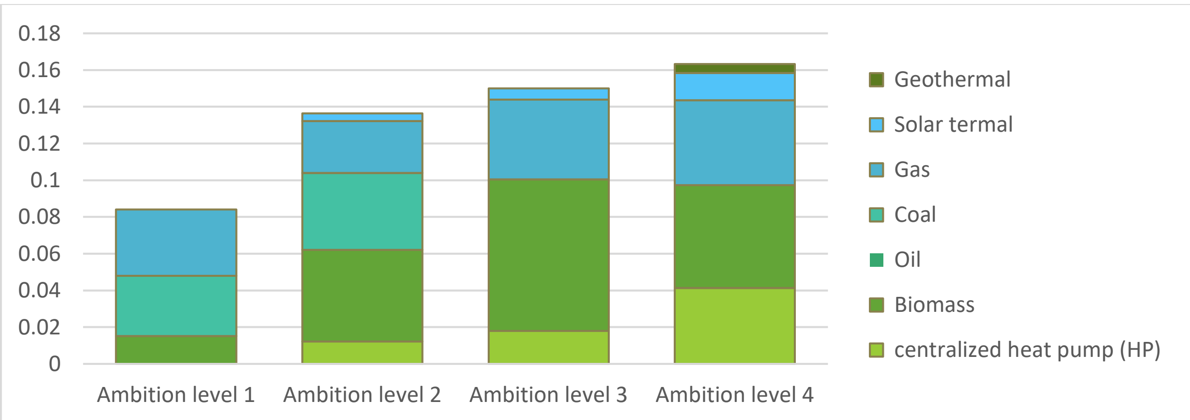

Figure 9 – Ambition levels for district heating penetration by 2050 in the EU28+1

The district heating share as well as the fuel switch levers will directly affect the demand for bioenergy. The district heating share of the building module is based on the "Heat Roadmap Europe" project (Nijs et al., 2017). The later provides the district heating contribution as a whole, and by technology. As shown by Figure 9, depending on the lever setting, the biomass can contribute from 18 to 55% by 2050 in the EU28+1 as district heating fuel.

The switch from fossils towards renewable energy sets the energy mix for heating purposes, excluding district heating. The lever assumes a decrease of fossils fuels contribution, gas, oil and coal, from 5 to 95%, which would be substituted by bioenergy and heat pumps. Depending on the ambition level, biomass is assumed to substitute from 30 to 70% of the fossil fuels phase out.

The lever setting for living space demand per person, heating systems efficiency, the average indoor temperature, the renovation rate as well as the average insulation quality for new and existing constructions will drive the total energy demand and thus affect the bioenergy demand. As a result, the building sector will drive the bioenergy demand associated with the heat demand, expressed in TWh:

Table 7 – Bioenergy demand in the building sector in EU28+1

	Bioenergy type	EUCalc	Aggregation rationales in brief
Bioenergy	Solid bioenergy	Pellets & aggregates	Pellets regroup pellets, chips and other woody aggregates as the FAOSTAT database as well as EUROSTAT do not provide a detailed data base for EU28+1 since 1990
		Wood fuel	Wood fuel production and trade balance is provided by FAOSTAT, no aggregation required
	Gaseous bioenergy	Biogas	Biogas consumption and production is provided by EUROSTAT for each EU members since 1990, no aggregation required

4.1.1.3.Transport's inputs

The transport module provides agriculture with the bioenergy demand for transportation by type expressed in TWh/year/country. Such as the building sector, the transport module involves both direct and indirect drivers for bioenergy consumption through lifestyle and technology patterns.

<u>Direct drivers</u>: through the fuel mix lever, the transport sector sets the demand for the different fuels, including bioenergy. In the transportation scenarios, the demand for liquid biofuels range between 7% to 50% (Ecorys et al., 2017), which represents the current situation and the most ambitious biofuel scenario for Europe with 147 Mtoe by 2050 in volume against 14 in 2015.

<u>Indirect drivers</u>: The passenger travel distance is driven by the lifestyle patterns, through the transportation demand, expressed in passenger-kilometre. The vehicle technology mix, and thus fuel mix also affect the demand for bioenergy through the share of ICE vehicles (Internal Combustion Engine) for which biofuel blending are computed.

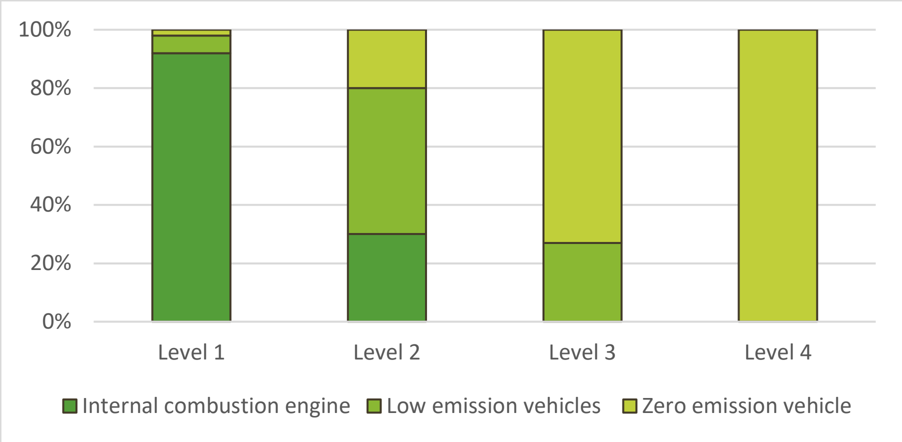

Figure 10 – Ambition levels for ICE phase out in the transport sector

Figure 10 illustrates the ambition levels of the transport sector regarding the phase out of ICE vehicles. Ambition levels presents the evolution of the sale of new cars from 2015 to 2050. The most ambitious levels imply a fast phase out of ICE vehicles, and thus a relative decrease of biofuel contribution to the transportation sector. Other drivers of bioenergy consumption in the transport sector includes the modal share (e.g. split between bus, metro, cars, etc.), the occupancy rate, and the passenger-vehicle efficiency.

Table 8 – Bioenergy demand in the building sector in EU28+1

	Bioenergy type	EUCalc	Aggregation rationales in brief
Bioenergy	Liquid bioenergy	Biodiesel	Biogas consumption and production is provided by EUROSTAT for each EU members since 1990, no aggregation required
		Biogasoline	Biogas consumption and production is provided by EUROSTAT for each EU members since 1990, no aggregation required
		Biojetfuel	Biogas consumption and production is provided by EUROSTAT for each EU members since 1990, no aggregation required
	Gaseous bioenergy	Biogas	Biogas consumption and production is provided by EUROSTAT for each EU members since 1990, no aggregation required

Table 8 presents the variables that are sent from transport to the agriculture module. The agriculture module then sets the technology mix and the feedstock mix to supply the bioenergy demand given the lever setting.

4.1.1.4.Industry's inputs

<u>Industry in brief:</u> The industry module is gathering together the demand for consumption goods from the lifestyle (e.g. appliances), building sector (e.g. construction) and transport sector (e.g. cars), and computes a demand for raw material and energy, including bioenergy and biosourced materials. The extent of the energy and material demand depends on the consumption levels, the self-sufficiency ratio, and the technology-mix & efficiency across the multiple industries (e.g. steel, cement, chemicals, paper, aluminium, etc.). Such as the transport and

building sectors, some levers have a direct impact on the demand for bioenergy and biosourced materials, while others have indirect impacts.

Direct drivers: the material switch lever allows the industry to switch from fossil and mineral based raw material to biosourced materials across the multiple industrial sectors that are modelled. For instance, the construction industry can switch from steel to wood structures in some extent, based on the EU CTI 2050 Roadmap Tool[19] (2018) estimates. The energy carrier lever switch operates through a common pattern which is illustrated in Figure 11.

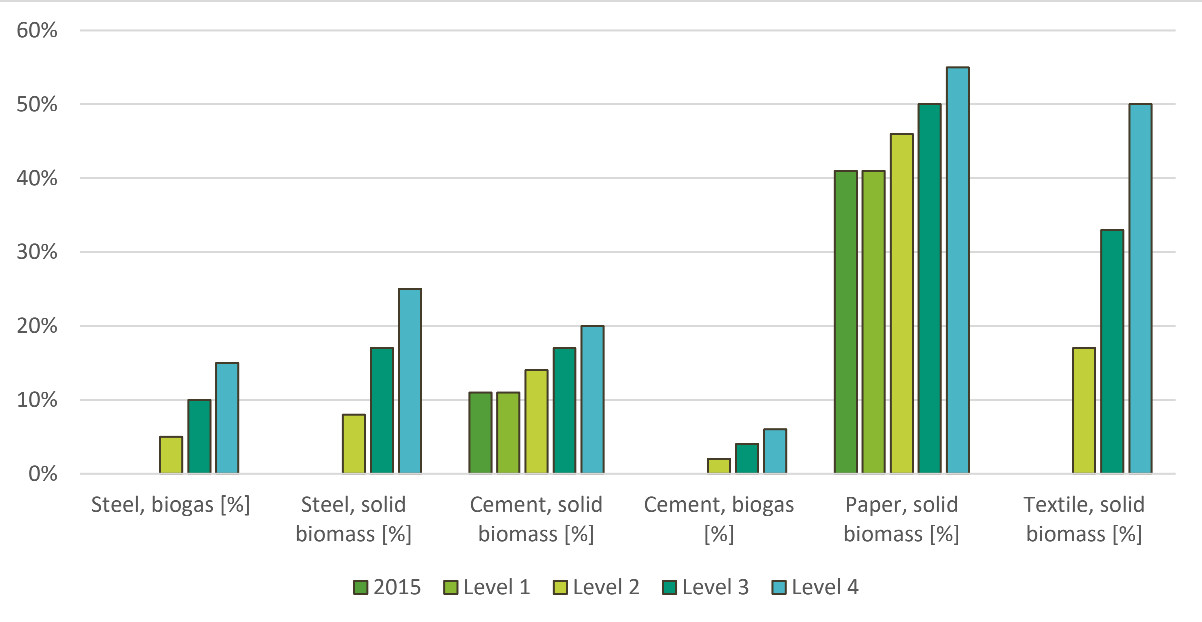

Figure 11 – Ambition levels for bioenergy penetration in several industries

Figure 11 illustrates how the biomass may have to contribute to supply the energy demand of different industries depending on the lever setting. The higher the ambition, the higher the bioenergy contribution. It is worth mentioning that the extent of this contribution not only depend on the industry type but also on the technology that is used.

Indirect drivers: Material efficiency, technology share & recycling are the main indirect drivers for biomass demand, for both bioenergy and biosourced materials. In other words, the higher the material efficiency, the more advanced the technology and recycling, the lower the overall demand for raw materials and energy, for both fossil and biosourced ones.

Table 9 presents the interface between the industry and agriculture modules. Liquid biomass as feedstock (e.g. ethanol) remains to be implemented.

Table 9 – Bioenergy and biosourced biomass demand from the industry sector in the EU28+1

19 EU CTI 2050 Roadmap Tool (2018), Direct link: https://europeanclimate.org/wp-content/uploads/2018/09/EU-2050-CTI-Industry-sector.pdf

	Bioenergy type	EUCalc	Aggregation rationales in brief
Bioenergy & biosourced materials	Solid biomass	Wood pulp	Wood pulp consumption and production is provided by FAOSTAT for each EU members since 1990, no aggregation required
		Timber	Timber is converted in industrial wood, that is provided by FAOSTAT for each EU members since 1990
	Gaseous bioenergy	Biogas (energy)	Biogas consumption and production is provided by EUROSTAT for each EU members since 1990. No data base provides the distinguished biogas flows for bioenergy and biomaterial at the country level, they are assimilated in the model. Biogas is upgraded depending on its use in the energy supply module.
	Gaseous biomaterial	Biogas (feedstock)	

4.1.1.5. Climate inputs

The evolution of the climate and temperature will affect the crop yields, either positively or negatively depending on the European regions. Using the FAO factors developed for the 2050 alternative pathways for food and agriculture (FAO, 2018), the climate module provides the factors will affect each of the crop yields in a different extent deepening on the European region and the crop type.

Table 10 –Crop yield factors implied by climate change in High income countries

		Crop type	Level 1	Level 2	Level 3	Level 4
		Scenario	**RCP8.5**	**RCP4.5**	**RCP4.5$_{2048}$**	**RCP4.5$_{2030}$**
Crop yields	High incomes	Cereal	103	102	102	102
		Rice	103	103	103	103
		Oil crop	94	101	101	101
		Pulses	94	101	101	101
		Starchy roots	94	101	101	101
		Sugar crops	94	101	101	101
		Fruits	98	102	102	102
		Vegetables	88	97	97	97
		Energy crops	94	101	101	101
		Microalgae	94	105	105	105
	Europe, others	Cereal	91	98	98	98
		Rice	96	100	100	100
		Oil crop	100	100	105	105
		Pulses	96	96	100	100
		Starchy roots	90	90	97	97
		Sugar crops	96	96	100	100
		Fruits	102	102	100	100
		Vegetables	94	94	99	99
		Energy crops	96	96	100	100

Table 10 presents how the climate change scenario will affect the yields in the agriculture module. The later mostly depends on the rest of the World emission patterns. Based on FAO, these climate impact factors are divided for Europe between high incomes country and the rest of Europe. The climate module setting considers RCP8.5 and three variants of RCP 4.5, for which sub-scenarios start to diverge by 2030 and 2048. For example, Level 4 means that the factors by 2050 are on the same trajectory until 2030, and then constant until 2050[20].

[20] See: EUCalc WP1 Climate documentation

4.1.2.Agriculture input levers

The lever set results from an in-depth literature review, a 2-days' stakeholder workshop, and multiple expert interviews. Table 11 offers a brief presentation of the agriculture module levers. The following sections detail each of the levers individually.

Table 11 – Lever list of the agriculture module

#	Lever...	... in brief
1	Food self-sufficiency	Sets the self-sufficiency level and implicitly the trade balance for each agricultural commodity (livestock and crop-based)
2	Climate Smart Cropping Systems	Sets the patterns for cropping production systems including both sustainable intensive and extensive practices
3	Climate Smart Livestock	Sets the patterns for livestock production systems including both sustainable intensive and extensive practices
4	Alternative Protein Sources	Sets the deployment of alternative protein sources for livestock, including microalgae and insect-based meals
5	Biomass hierarchy	Drives the biomass residues and industrial byproducts feedstock towards bioenergy, biosourced materials, animal feed, and fertilizers markets
6	Climate Smart Fisheries[21]	Sets the patterns for fisheries & aquaculture production systems including both sustainable intensive and extensive practices

4.1.2.1.Self-sufficiency & net-food trade balance

Lever rationales

Since 1990, the European Union GHG emissions have fallen from 5.4 to 4GtCO_2 equivalent[22]. In the same period, the global embedded CO_2 emissions that stems from international good trade increased from 4.3Gt to 9.3 GtCO_2 (Barrett et al., 2013). In other words, it is estimated that around 20 to 25% of the global CO_2 emissions are coming from the production of goods that are consumed in a different country. Most industrialized countries, including the European Union, are net importers of carbon emissions through their consumption of goods and services (Jakob and Marschinski, 2013). The trade balance is thus a major driver of carbon leakage risk (Martin et al., 2014), and in a wider extent, sustainability impacts leakage risk (e.g. uneven working conditions, land-use and land-use change).

The EU's self-sufficiency level for crop-based food is approximatively 81%, and 103% for livestock-based food (Strapasson et al., 2016). Nevertheless, the European Member States present highly heterogenous self-sufficiency ratio, and thus embedded GHG emissions through food goods, as illustrated by the Figure 12.

Ireland is exporting 5.6 times more cattle meat than it is consuming. Based on the most recent emission factors estimated by the FAO[23], the meat production in

[21] The climate smart fisheries & aquaculture is not implemented yet (target: summer 2019)

[22] United Nations Framework Convention on Climate Change (UNFCCC), Greenhouse Gas Inventory Data - Detailed data by Party, Total GHG emissions without LULUCF, European Union (Convention); Direct link: https://di.unfccc.int/detailed_data_by_party

[23] FAOSTAT, Emissions intensities; Direct link: http://www.fao.org/faostat/en/#data/EI

Ireland involves around 10 $MtCO_2e$ emissions while only 2 are associated with the domestic consumption. The other way around, the Greek domestic production of cattle meat only supplies 37% of its consumption. Consequently, the GHG inventory does not consider most of the GHG emissions associated with cattle meat consumption. The extent of the embedded GHG emissions relies on the producing country carbon emission intensity, which varies from 8 to 55 tCO2e/t in the EU28+1, and up to 260 tCO2e/t worldwide. The same analysis could be done with other resources requirement such as land which may eventually lead to deforestation, and even more GHG emission.

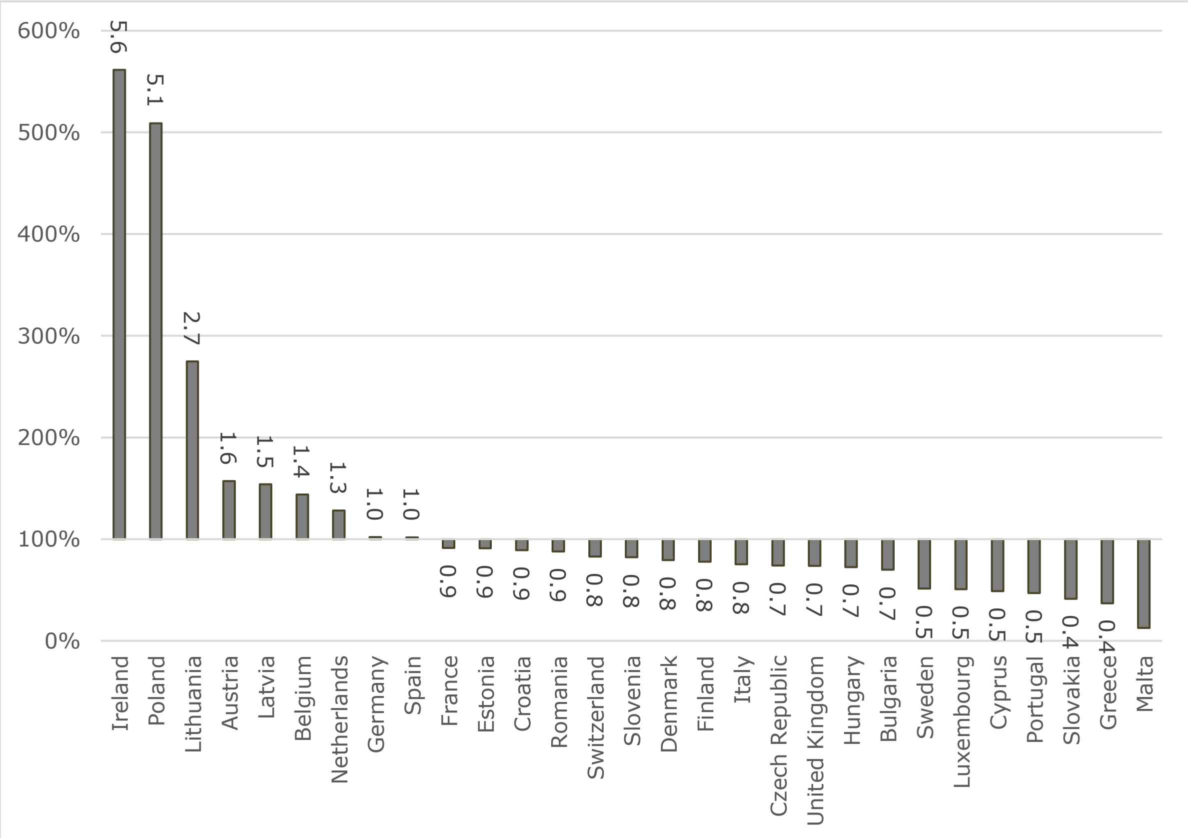

Figure 12 – Self-sufficiency for cattle meat in the EU28+1(2013)[24]

<u>Author suggestion for further model improvement:</u> Possible additional features: tracking the range of the possible "embedded land requirement" and adding the land grabbing risk based on the current values.

Lever description

The self-sufficiency lever was already used in the European land-use future approach (Strapasson et al., 2016), and feeds the modelling framework with the share of each individual food commodity produced domestically, expressed in

[24] Food and Agriculture Organization (FAO), FAOSTAT, Food Supply - Crops Primary Equivalent / Livestock Primary Equivalent;
Direct link: http://www.fao.org/faostat/en/#data/CC / http://www.fao.org/faostat/en/#data/CL

percentage (%). The levers enable us to set the imports, exports and domestic production for each food group, expressed in kcal. Given the import level, the lever also enables us to track and asses the embedded GHG emissions in the food goods for each country. Considering the uncertainty about the international food trade flows, the embedded GHG emissions is provided as a range expressed in $MtCO_2e$, bounded by the most optimistic and pessimistic emission intensities.

The food trade balance lever cannot be calibrated through a 1-4 scale approach, (i.e. considering a higher ambition as a higher GHG mitigation effort). One country may for example be self-sufficient while presenting high emission intensity. Thus, food imports may involve GHG mitigation in this setting. The other way around, one country may present low carbon intensity while importing food goods from less efficient countries. Thus, food imports may increase embedded GHG mitigation in this setting. The ambition levels are considered through an A-D scale for the food trade balance (i.e. considering a set of scenarios regardless to any GHG ranking, see Section 4).

Beyond GHG emission, the lever is associated with critical sustainability issues such as self-sufficiency, food security, and bioeconomy.

Feedback from the stakeholder consultations (in brief)

It was pointed out that self-sufficiency ratio has to be considered for the assessment of the agri-food system sustainability food production systems, for both carbon leakages and bioeconomy issues. Moreover, it has been asked to address the self-sufficiency ratio issues for cakes (animal feed). Cakes are thus also considered in the self-sufficiency ratio lever.

Scenarios to explore & addressed issues

- ✓ How may the food trade balance affect the land demand and other critical resources such as water, energy or biodiversity?
- ✓ How may the food trade balance affect the GHG emission, including embedded emission, direct emission, and land carbon dynamics?
- ✓ How may the food trade balance and diet patterns affect the ability to reach or maintain self-sufficiency?
- ✓ How may the food trade balance and diet patterns affect the sustainability of the food & agriculture production systems?
- ✓ The other way around, how may the food trade balance and diet patterns should be adapted to match the local sustainable and available resources?

Lever setting – Observed data

Current situation: As mentioned previously, the EU's self-sufficiency level for the livestock-based food is slightly positive (Figure 13). The production of the major crop types and crop-based goods is much more heterogeneous (Figure 14).

The European trends for meat are positive for poultry and pigs, slightly under 100% for bovine. Nevertheless, the end of milk quotas in 2015 led to increase cow-slaughtering and thus meat production[25]. Coupled to an overall decrease of meat consumption in Europe due to diet shifts, meat self-sufficiency has been slightly increasing since 2013. Sheep, goat and other animal-based meats (e.g. rabbits, horse) presents a lower self-sufficiency ratio, but they are only representing about 3% of the total meet production.

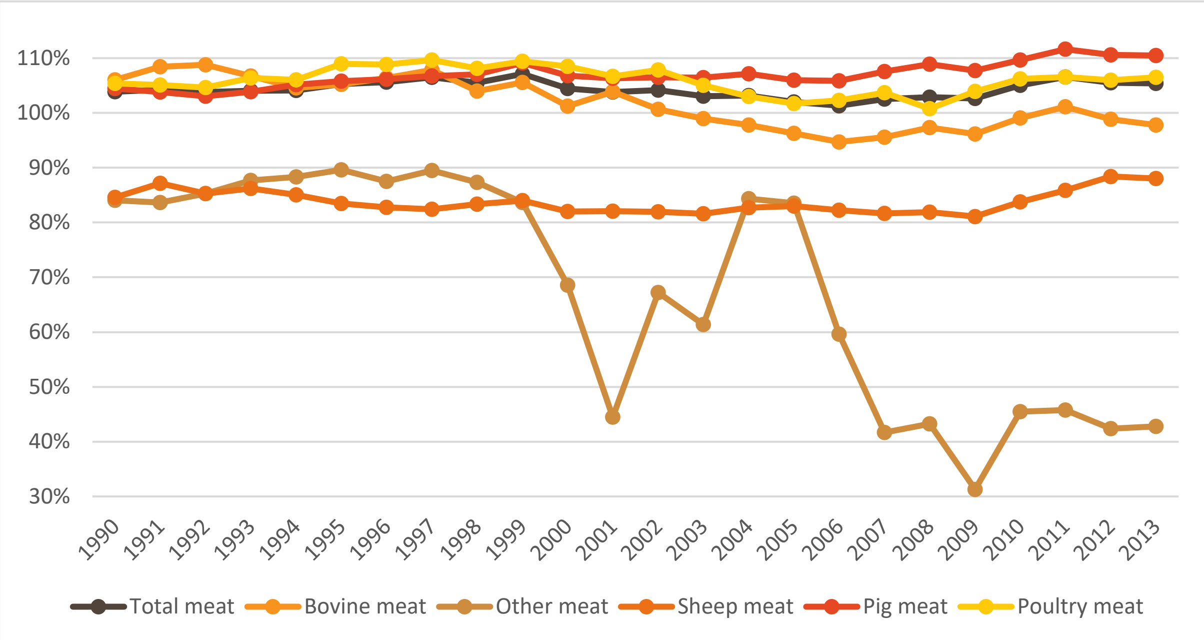

Figure 13 – Self-sufficiency for meat in the EU28[26]

As shown by Figure 14, the EU is a net-exporter of cereals, self-sufficient with vegetables, starchy roots and sugar crops, but a net-importer regarding the other major crops. Vegetable oil and cakes are especially massively imported to supply food, feed, and bioenergy domestic consumption. It is also worth mentioning that almost 100% of the stimulants, including coffee, cocoa, and tea, are imported, which also represent a significant embedded GHG emissions. According to (Noponen et al., 2012), the carbon footprints for 1 kg of fresh coffee cherries were between 0.26 and 0.67 kgCO2e for conventional and 0.12 and 0.52 kgCO2e for organic systems, i.e. between 0.65 and 1.65 MtCO_2e given the 2013 EU consumption level.

[25] Eurostat, statistics explained, Agricultural production - livestock and meat (2018); Direct link: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Agricultural_production_-_livestock_and_meat&oldid=427096

[26] Food and Agriculture Organization (FAO), FAOSTAT, Food Supply - Crops Primary Equivalent / Livestock Primary Equivalent;
Direct link: http://www.fao.org/faostat/en/#data/CC / http://www.fao.org/faostat/en/#data/CL

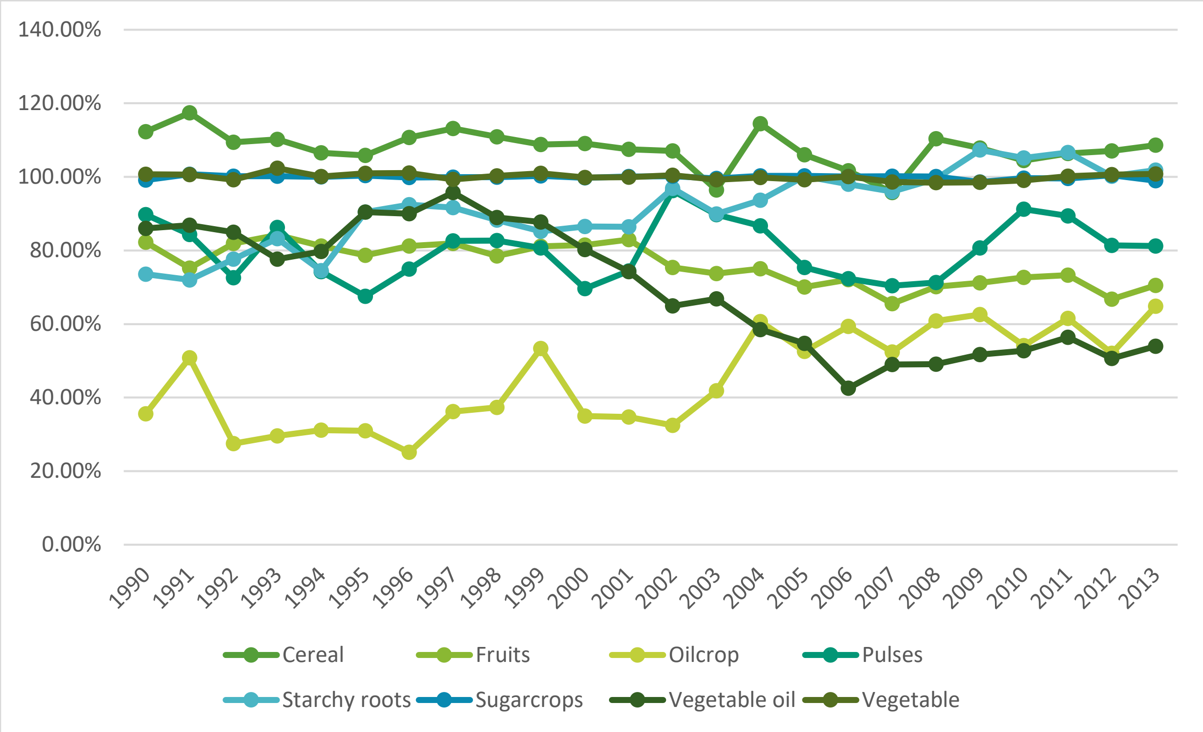

Figure 14 – Self-sufficiency for major crop-based food group in the EU28[27]

Lever setting – Ambition levels

Scenarios for 2050: In the Europe land-use future model (Strapasson et al., 2016) it is assumed that plant-based food self-sufficiency may range between 70 and 110% for plant-based food, and 90 to 120% for meat-based food (Table 12).

Table 12 –Ambitions levels for trade balance

Food groups	A	B	C	D
Plant-based food [%]	70.0%	81.0%	100.0%	110.0%
Meat-based food [%]	90.0%	100.0%	107.1%	120.0%

Given this approach, Figure 15 and 16 illustrated how the ambition levels are applied in the EU for meat and crops, confronted to observed data since 1960.

Compared to the linear trends computed from observed data since 1960, the agriculture model considers 2 conservative scenarios, pretty close to the most recent observed trends, one considering EU as a slightly net-importer (level B), the other considering the EU as a slightly net-exporter (level C). Level A and D are less nuanced and considers a fall of self-sufficiency 5% under the minimum observed levels since 1960 (level A), when level D considers an increase a self-sufficiency ratio 12% higher than the maximum observed levels since 1960.

These levels can easily be illustrated given the possible settings of the framework. For instance, the decreasing meat domestic consumption in Europe in the recent years drives the exportation up. At the opposite, the increasing demand for organic

[27] Food and Agriculture Organization (FAO), FAOSTAT, Food Supply - Crops Primary Equivalent / Livestock Primary Equivalent;
Direct link: *http://www.fao.org/faostat/en/#data/CC* / *http://www.fao.org/faostat/en/#data/CL*

and extensive agricultural production may require more resources than locally available that may lead to massive importation. This can for instance be illustrated by the German current demand for organic farming, exceeding by far the national organic production, leading to massive importation of organic food products (Baudry and Costa, 2019).

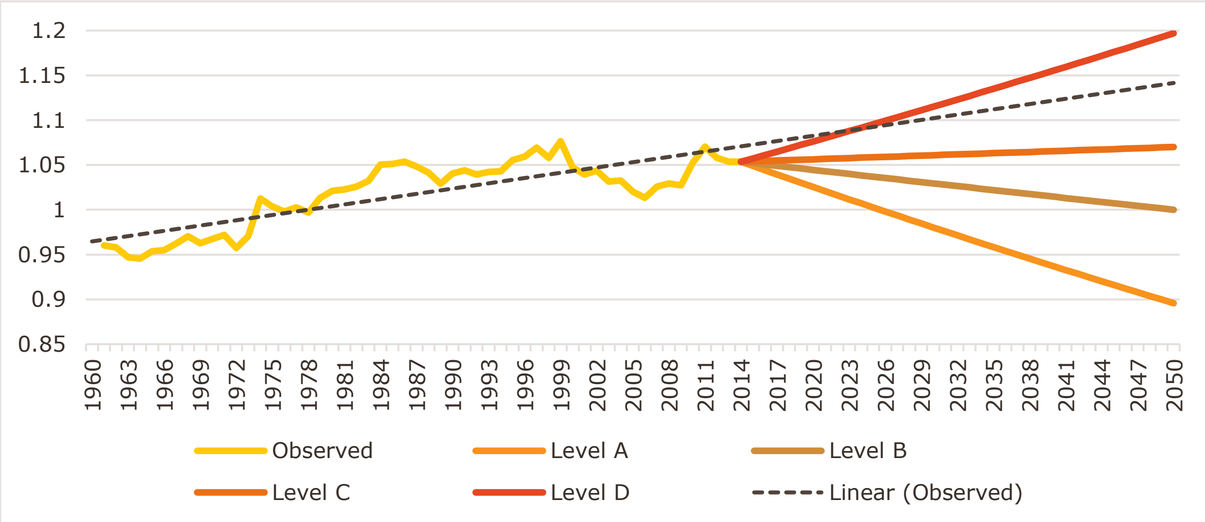

Figure 15 – Self-sufficiency for meat in the EU28 by 2050[28]

The same rationales can be applied to crops (Figure 16). Nevertheless, the extent of the possible scenarios is wider as crops are used as feedstock for food, feed, non-food and bioenergy. Therefore, depending on the lever setting, one may have to find compromise between self-sufficiency ratio, agricultural practices and diets.

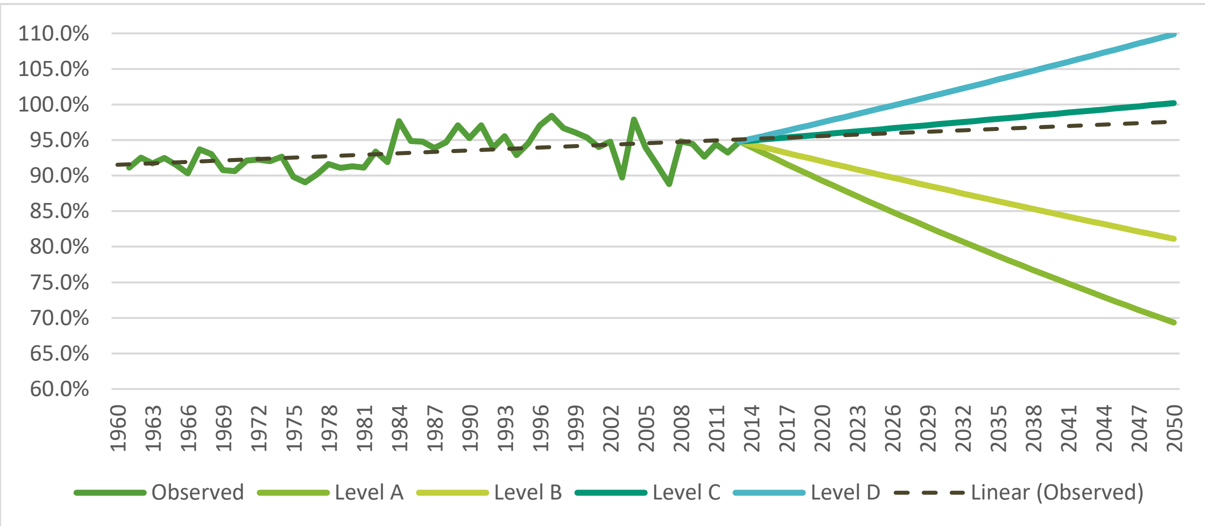

Figure 16 – Self-sufficiency for crop-based food in the EU28 by 2050[29]

[28] Food and Agriculture Organization (FAO), FAOSTAT, Food Supply - Crops Primary Equivalent / Livestock Primary Equivalent;
Direct link: http://www.fao.org/faostat/en/#data/CC / http://www.fao.org/faostat/en/#data/CL

[29] Food and Agriculture Organization (FAO), FAOSTAT, Food Supply - Crops Primary Equivalent / Livestock Primary Equivalent;
Direct link: http://www.fao.org/faostat/en/#data/CC / http://www.fao.org/faostat/en/#data/CL

Lever setting – Disaggregation method

As shown by the Figure 17, the self-sufficiency by member state is highly heterogeneous, ranging from 7 to 250% for crops and 32 to 310% for meat. Thus, the ambition levels will set European global trajectories as shown in Figures 15-16, but without setting any convergence between the countries to keep considering the heterogeneous agricultural context of each member states.

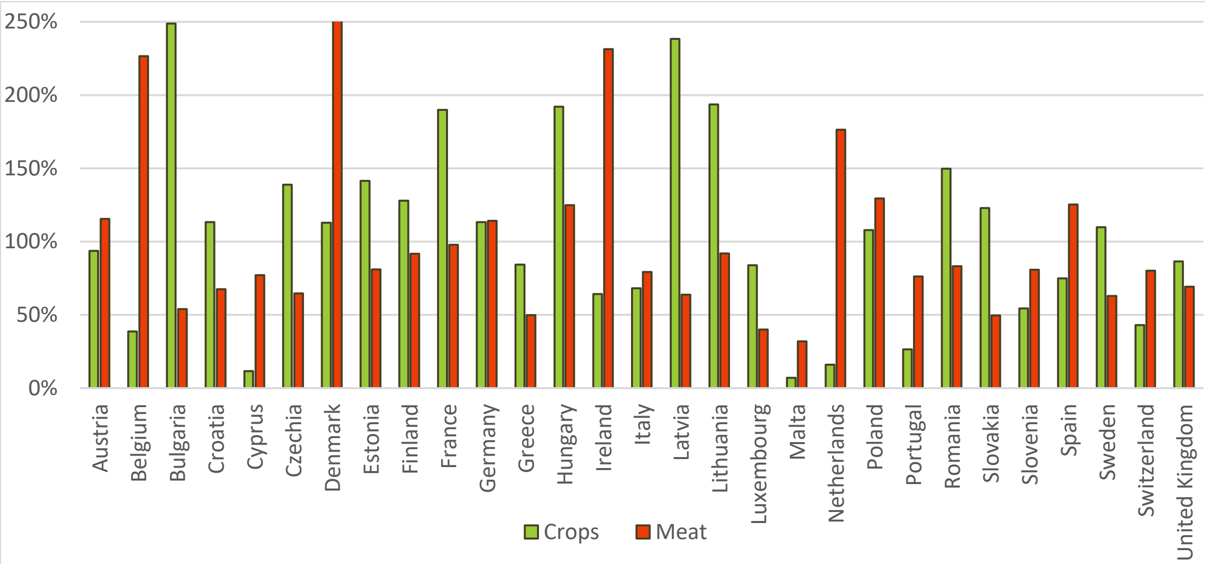

Figure 17 – Food self-sufficiency ratio among EU member states + Switzerland in 2013[30]

4.1.2.2.Climate smart crop production systems

Lever rationales

As pointed out by the (FAO, 2018), the overarching concern regarding the future of food and agriculture is whether the global and regional systems will be able to sustainably feed people up to 2050 and beyond, while supplying non-food agricultural commodities to substitute fossil-based energy and material. The challenges for the agriculture sector also involve preserving and enhancing the sustainable use of natural resources, adapting to climate change and contributing to climate change mitigation.

As shown by Figure 18, the agriculture production has increased over the years towards the population demography and rising individual demand for food and non-food commodities. Despite tremendous agriculture progress, expanding agriculture commodity production came at the cost of natural environment and social issues. One would highlight the pressure on water resources and biodiversity; nitrates, herbicides and pesticides pollution, not to mention the depression and suicide issues in the farming community (Bossard et al., 2016).

[30]Food and Agriculture Organization (FAO), FAOSTAT, Food Supply - Crops Primary Equivalent / Livestock Primary Equivalent;
Direct link: http://www.fao.org/faostat/en/#data/CC / http://www.fao.org/faostat/en/#data/CL

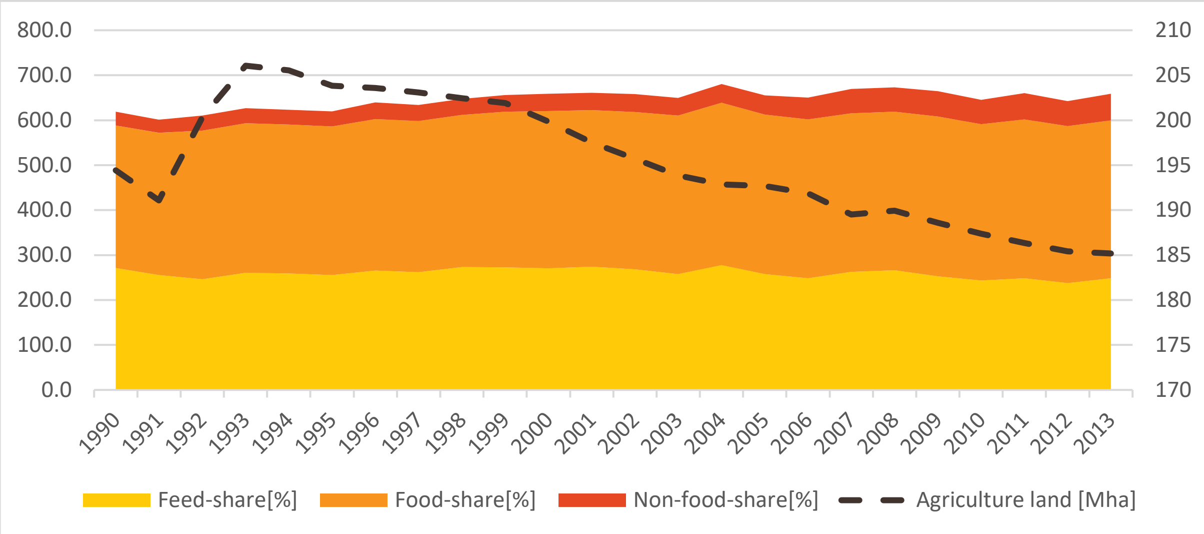

Figure 18 – Agriculture commodity consumption by use (%, left axis) and total agriculture land use (Mha, right axis)[31]

The extent and depth of the challenges to tackle to achieve the agri-food system sustainability in the future depend on key socio-economic drivers (e.g. diet choices, food security) and sustainable use of natural resources. There is no unique but a set of possible options to tackle these sustainability challenges. In the agriculture modelling framework, this set option will be referring as 'Climate Smart Agriculture', for both cropping and livestock production systems. According to the FAO (FAO, 2013), CSA can be defined as approaches:

> "*needed to transform and reorient agricultural systems (…) to tackle three main objectives: sustainably increasing agricultural productivity and incomes; adapting and building resilience to climate change; and reducing and/or removing greenhouse gas emissions, where possible.*"

However, one may strongly point out that achieving sustainability in the agri-food system requires these key socio-economic and environmental drivers to be properly aligned not to generate unintended drawbacks, to foster the synergies and limit trades-off.

CSA practices include several approaches and practices such as conservation agriculture, organic farming, alterations in cropping patterns and rotations, crop diversification and so on, which are driving the resource-use intensity and the extent of both positive and negative sustainability impacts.

[31] Food and Agriculture Organization (FAO), FAOSTAT, Food Supply - Crops Primary Equivalent / Livestock Primary Equivalent;
Direct link: http://www.fao.org/faostat/en/#data/CC / http://www.fao.org/faostat/en/#data/CL

Lever description

The 'climate smart crop production systems' lever enables the modelling framework to consider a set of agricultural practices ranging from intensive to extensive approaches.

Table 13 – Sub-lever list included in the CSCP lever (FAO, 2013)

#	Sub-lever…	… in brief	Unit
1	Losses (crop-based)	Sets the share of losses towards the agri-food production system including agriculture production, postharvest handling and storage, and processing	%
2	Crop yields	Sets the yield for each crop type depending on the relative deployment of intensive/extensive sustainable practices	kcal/ha
3	Fertilizer-use	Sets the demand of fertilizer per hectare depending on the relative deployment of intensive/extensive sustainable practices	kg/ha
4	Pesticide-use	Sets the demand of pesticide per hectare depending on the relative deployment of intensive/extensive sustainable practices	kg/ha
5	Energy-use	Sets the demand of energy per hectare and per type depending on the relative deployment of intensive/extensive sustainable practices	TWh/ha
6	Residues for soil quality	Sets the share of residues that remains in-site for soil quality and the share that is available for other uses (e.g. electricity production, livestock bedding)	%
7	Land use intensity	Sets the land-use intensity (land multi-use) – *not implemented yet* -	%

Table 13 presents the set of parameters and variables that will be driven by the climate smart crop production systems lever:

Losses are expressed in percentage (%) and cover food wastes and losses at the agriculture, postharvest handling and storage, and finally, at processing and packaging production stages. Such as mentioned previously, the data availability does not allow us to apply a country specific approach (Gustafsson et al., 2013), and wastes and losses will be considered homogeneous across the European countries.

The lever will set the resources demand including land, through crop yields and land use intensity, expressed in kcal/ha and percentage respectively; inputs demand including fertilizer-use, pesticide use, and energy-use, expressed in kg/ha; energy demand by type and by hectare, expressed in TWh/ha. The demand for resources is computed at the country level given the extent of agriculture land. The crop yields evolution is also considered for each crop type at the country level.

Focusing on crop residues, the lever is setting the share of residue that remains in-field for soil quality and nitrogen balance issues. The underlying hypothesis is that the most intensive practices lead to use a larger share of the sustainability available residues as feedstock for other uses such as bioenergy, or livestock bedding. The drawback being to require more fertilizer inputs to maintain the nitrogen balance of the soil. Extensive approach lead to leave more residues in the fields to prevent soil carbon loss and to return some nutrients to the soil (Searle and Malins, 2015). The drawback being that the extent of the cellulosic feedstock is lowered for possible other uses.

As pointed out previously, the agri-food system sustainability – including GHG emission balance – requires the diets, the trade balance and the agricultural practices to be relevantly aligned. Thus, the climate smart crop production systems lever cannot be calibrated through a 1-4 scale approach, (i.e. considering a higher ambition as a higher GHG mitigation effort). In other words, the diet and food trade balance widen or narrow the scope of sustainable agriculture practices. For example, according to the IDDRI (Poux and Aubert, 2018), a fully agroecological Europe in 2050 is possible, reducing GHG emissions by 40%, but while considering tremendous diet shifts given the current food trade balance. Without this shift, the same scenario would lead to import food products massively (embedded GHG) or to turn large areas into new agriculture lands. The ambition levels are thus considered through an A-D scale, considering a set of scenarios regardless to any GHG ranking.

Beyond GHG emission, the lever is associated with critical sustainability issues such as self-sufficiency, food security, bioeconomy and so on.

Feedback from the stakeholder consultations (in brief)

The agriculture module first developed levers associated with the deployment of each major agriculture practices for livestock and cropping systems (e.g. organic farming, agroforestry). Nevertheless, the stakeholders suggest using an "umbrella" lever, gathering a set of agriculture practices ranging from extensive to intensive approach, which led to develop the present climate smart agriculture approach. Moreover, stakeholders suggested to explicitly distinguishing cropping and livestock system, using one lever for each, and not a unique agriculture lever. This has been done through the climate smart livestock production systems lever.

Scenarios to explore & addressed issues

- ✓ How may CSA practices affect the demand for resources in terms of energy, land, water, fertilizer?
- ✓ How may diets and practices should align to make the agriculture-food system sustainable in terms of land, water and GHG emissions?
- ✓ How do diets, trade balances, agriculture practices issues interact?

Lever setting – Observed data

Agriculture land represents 39% of the Europe land cover[32], an extent that can vary widely in both ways depending on the future agricultural patterns. Nevertheless, according to the European Environment Agency, the "*patterns of agricultural production vary considerably across Europe and no general picture can be drawn*". For example, although a global increasing trend can be seen in terms of organic farming area deployment (Figure 19), the context in each member state

[32] EUROSTAT, Main land use by land use type, EU-28, 2015 (% of total area)
Direct link: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Land_use_statistics

(and Switzerland) is highly heterogeneous, ranging from a couple hectares to nearly 25% of the total country's agriculture land. The same picture can be done regarding agroforestry practices, ranging from a couple thousand hectares to nearly 40% of the total country's agriculture land (den Herder et al., 2017). At the EU level, agriculture land under organic farming and agroforestry represents about 7 and 8.8% respectively.

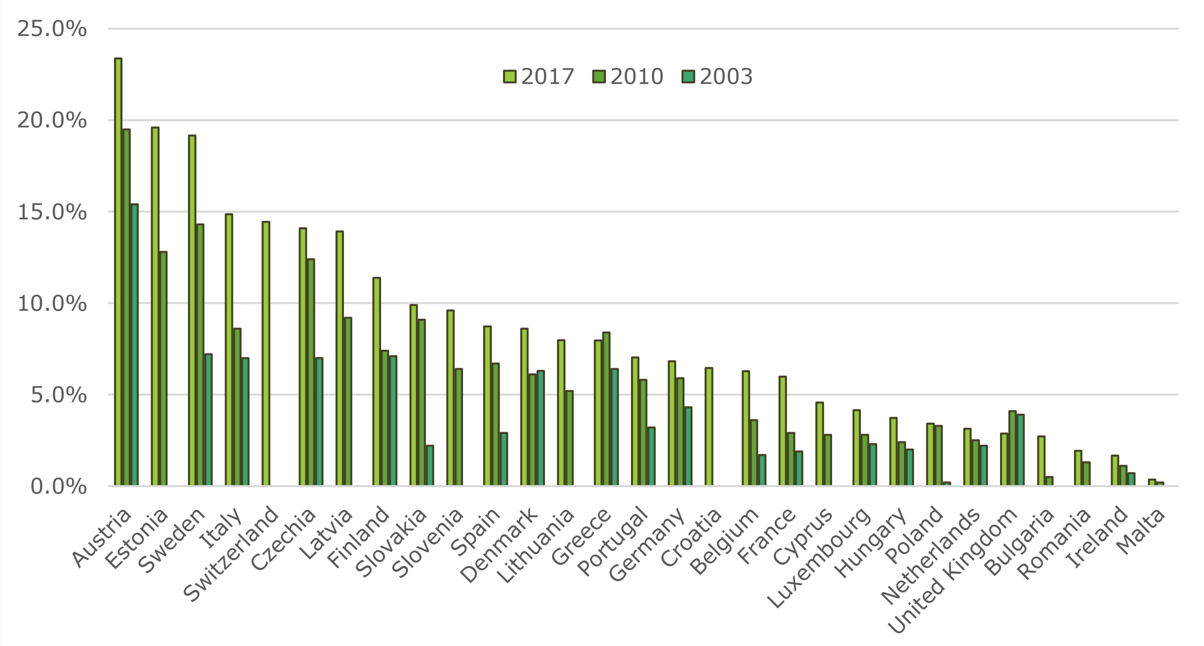

Figure 19 – Share of land under organic farming practices in the EU 28+1 since 2003[33]

As another major agricultural production system, the land under conservation agriculture practices have been continuously increasing over the years in Europe (Kertész and Madarász, 2014). Area under conservation and no tillage practices represents more than 25% of the arable lands. Such as agroforestry and organic farming, the conservation agriculture deployment in the European agriculture landscape remains heterogenous. Nevertheless, it is worth mentioning the practice is widely deployed in the most important European agricultural producers. In France, in the UK and in Germany, arable lands under conservation agriculture represented 41.1%, 36.4% and 23% in 2012 respectively.

Nevertheless, the practice deployment pace is far less from the rest of the World. According to the European Conservation Agriculture Federation, the reason is a lack of technology for European conditions, lack of institutional support, and a slighter cost reduction compared to other World areas. Conservation agriculture consists of promoting maintenance of a permanent soil cover, minimum soil disturbance (i.e. no tillage), and diversification of plant species[34]. The practice enables using less inputs while using best ecosystem natural services. Depending

[33] EUROSTAT: land-cover (dataset: org_cropar), Direct link: https://ec.europa.eu/eurostat/data/database
[34] FAO definition, Conservation agriculture; Direct link: http://www.fao.org/conservation-agriculture/en/

on the country, the reported yield increases under conservation agriculture is ranging between 5-15%(Kertész and Madarász, 2014).

Given the set of agriculture practices in the EU, the following Figures presents the observed data for the variables that will be considered through the climate smart production systems lever:

Crop yields: the crop yields at the EU level have almost been increasing continuously since 1990, a 40% increase in 25 years (Figure 20, right axis). The trend is common across the food crop types and as one should expect, prospect scenarios usually consider further increase in the future under business as usual hypothesis.

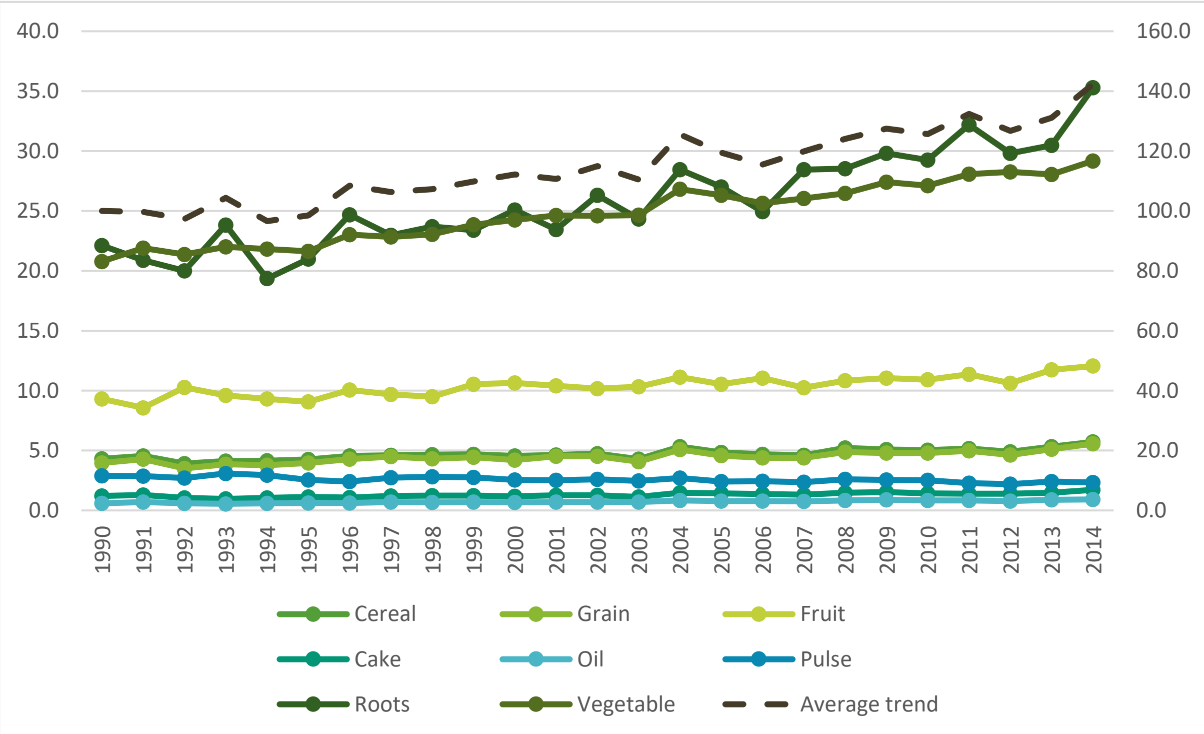

Figure 20 – Average crop yield in the EU28 since 1990[35]

Fertilizer-use: At the European level, the use of fertilizer per hectare has increased by 9% in average between 2002 and 2016. Associated with the highly heterogeneous practices, and such as crop yields, the synthetic fertilizer use by hectare varies widely across the countries, from 25 to 205 kg/ha (Figure 21).

[35]Food and Agriculture Organization (FAO), FAOSTAT, Crops;
Direct link: http://www.fao.org/faostat/en/#data/QC

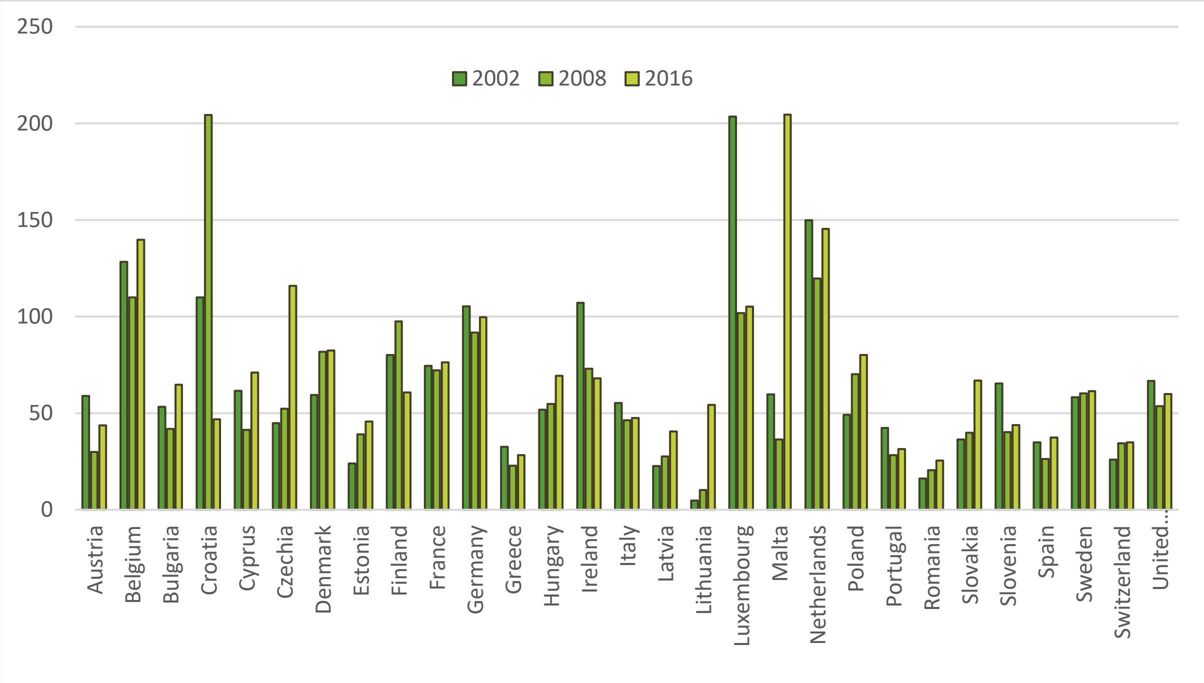

Figure 21 – Synthetic fertilizer use in the EU28+1 in *kg/ha*[36]

Energy-use: the energy demand by hectare has been decreasing by nearly 15% between 1990 and 2012. However, the energy mix remains nearly unchanged, with a massive contribution of diesel, and in a lower extent gas and electricity, including power for irrigation.

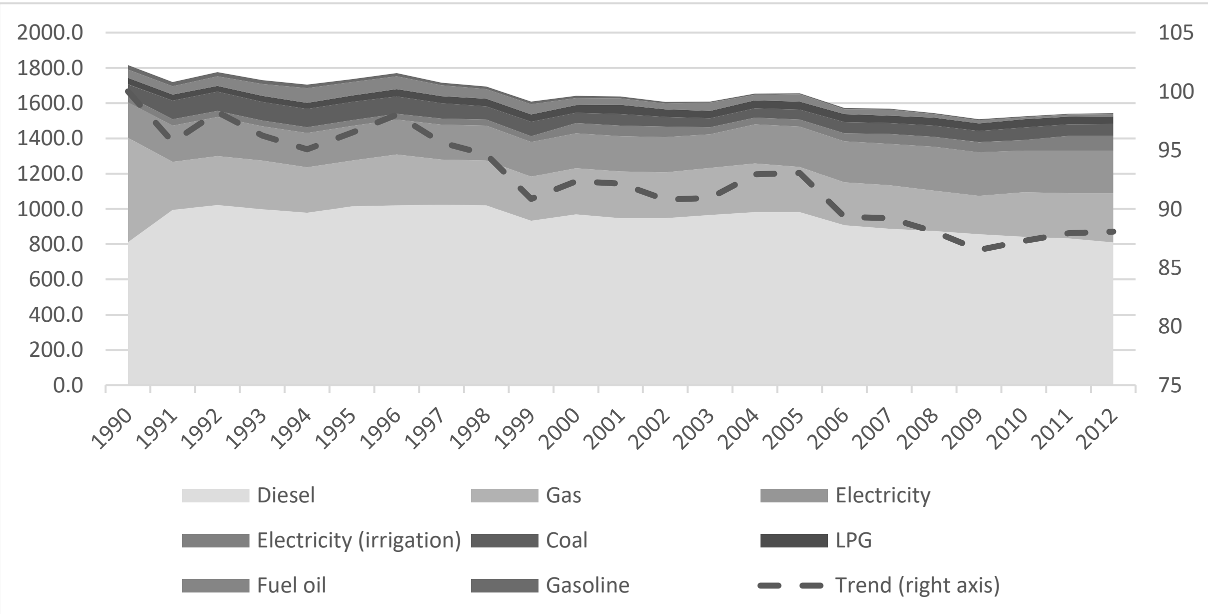

Figure 22 – Average energy consumption by type in kWh/ha in the EU28, since 1990[37]

[36]Food and Agriculture Organization (FAO), FAOSTAT, Fertilizers by nutriment;
Direct link: http://www.fao.org/faostat/en/#data/RFN
[37]Food and Agriculture Organization (FAO), FAOSTAT, Energy-use;

Food wastes and losses (crop-based): according to the FAO, the extent of wood waste at the different production stages widely vary depending on the food commodity. For example, the extent of wastes and losses for milk is estimated to be 5.2% compared with nearly 45% for roots and tubers. In terms of production stage, the extent of wastes and losses for agriculture production, postharvest handling and storage, the processing and packaging stages are 2-20%,1-9% and 1.2-15% respectively (Figure 23).

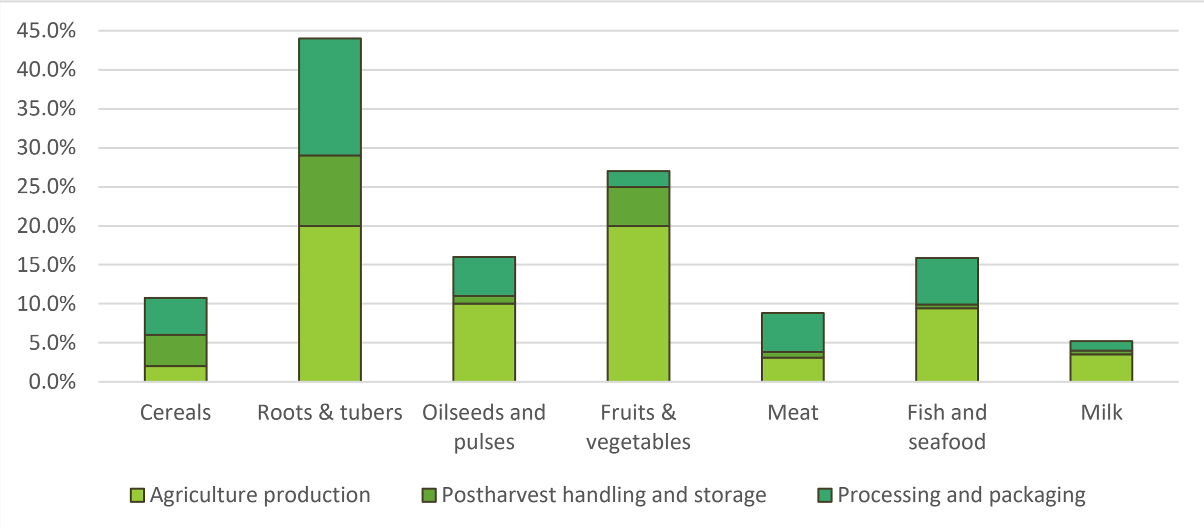

Figure 23 – Food losses by production stages in Europe (Gustafsson et al., 2013)

Residues for soil quality: Table 14 presents the current use of the residues in each EU member state, based on (Searle and Malins, 2015). Data from Table 14 will feed both the climate smart cropping systems lever and the biomass-use hierarchy, which will enable one to drive biomass towards different final uses.

Given the minimum quantities that should be left on the soil surface and the current other biomass uses, Searle & Malins (2016) estimates that there is currently 85 Mt of sustainably available residues (i.e. 28% of the resource). This resource availability is heterogeneous across the EU members, directly associated with the agricultural sector activity. Thus, the available resource ranges from none in the countries with the smaller agricultural sectors, to up to 22 Mt in the major agricultural producers such as Germany and France.

Direct link: http://www.fao.org/faostat/en/#data/GN

Table 14 – Agricultural residues in the EU (2015)

Country list	Recommended retention	Heat, power & biogas	Other uses	Sustainably available
Austria	61%	6%	7%	28%
Belgium	44%	6%	18%	32%
Bulgaria	77%	0%	2%	21%
Croatia	63%	0%	3%	34%
Cyprus	100%	0%	0%	0%
Czech Republic	71%	2%	2%	25%
Denmark	58%	26%	29%	0%
Estonia	73%	27%	0%	0%
Finland	64%	0%	6%	33%
France	64%	1%	5%	31%
Germany	50%	0%	5%	45%
Greece	65%	6%	10%	19%
Hungary	64%	3%	2%	31%
Ireland	47%	0%	65%	0%
Italy	61%	1%	9%	29%
Latvia	75%	0%	5%	20%
Lithuania	75%	0%	5%	20%
Luxembourg	50%	0%	50%	0%
Malta	100%	0%	0%	0%
Netherlands	38%	12%	65%	0%
Poland	66%	10%	7%	17%
Portugal	58%	33%	25%	0%
Romania	71%	0%	6%	24%
Slovakia	71%	0%	2%	24%
Slovenia	60%	0%	20%	20%
Spain	72%	4%	10%	13%
Sweden	55%	27%	6%	14%
United Kingdom	51%	6%	30%	14%
EU28	61%	6%	7%	28%

Lever setting – Ambition levels

The ambition levels for the climate smart cropping production system lever – as well as the following climate smart livestock production system lever – are based on '*the future of food and agriculture, alternative pathways to 2050*' developed by the (FAO, 2018); and the scenario developed by the IDDRI (Poux and Aubert, 2018): '*An agroecological Europe in 2050: multifunctional agriculture for healthy eating*'. For facilitate understanding, the ambition level A-D will range from the most intensive approaches (A) to the most extensive ones (D).

Table 15 – Match between EUCalc and alternative future patterns for the agri-food system in Europe by 2050

Variables & parameters from…	Level A	Level B	Level C	Level D
FAO alternative pathways to 2050, stratified societies scenario	x			
FAO alternative pathways to 2050, business as usual scenario		x		
FAO alternative pathways to 2050, towards sustainable society			x	(x)
IDDRI, towards a 100% agroecological Europe				x

The following paragraph offers short narratives for the different scenarios (Table 15), while focusing on agriculture issues, given that other drivers are considered in other parts of the model, such as key socio-economic drivers and diets. Thus, the model will be able to match the scenarios through a specific lever setting across the multiple modules, but it will also enable one to explore variations given the overall agri-food system, for example, diet shifts, self-sufficiency ratio, and so on.

Stratified societies scenario (FAO, 2018): the scenario considers the continued adoption of conventional agricultural techniques, and the intensive use of chemicals, fossils and land. The land demand per unit of output decreases, but it comes with an environmental cost through land degradation. New lands are required to compensate the loss of degraded lands, which are left unmanaged (see land management lever). Monoculture practice prevails and crop diversification and resilience to shocks are both limited. Finally, the potential for land GHG sequestration is not exploited.

Business as usual (FAO, 2018): the scenario considers a stagnation of alternative practices to conventional agriculture. Agriculture yields increases and the land intensity per unit of output decreases. Nevertheless, the potential for GHG sequestration remains limited too. Food losses and wastes and land degradation are only partially addressed but mostly unabated.

Towards sustainability (FAO, 2018): the scenario considers the deployment of low-input precision agriculture, agroforestry, intercropping, and organic agriculture and other resource and climate-friendly production methods. It also considers chemical use to be restrained. Food losses and wastes are considered to be drastically reduced. The land-use intensity is still improving but in a lower extent compared to scenarios turned towards intensification. The potential for GHG sequestration is high given the agriculture practices. Agricultural land does not expand due to land degradation, a problem considered tackled in this scenario. Thanks to crop diversification and integrated pest management approaches, the agriculture system resilience is strengthened. The livestock production systems are assumed to decrease by 10 percent the share of ruminant systems based on grassland.

Towards agroecology, TYFA (Poux and Aubert, 2018): the TYFA scenario aims at maximising the use of ecological processes in the functioning of agro-ecosystems. Pesticides are not used; pest management is handled through crop rotation and diversification; Contrary to the FAO sustainability scenario, an extensive livestock production system is considered to limit the feed-food competition and to foster carbon sequestration in permanent grassland. Only local feed is considered to avoid emission from exported deforestation. A significant decrease in terms of yields is expected.

The EUCalc agriculture modelling framework ambition levels for cropping systems patterns assume a linear extrapolation for the period 2015-2021 (when observed data are not available). The underlying assumption being that agriculture patterns will evolve linearly until the new CAP by 2021. The deployment of the new agriculture production patterns is assumed to be deployed in a decade following the CAP implementation, through an '*S curve pattern*'.

Losses: Following the patterns proposed by the FAO, the food wastes & losses patterns are associated with the agricultural practices.

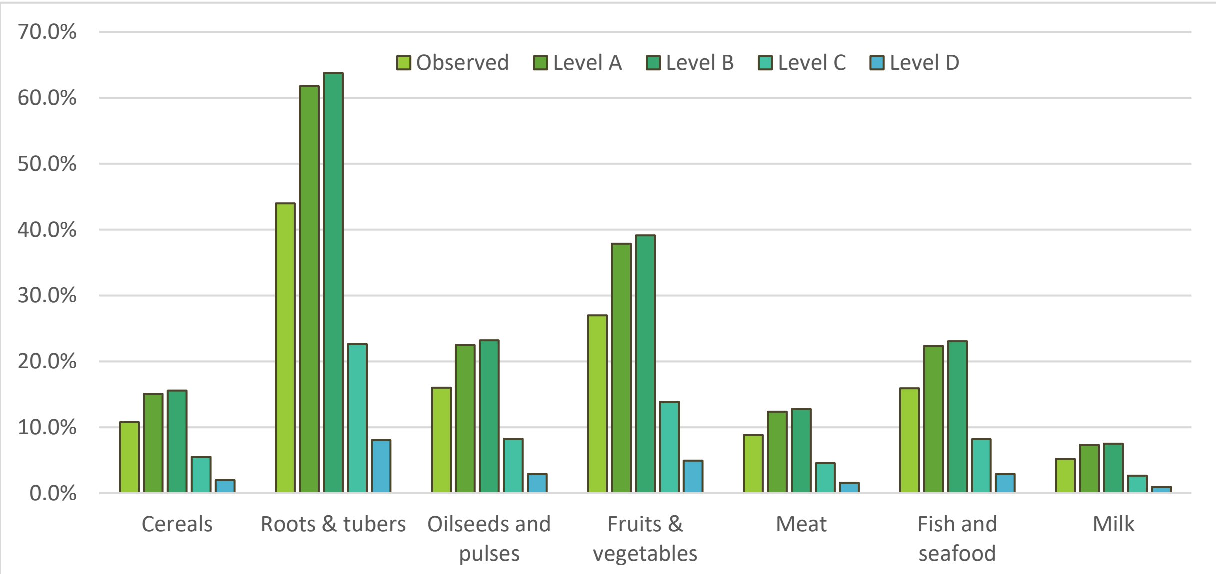

Figure 24 – Estimated food wastes & losses by production stages in Europe by 2050(Gustafsson et al., 2013)

As shown by Figure 24, the most intensive practices lead to generate more wastes and losses, up to an increase by 40% in the worst case. At the opposite, extensive approaches lead to divide the food wastes and losses by nearly 3 compared with the reference year.

Crop yields: data for the levels A, B, and C are based on FAO 2050 pathways, whereas the Level D is based on TYFA's assumption (FAO, 2018; Poux and Aubert, 2018). Figure 25 presents the example of the maize yield according to the 4 scenarios.

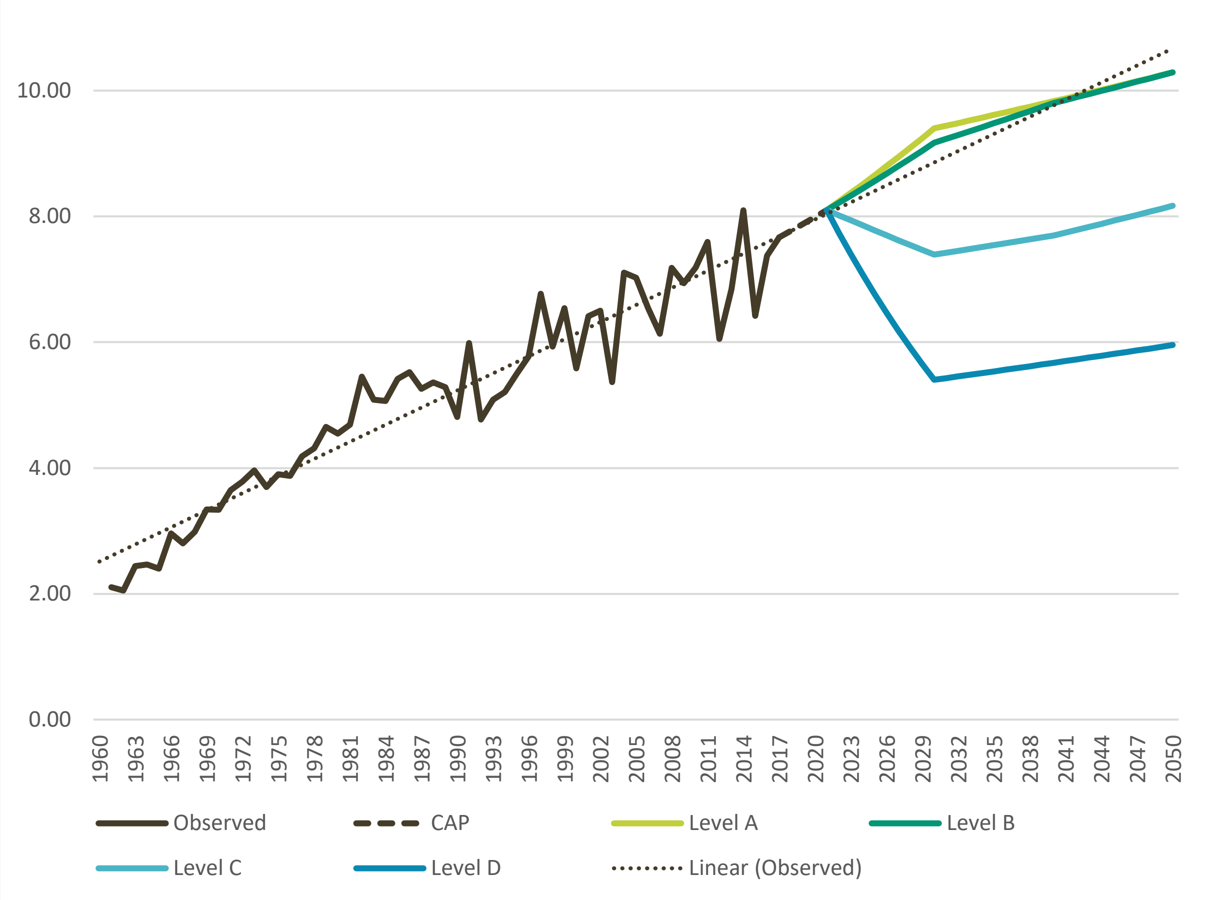

Figure 25 – Average estimated maize yield evolution in Europe by 2050 per scenario

Given the previously mentioned assumptions, and building on the FAO approach, the modelling framework will assume:

Intensive approach: a strong crop yield increase of the yields on the period 2021-2030, and a slight crop increase post 2030.

Extensive approach: both IDDRI and FAO consider a decrease of the crop yields through the deployment of extensive agriculture production systems between 2021-2030, which is more important in the agroecology scenario. In FAO scenario, the decrease is compensated by further improvement over the years post 2030 (level C).

It is worth mentioning that the original IDDRI scenario (Poux and Aubert, 2018): '*do not include the potential effects of agroecological innovation over the next 30 years between now and 2050*'. Thus, the scenario has been adapted by using a common increase patterns between the FAO TSS scenario and the IDDRI scenario but while keeping a conservative gap with the current yields.

Fertilizer-use (synthetic): Given the progressive deployment of the agriculture production systems, Figure 26 present the fertilizer-use in kg/ha in 2012 (use as reference year), 2030 and 2050 for each of the ambition level (FAO, 2018; Poux and Aubert, 2018).

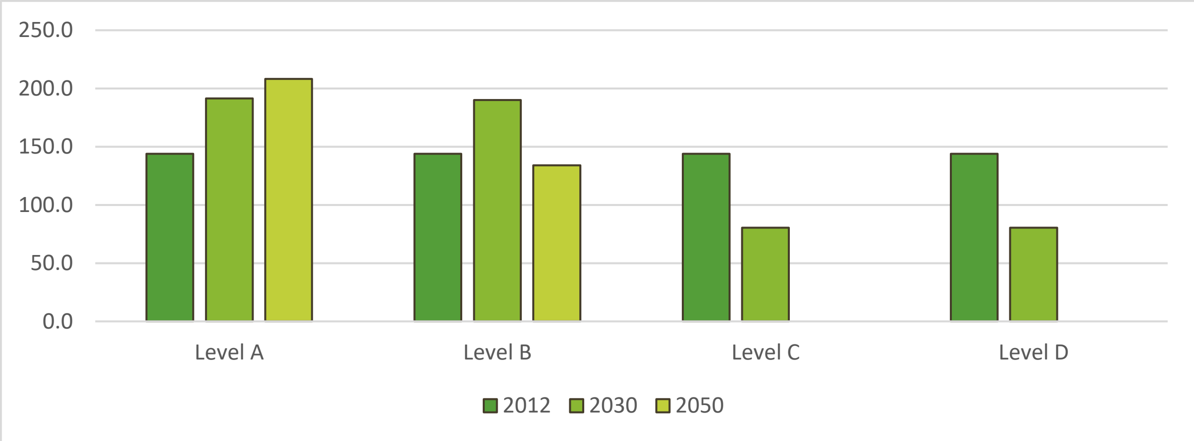

Figure 26 – Estimated of the average fertilizer-use evolution in Europe by 2050

Given the lake of detailed data for pesticides use, a common phase out or intensification pattern with fertilizer input use is considered.

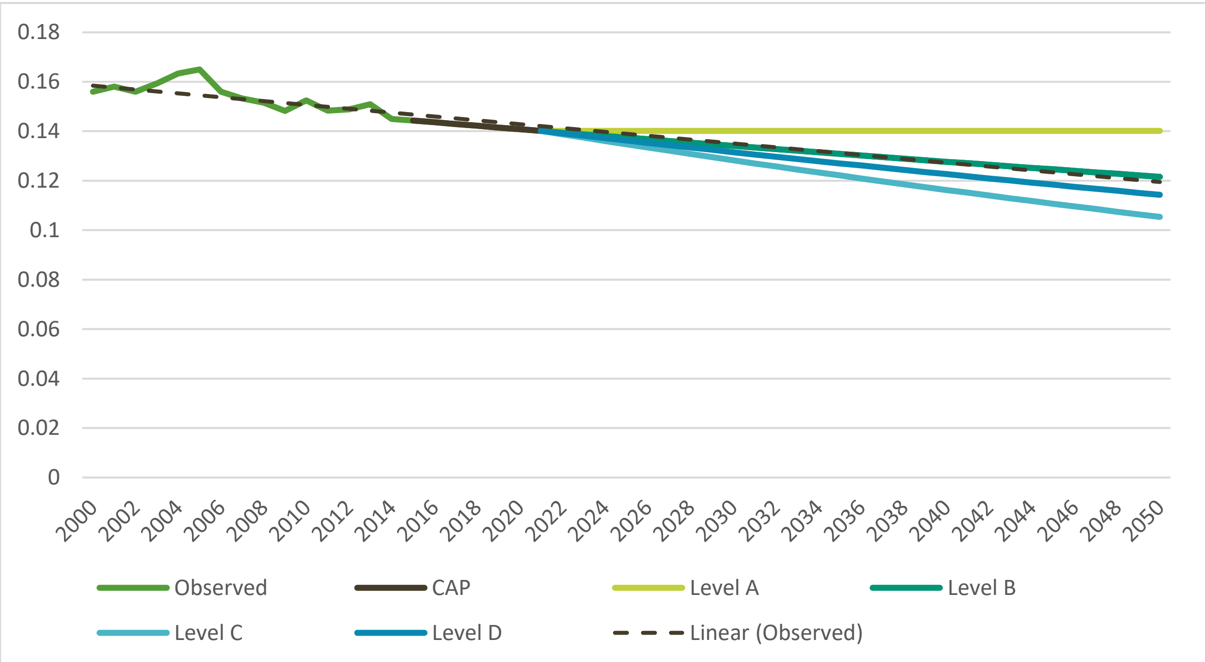

Figure 27 – Estimated energy-use per ha by 2050 [38]

Figure 27 presents the energy-use associated with the deployment of the different scenarios. Main assumptions are based on FAO pathways by 2050 (FAO, 2018), which includes a stagnation of energy efficiency for the most intensive scenario (level A), a continuous decrease based on the observed trends for the business as usual scenario (level B), an increase of energy efficiency in the most extensive scenario of the FAO (level C). Finally, the energy efficiency is also assumed to

[38]FAO crop

increase for the level D (Poux and Aubert, 2018), but in a lower extent compared with level C. Such as the other parameters, a linear trend is assumed in all scenarios before the lunch of the new CAP (2015-2021). In other words, it is assumed that the CAP scheme will set direction for agriculture long-term pathways.

Agricultural residues retention: none of the FAO and IDDRI scenarios provide specific assumptions regarding crop residues. Currently, the use of residues varies between 0 and 200% of the share that is sustainably available across the European countries (Searle and Malins, 2015). We assumed that scenario C & D respects the recommended retention rates proposed by Searle and Malins, (2015). Level B considers that the current retention rate will remain the same as 2015 by 2050 as a business as usual scenario. At the opposite, consistently with the hypothesis of the increase of nitrogen fertilizer-use (FAO, 2018), we consider that residues are intensively use, by 145% of what is sustainably available. It corresponds to the average rate of the European countries that are currently extracting more residues than what is sustainably available. This is also in line with the intensive use of synthetic fertilizers for Level A.

Lever setting – Disaggregation method

Disaggregation is used for the ambition level D, based on IDDRI (Poux and Aubert, 2018), as the road map is focused on Europe, contrary to level A, B, and C for which the FAO is providing data specific to each country. For the level D, the crop yield decreases are adapted from the IDDRI estimation, presented in Figure 28. Given the lack of data at the Country level, the presented rates are applied against the reference year data for each country (2010).

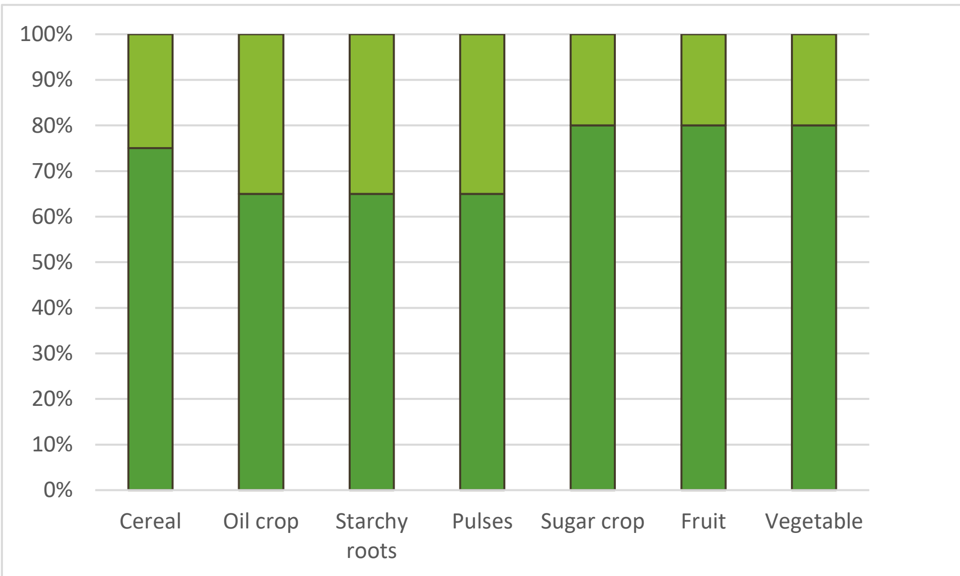

Figure 28 – Estimated yield decrease compared with 2010 for agroecology in Europe (Poux and Aubert, 2018)

4.1.2.3.Climate Smart Livestock production systems

Lever rationales

Emission factors associated with livestock-based products are much higher than crop-based ones. For instance, FAO estimates that each kg of cattle meat production involves 80 times more GHG emissions than cereals (Figure 29), which even becomes 180 times more for each kcal of food output. In other words, livestock production is the major driver of GHG emissions in the agriculture sector, especially through manure management and enteric emissions. According to the EU, the decreasing livestock population has been one of the main drivers of the recent GHG decrease in the agriculture sector.

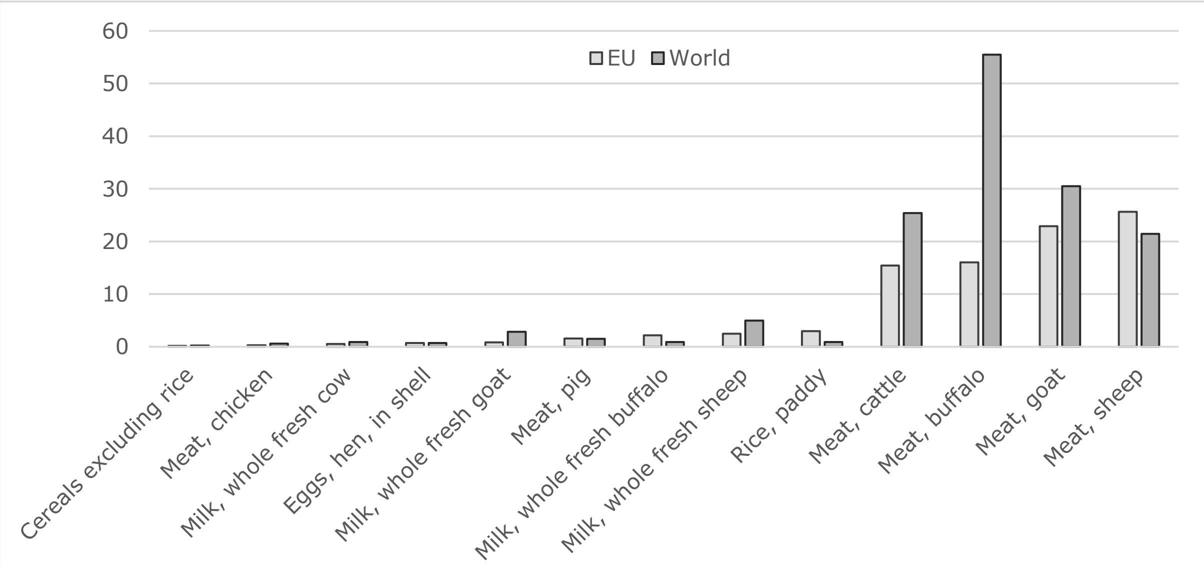

Figure 29 – Emission factor by food group (2013)[39]

Such as the climate smart crop production systems, the extent and depth of the challenges to tackle to achieve the livestock production system sustainability in the future depends on the key socio-economic drivers (e.g. meat consumption) and sustainable use of natural resources (e.g. water availability, biodiversity preservation). Added to the already mentioned challenges, one may point out animal welfare and wellbeing associated with livestock production systems that adds additional trade-offs / synergies in the whole agri-food system sustainability.

In terms of livestock production, CSA include multiple approaches and practices ranging from feedlots to silvopasture, which will drive resource-use intensity and the extent of the sustainability impacts, both positive and negative impacts (FAO, 2013). Climate smart livestock production systems includes landless, land-based and mixed systems that offer different options to tackle climate change and agriculture challenges. For instance, landless approach allows one to collect

[39] Food and Agriculture Organization (FAO), emissions intensities;
Direct link: http://www.fao.org/faostat/en/#data/EI

manure in much higher extent compared with grassland-based production systems, which enables to produce biogas and fertilizer through anaerobic digestion, or to improve manure treatment and management while limiting emission from manure left on pasture. At the opposite, well managed extensive permanent grassland enables to store carbon in the soil.

Lever description

Similar to the previous lever, the 'climate smart livestock production systems' lever enables the modelling framework to consider a set of agricultural practices ranging from intensive to extensive approaches.

Table 16 – Sub-lever list included in the CSLP lever (FAO, 2013)

#	Sub-lever...	... in brief	Unit
1	Losses (meat)	Sets the share of losses towards the agri-food production system including agriculture production, postharvest handling and storage, and processing	%
2	Livestock yields	Sets the yield for animal-based products depending on the relative deployment of intensive/extensive sustainable practices	kcal/lsu
3	Slaughter rate	Sets the slaughter rate for each livestock type, depends on the relative deployment of intensive/extensive sustainable practices	%
4	Manure management	Sets the split between manure management approaches, including manure treatment, soil application, manure left on pasture	%
5	Enteric emission	Enable us to set the enteric emission factors for each livestock type (not used for now)	MtCH4 /lsu
6	Grazing intensity	Sets the grazing intensity / livestock pressure on pastureland, i.e. indirectly the grazing livestock density index	kcal/ha

Losses are expressed in percentage (%) and cover food wastes and losses at the agriculture (Gustafsson et al., 2013); postharvest handling and storage; and finally, at processing and packaging production stages. Such as mentioned for food-crop based wastes and losses, the data availability does not allow us to apply a country specific approach, and wastes and losses will be considered homogeneous across the countries.

The livestock yield sets the quantity of animal-based products produced for each livestock head, expressed in energy content per livestock unit (kcal/lsu). The livestock unit (lsu) is:

> *'a reference unit which facilitates the aggregation of livestock from various species and age as per convention, via the use of specific coefficients established initially on the basis of the nutritional or feed requirement of each type of animal (see table below for an overview of the most commonly used coefficients).'*[40]

Thanks to the LSU, livestock can be expressed in a common unit which enables aggregating different animal types. Table 17 presents the lsu factors that are used in the model:

[40] Eurostat glossary, livestock unit definition;
Direct link: *https://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary:Livestock_unit_(LSU)*

Table 17 – LSU equivalent used in EUCalc

Animal	EUCalc aggregation	lsu
Cattle	Bovine	0.6
Buffaloes		0.6
Goats	Sheep	0.1
Sheep		0.1
Pigs	Pig	0.22
Chicken	Poultry	0.007
Duck		0.03
Goose		0.03
Turkey		0.03
Pigeons		0.03
Other birds		0.03
Rabbit	Other animals	0.02
Horses		0.8
Asses		0.8
Mules		0.8
Game		0.03
Other non-specified		0.03
Dairy cows	Dairy-milk	0.7
Dairy sheep		0.14
Dairy goats		0.14
Dairy buffaloes		0.7
Chicken laying hens	Hens-egg	0.014
Other laying hens		0.014

The aggregation of the livestock units per country and per year thus depends on livestock split in each group. For example, the LSU equivalent of poultry aggregated animal types depends on the actual population of chickens, turkey, and so on.

The slaughter rate sets the share of the overall population that is slaughtered each year, expressed in percentage. In other words, it sets the average slaughter age of each livestock type. Extensive approach leads to extend the livestock slaughter age, which leads the livestock population to be higher for a fixed amount of meat production, compared to much more intensive livestock production practices.

The lever is setting the split of the manure management method expressed in percentage (%), which affect the extent of GHG emissions, but also the possible contribution of manure to soil & nutriment management, or else biogas production. Typically, intensified landless systems enables to collect a higher share of manure for anaerobic digestion compared to extensive practices which led livestock outdoors more often (Poux and Aubert, 2018).

The enteric fermentation associated emission factors are technically considered in the climate smart livestock production system lever. The literature provides several studies that are demonstrating that supplementary feed compound or optimized diets can reduce the extent of livestock enteric fermentation emissions (Beauchemin et al., 2008; Maia et al., 2016). Nevertheless, studies usually provide short-term and results only focussed on changes in enteric emissions, regardless to long-term sustainability of reductions in CH_4 production and impacts on the entire farm GHG budget. Future research is required before considering such tremendous GHG mitigation potential. Thus, we prefer using a more conservative approach and not to consider such lever of action, keeping enteric emission factors constant[41].

Finally, the grazing intensity expressed in kcal per ha, set the amount of grazing feed available for livestock for each hectare of pastureland. In other words, it is setting the grazing livestock density index (lsu/ha). Intensive approaches will enable to reduce the land-pressure while potentially degrading the pastureland and thus its carbon storage capacity. At the opposite, extensive approach increases the demand for grassland and agriculture land, but while fostering a better management of grassland and its associated ecosystems.

Feedback from the stakeholder consultations

As mentioned previously, the climate smart livestock production system lever results from the stakeholder consultation. The stakeholders asked for 'umbrella' levers for agriculture that gathers sets of agriculture practices ranging from extensive to intensive approach, and explicitly suggest distinguishing cropping and livestock system.

Scenarios to explore & addressed issues

- ✓ How may CSA practices affect the demand for resources in terms of energy, land, water, fertilizer?
- ✓ How may diets and practices should align to make the agriculture-food system sustainable in terms of land, water and GHG emissions?
- ✓ How do diets, trade balances, agriculture practices issues interact?

Lever setting – Observed data

EUROSTAT classifies livestock between non-organic and organic farming standards. According to the EU definition, organic livestock farming rules means:

> "*respect for animal welfare, feeding the animals in accordance with their nutritional needs and are designed to protect the animal's health and environment. These rules also help to build public trust as they ensure that organically farmed animals are kept separate from non-organic*[42]*.*"

[41] Food and Agriculture Organization (FAO), enteric fermentation;
Direct link: http://www.fao.org/faostat/en/#data/GE
[42] European Commission, Products covered by EU organics rules; Direct link: https://ec.europa.eu/info/food-farming-fisheries/farming/organic-farming/organic-production-and-products_en

As shown by Figure 30, despite an increasing trend, the share of livestock organic farming is still representing a slight share of livestock production.

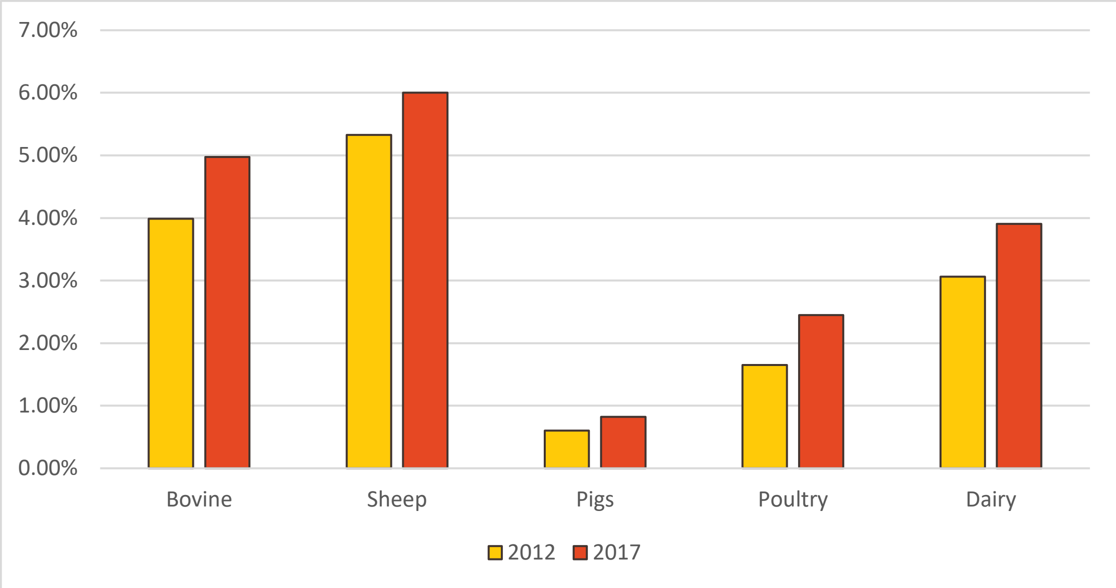

Figure 30 – Organic share of the livestock population in the EU28+1[43]

Such as organic farming for crops, livestock organic farming deployment in the EU is highly heterogeneous. The highest shares of organic non-dairy cattle production are in Latvia, Austria and Sweden with 23.6%, 21.7%, and 21.2% respectively. The ranking for dairy cows is the same but in a reverse order, with roughly 21, 16 and 13% in Austria, Sweden, and Latvia respectively. One third of the sheep and goat's production is under organic practices in Latvia and Austria, and up to one quarter is Slovakia. Finally, pigs are the least produced meat under organic farming practices, with less than 3% as a maximum share in Denmark. It is worth mentioning that the main European livestock producers are usually not the country where organic farming is widely deployed, namely France, Germany, the United Kingdom and Spain.

Such as the previous lever, the main parameters and variables are based on the FAO and IDDRI's scenarios (FAO, 2018; Poux and Aubert, 2018). The following Figures and Tables present the observed data for the variables that will be considered through the climate smart livestock production systems lever:

Food wastes & losses (meat): the extent of wood waste at the different production stages for the livestock-based commodity are aggregated though the meat, fish and milk groups. The following Table presents the assumptions that have been made for the historical period (1990-2015), based on the FAO global food wastes report (Gustafsson et al., 2013):

[43]EURSOTAT, Organic livestock of animals (org_lstspec) & Slaughtering in slaughterhouses - annual data (apro_mt_pann); Direct link: https://ec.europa.eu/eurostat/data/database

Table 18 – Animal based products wastes & losses %

Food Group	Agriculture production	Postharvest handling and storage	Processing and packaging
Meat	3.1%	0.7%	5.0%
Bovine meat	3.1%	0.7%	5.0%
Sheep meat	3.1%	0.7%	5.0%
Pig meat	3.1%	0.7%	5.0%
Poultry meat	3.1%	0.7%	5.0%
Other meat	3.1%	0.7%	5.0%
Animal based products	3.5%	0.5%	1.2%
Milk	3.5%	0.5%	1.2%
Eggs	3.5%	0.5%	1.2%
Animal fats	3.5%	0.5%	1.2%
Offals	3.5%	0.5%	1.2%

The FAO report only provides an estimate of meat food wastes and losses as a whole, and for milk. The assumption has been made that wastes and losses for all meat types are in the same extent, and that all animal non-meat-based products are following the milk wastes and losses patterns.

Livestock yields: the trend for livestock yield during the last decades is mainly positive (Figure 31) for all livestock types, mainly thanks to genetics (e.g. breeding) and feed (e.g. concentrates) (Poux and Aubert, 2018).

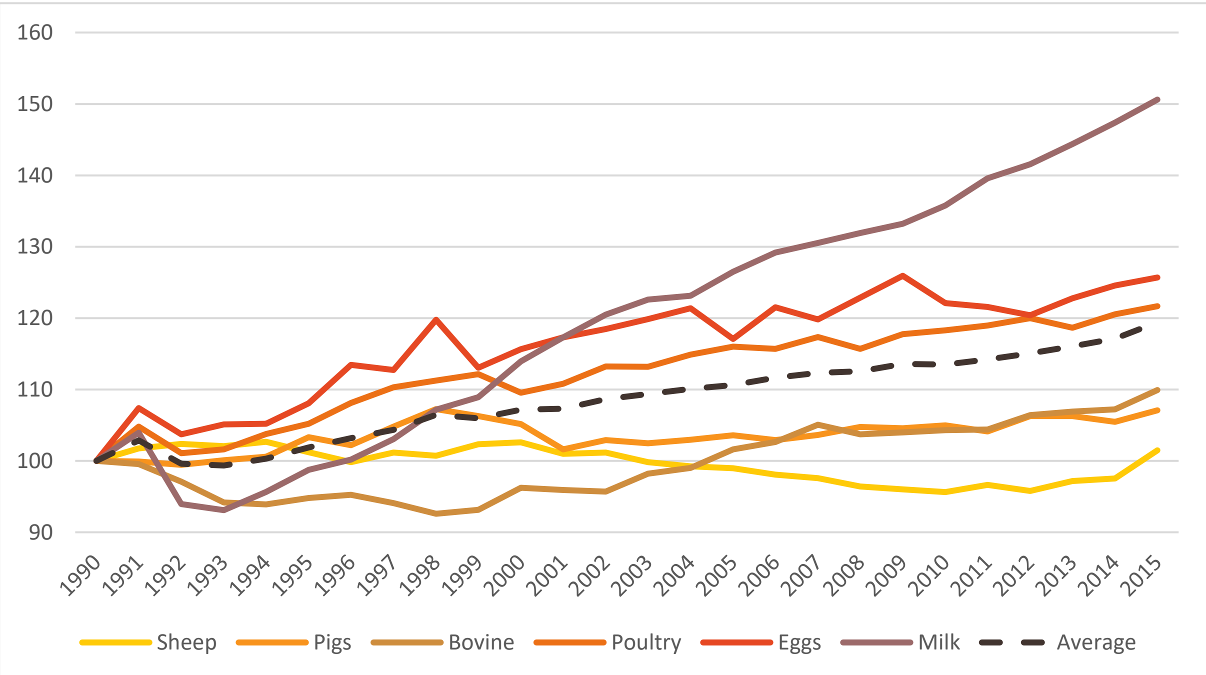

Figure 31 – Livestock yield evolution in the EU28+1[44]

[44]Food and Agriculture Organization (FAO), Livestock primary;
Direct link: http://www.fao.org/faostat/en/#data/QL

The livestock-based products yields have been increasing by 20% since 1990. Milk production per animal has known the highest increase with nearly 50%, followed by eggs and pig meat with a respective 25.6 and 21.6% increase.

Livestock slaughter rate: the average slaughter age enables to compute the livestock population considering the yields and meat demand. In other words, given a constant yield and demand, the higher the slaughter age, the higher the livestock population.

The average slaughter age per livestock type has mainly decreased over the years for non-ruminant livestock, whereas it is the opposite for ruminants. As shown by Figure 32, the average slaughter age for bovine were 33 months in 1990 compared to 45 months in 2015, which means a 36% increase. During the same period, the poultry average slaughter age decreased by 20%.

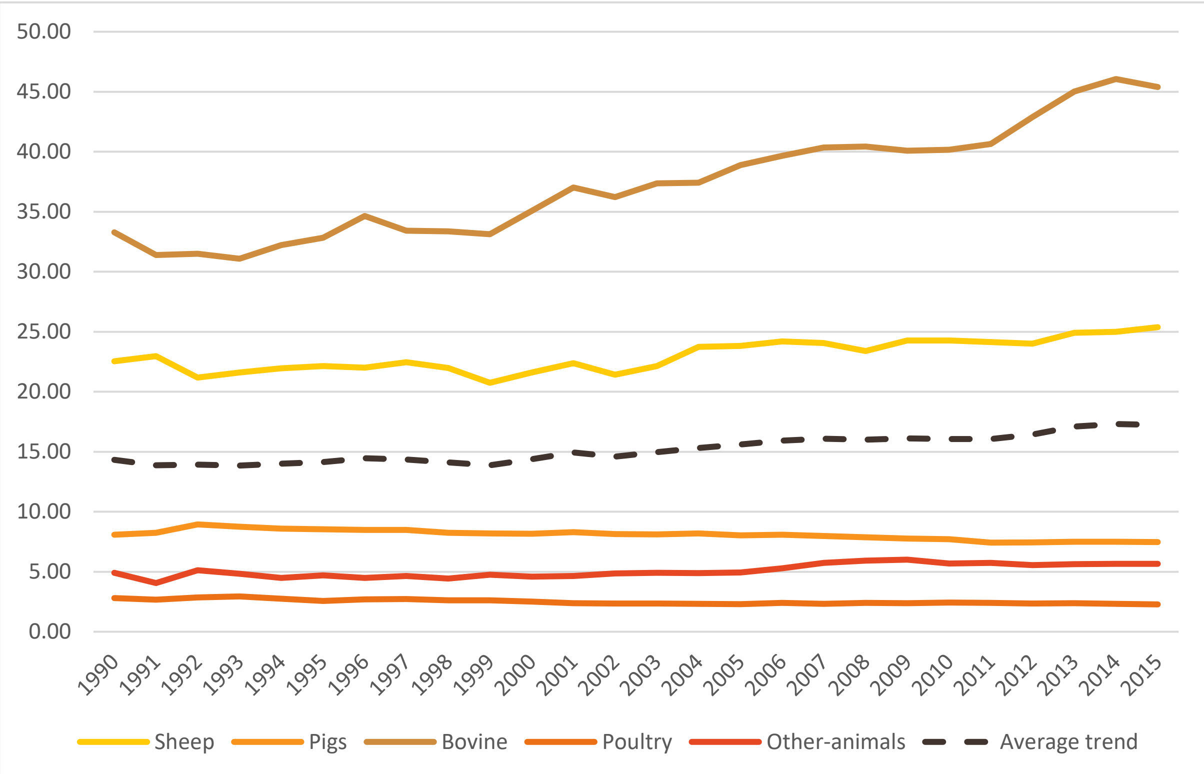

Figure 32 – Livestock average slaughter age in EU28+1 since 1990 (months/animal type)[45]

Manure management: the split of manure management practice depends on the livestock type, and the agricultural practices within the country. As shown by Figure 33, although the manure production decreased with the livestock population, the manure management practices mix remains roughly constant.

[45] Food and Agriculture Organization (FAO), Livestock primary;
Direct link: http://www.fao.org/faostat/en/#data/QL

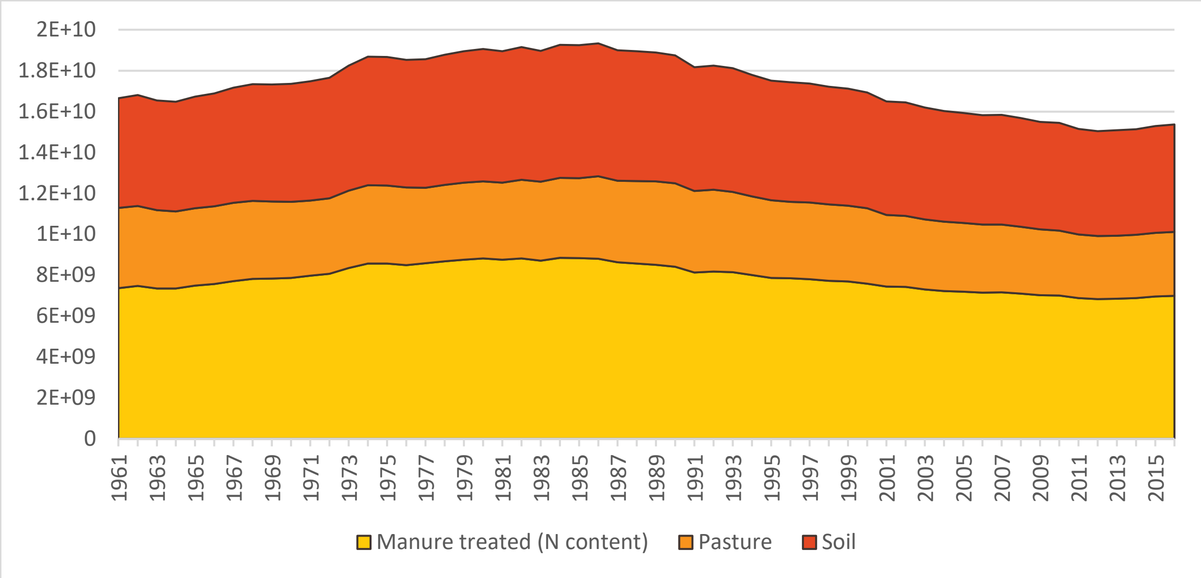

Figure 33 – Manure management practices in the EU28 since 1961 (kgN)

Enteric emission: are considered constant across the years and countries, except for Cyprus. For example, non-dairy cattle emission factor for Cyprus is estimated to be 35 against 57 for the other European country. Table 19 enteric fermentation emission factors per livestock type used by FAOSTAT.

Table 19 – Enteric fermentation emission per livestock type[46]

Livestock type	$kgCH_4$/animal
Asses	10
Cattle, dairy	117
Cattle, non-dairy	57
Goats	5
Horses	18
Mules	10
Sheep	8
Swine, breeding	1.5
Swine, market	1.5

The agriculture modelling framework considers the population split into the aggregated items (e.g. bovine considers the cattle/buffalo population pattern).

Grazing intensity is computed from the ruminant livestock patterns provided by the FAO (Figure 34).

[46] Food and Agriculture Organization (FAO), enteric fermentation;
Direct link: *http://www.fao.org/faostat/en/#data/GE*

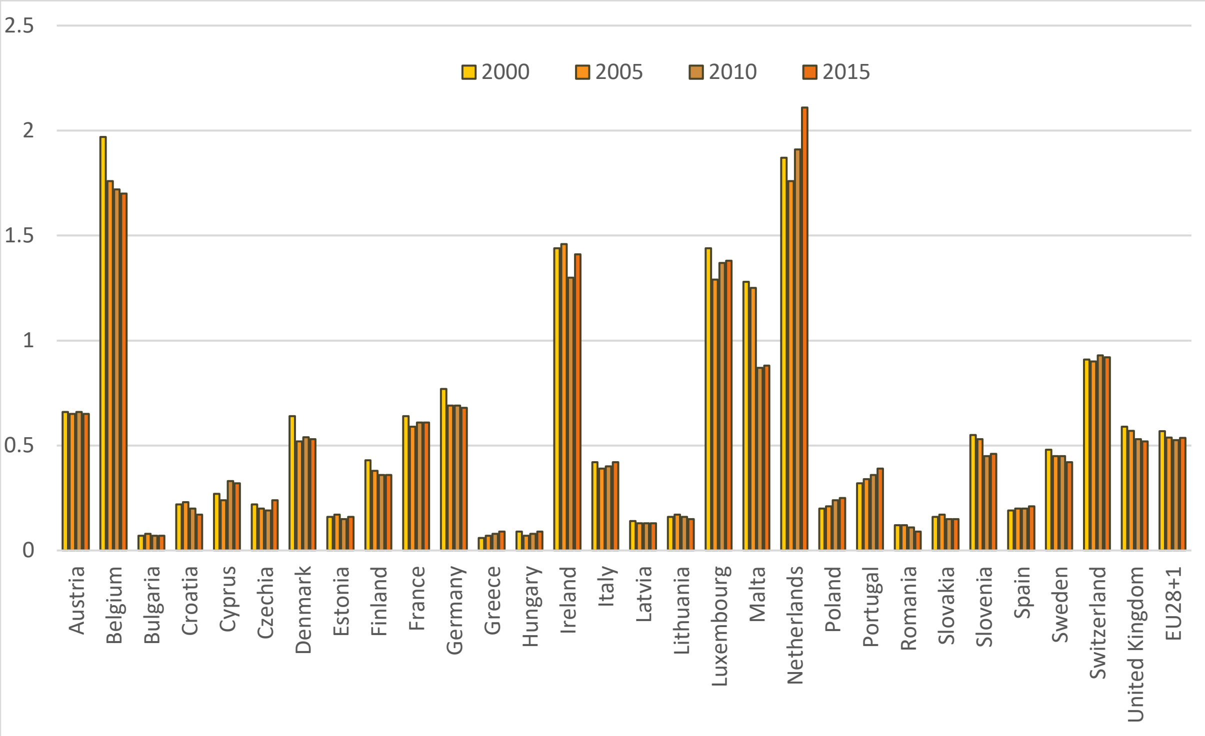

Figure 34 – Cattle density in the EU28+1[47]

In the modelling framework, the grazing livestock density index is expressed into 3 level of pastureland pressure:

> *Low pressure*: consists of fodder areas under extensive grazing density (Poux and Aubert, 2018), they account for less than 1 LSU per hectare. Grass fed system are less efficient in terms of energy conversion ratio, but it limits competition between animal feed and human food and foster the development of semi-natural prairies and its associated biodiversity.
>
> *Medium pressure*: includes the grassland under a grazing index included between 1 and 1.5 LSU/ha.
>
> *High pressure*: includes the grassland under a grazing index greater than 1.5 LSU/ha, such as the Netherlands and Belgium.

Lever setting – Ambition levels

The ambition levels are based on the scenarios detailed for the climate smart cropping production systems.

Livestock based wastes & losses: as previously mentioned, the livestock-based wastes & losses follow the patterns proposed by the FAO (2018) and TYFA's scenario (Poux and Aubert, 2018)(Table 20).

[47] Food and Agriculture Organization (FAO), Livestock patterns;
Direct link: http://www.fao.org/faostat/en/#data/EK

Table 20 – Animal based products wastes & losses %

Food group	Observed	Level A	Level B	Level C	Level D
Meat	8.8%	12.7%	12.3%	4.5%	1.6%
Bovine meat	8.8%	12.7%	12.3%	4.5%	1.6%
Sheep meat	8.8%	12.7%	12.3%	4.5%	1.6%
Pig meat	8.8%	12.7%	12.3%	4.5%	1.6%
Poultry meat	8.8%	12.7%	12.3%	4.5%	1.6%
Other meat	8.8%	12.7%	12.3%	4.5%	1.6%
Animal based products	5.2%	7.5%	7.3%	2.7%	0.9%
Milk	5.2%	7.5%	7.3%	2.7%	0.9%
Eggs	5.2%	7.5%	7.3%	2.7%	0.9%
Animal fats	5.2%	7.5%	7.3%	2.7%	0.9%
Offals	5.2%	7.5%	7.3%	2.7%	0.9%

Such as crop-based food, the most intensive practices lead to generate more wastes and losses, up to an increase by 40% in the worst case. At the opposite, extensive approaches lead to reduce wastes and losses by 60%.

Livestock yields: are expected to increase for all scenarios but at a different rate depending on the ambition level (Figure 35). Such as crop yields which are affected by the change of production systems, the agriculture module assume a linear trends until 2021, i.e. until the new CAP. Yields are expected to increase by 12.2% 11.7%, 10.6%, and 10.3% for the level A, B, C, D respectively at the Euorpean level, but while considering the heterogenousty between the countries.

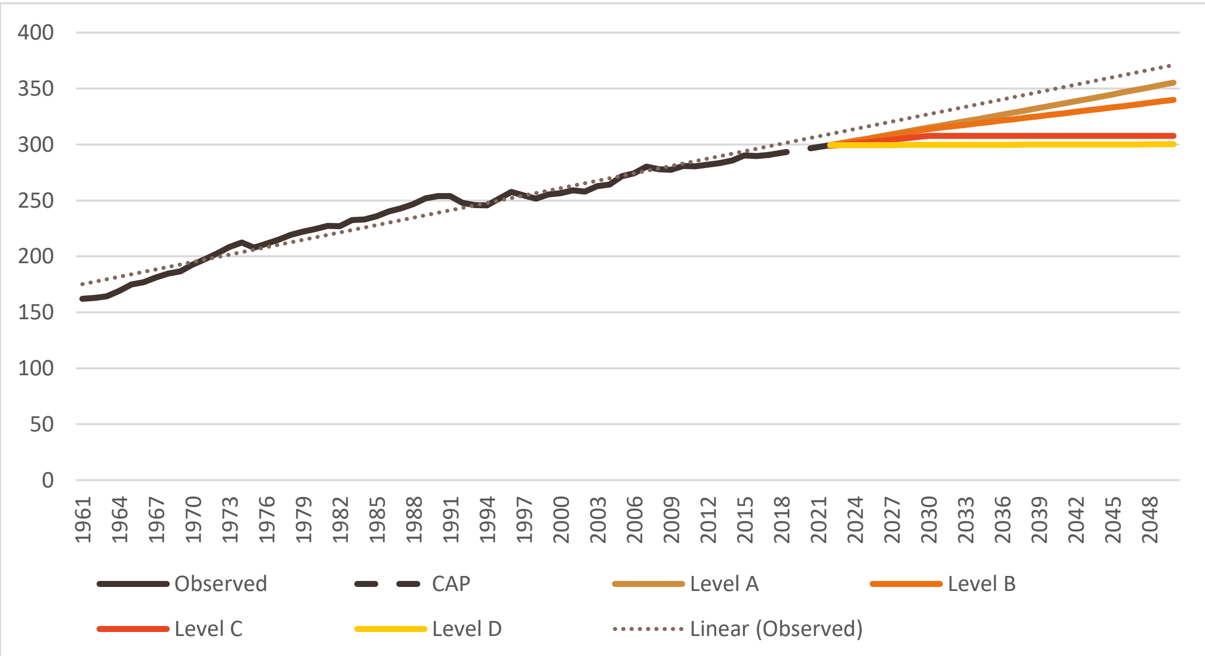

Figure 35 – Non-dairy cattle yields in the EU[48] (FAO, 2018; Poux and Aubert, 2018)

48 Food and Agriculture Organization (FAO), Livestock primary;
Direct link: http://www.fao.org/faostat/en/#data/QL

Slaughter rate: the slaughter rate is not explicitly mentioned in all the scenarios by 2050. Nevertheless, using extensive approach requires more time for the fattening period. Thus, an assumption has to be made in the agriculture module framework. Following the recommendations of FAO and IDDRI regarding the overall carcass yield, organic and extensive approaches should maintain a yield gap compared to intensive ones (FAO, 2018; Poux and Aubert, 2018). We will thus consider a linear trend for intensive approach for each and every country based on the data available since 1960[49]. For extensive approaches, we will apply the current gap between the average slaughter age of each livestock type, between intensive and extensive approach.

Table 21 – European average annual slaughter rate, 2015-2050 (in %)

Animal	Observed[50]	Organic	Conventional	Level A	Level B	Level C	Level D
Bovine	27%	54%	33.8%	54%	27%	27%	27%
Sheep	48%	101%	121.7%	122%	48%	48%	48%
Pigs	163%	201%	202.8%	203%	163%	163%	163%
Poultry	534%	451%	890.2%	890%	534%	451%	451%
Pattern	FAOSTAT	Literature	Literature	Max	Observed	Min	Min

A greater slaughter rate than 100% means that the lifetime of the livestock is inferior to one year. European livestock slaughter rate is in average lower than the organic farming slaughter rate recommendations found in the literature (Canbogulu et al., 2014; FAO, 1991). Thus, Level B keeps the observed values of 2015 (specific to each country); Level A considers the average minimum slaughter age found in the literature; Finally, Level C & D are considering the maximum slaughter age found in the literature. If the latter is lower than the current value, the latter is kept.

It is worth mentioning that we are currently looking for implementing animal welfare indicators for which the animal lifetime will be considered among other issues. For instance, poultry is slaughtered at 70 days but naturally lice up to 8 years.

Manure management: The manure management practices are affected by the livestock production patterns, given the time spent in housing and in pasture for the different animal types. The share of manure management for level A, B and C are not specified by the FAO, and given the past trends, we assume that they will remain constant by 2050. For level D, grassland is used extensively and the ruminants grazing time is extended, leading to increase the manure left on pasture (relatively).

[49] Food and Agriculture Organization (FAO), Livestock primary;
Direct link: http://www.fao.org/faostat/en/#data/QL
[50] Food and Agriculture Organization (FAO), Livestock primary;
Direct link: http://www.fao.org/faostat/en/#data/QL

Grazing intensity is set depending on the ambition level setting as presented by Table 22. The grazing intensity is moving towards high pressure for level A and B, medium pressure for level C, and low pressure for level D.

Table 22 – Assumed grassing intensity by 2050 by ambition level

Food group	Level A	Level B	Level C	Level D
Low pressure				x
Medium pressure			x	
High pressure	x	x		

It is worth mentioning that depending on the grassland management, including livestock density and fertilizer-use, the carbon storage in the soil range between 500 and 1200 tC/ha/year (Schulze et al., 2009).

Lever setting – Disaggregation method

With the exception of livestock-based wastes and losses that are based on European averages, the data is country/years specific based on FAO database.

4.1.2.4. Alternative protein sources (livestock)

Lever rationales

In the EU, the livestock is fed using approximatively 480 Mt of feedstuffs (FEFAC, 2016)[51]. In other words, more than half of the available crop, more than 60% of the cereals and 70% of oil crops are currently consumed livestock (Poux and Aubert, 2018), even more in terms of kcal consumed. The animal feeding practices involve major challenges in terms of resource-use and sustainability issues.

Based on the recent literature, insect-based meals and microalgae-based meals offer a relevant alternative to tackle the challenges regarding livestock feeding in a context of scarce resources, especially through land saving, and the need to fight against climate change (Madeira et al., 2017; Sánchez-Muros et al., 2014; Wang et al., 2017). These alternatives can also be seen a way to limit the risk of exporting deforestation through the substitution of imported cakes (FAO, 2013; Poux and Aubert, 2018). Although Figure 36 presents conservative yields for insects and microalgae, their yields remain higher to conventional crops in a large extent.

Although it is estimated that insects are currently part of the traditional diets of at least 2 billion people, at the European level, it seemed more realistic to limit insect-based meals for livestock only. Insects are natural food sources for many animals, including fish and poultry, which makes insect-meals relevant for these animals.

[51] FEFAC refers to the European Feed Manufacturers' Federation

Microalgae-based meals can be used to feed both ruminants and non-ruminants, but in a lower extent for the non-ruminants.

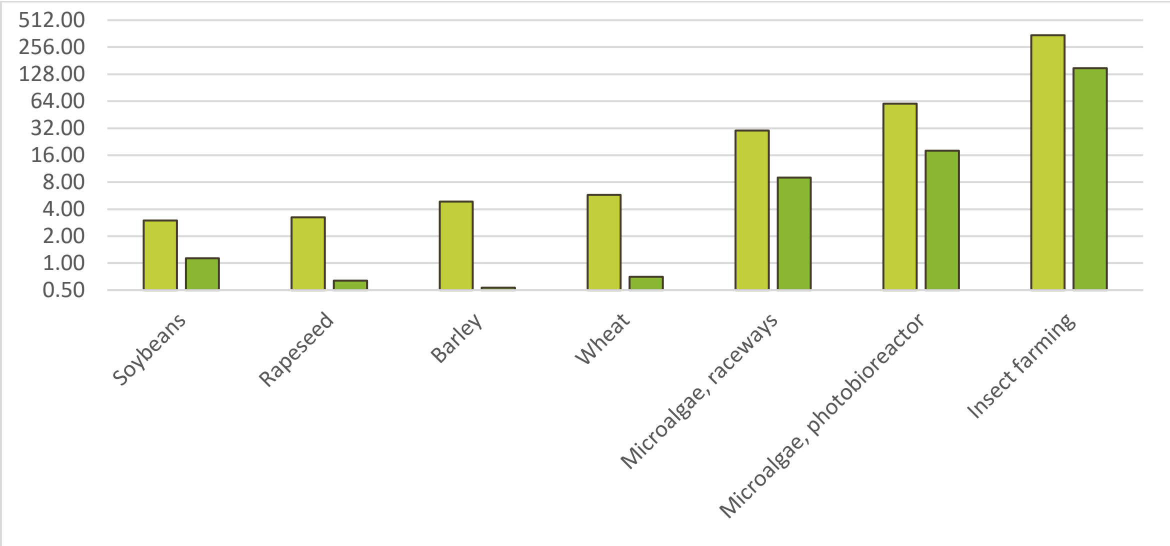

Figure 36 – Typical yields and protein yields of crops, microalgae and insects (t/ha, logarithm scale)[52], (Baudry et al., 2018a; Dossey et al., 2016)

It is worth mentioning that both microalgae biorefinery and insect farming must valorise the entire production output to remain profitable in a mainly low-value market (about 1000€/t). A biorefinery approach has thus to be considered. Given the large volume associated to feed production, one may only consider the byproducts that are representing large volumes too without considering high value but niche markets (Bobban G. Subhadra, 2011), which would lead to market gluts:

Table 23 – Main market volumes and prices ranges in the EU for insect farming & microalgae biorefinery (EnAlgae, 2015; IPIFF, 2018)

Product	European market volume	Price range
Biomethane	417Mtoe	0.037-0.049 € per kWh
Livestock cakes and meals	55 Mt	300-450 € per ton
Oil for biodiesel	11 Mt	900-1200 € per ton
Pet food	15Mt	1500-200 € per ton
Fertilizer	11 Mt	200-300 € per ton
Fish meals	2Mt	50-500 € per ton
Omega 3	0.1 Mt	300-1000 € per kg
Pigments	0.02 Mt	300-10000 € per kg

Lever description

Given the uncertainty regarding the large-scale deployment of microalgae and insect-based feed, the 'alternative protein sources for livestock' lever is dissociated

[52] Food and Agriculture Organization (FAO), FAOSTAT, Crops;
Direct link: http://www.fao.org/faostat/en/#data/QC

from agricultural production systems levers. Table 24 presents the sub-levers included in the 'alternative protein sources for livestock' lever:

Table 24 – Sub-lever list included in the APS lever

#	Sub-lever…	… in brief	Unit
1	Insect-based meals	Sets the share of insect-based meals in the typical ration of poultry and pigs, and aquaculture	%
2	Algae-based meals	Sets the share of microalgae-based meals in the typical ration of bovine, sheep, pigs, dairy-cows and in aquaculture	%

The lever drives the insect-based meal contribution to the typical feed ration of poultry, pig and aquaculture (fisheries & aquaculture remain to be implemented), and the microalgae-based meals to the typical feed ration of ruminants, pigs and poultry. The extent of alternative protein sources in the typical ration for each livestock type is considering the highest share that have been recommended by the literature so far, considering both animal health and food output quality issues (De Marco et al., 2015; Madeira et al., 2017; Sánchez-Muros et al., 2014; Vigani et al., 2015).

We would nevertheless recommend some caution as further research needs to be developed, especially for the assessment of mixed meals impacts in terms of digestibility and feed conversion ratio. In other words, it is assumed that combining different alternative protein sources do not affect neither their benefits nor their drawbacks.

Several assumptions have been made that needs to be explicated. First, insects are assumed to be fed by wastes only. In other words, we do not consider that insects could be fed using crops and cakes. Second, alternative protein source is assumed to be a domestic production in the modelling framework. However, the alternative protein source substitutes are still set by the trade balance lever. Finally, the model follows a biorefinery approach and the demand for insects and microalgae-based meals is driving the supply for oil (insect and microalgae) and manure (insect).

The higher the alternative protein source share, (1) the lower the demand for lands, that can be used for other purposes such as reforestation; (2) the lower the risk of exporting deforestation; (3) the higher the availability of byproducts for bioenergy feedstock; and so on. Thus, the lever setting consists of a 1-4 scale, implying that a higher share of insect and microalgae meals results in lower GHG emissions.

Feedback from the stakeholder consultations

Stakeholders first recommended the present lever to be part of livestock production systems practices. Nevertheless, given the large extent of the potential impact of a large deployment of the alternative protein sources (e.g. land-use, byproducts flows), it was finally acknowledged that it should be a stand-alone lever.

Scenarios to explore & addressed issues

- ✓ How may insect-farming/microalgae biorefinery deployment affect the resources demand (e.g. land, water, energy, fertilizer, etc.)?
- ✓ How may insect-farming/microalgae biorefinery deployment affect the bioenergy feedstock mix (e.g. land, water, energy, fertilizer, etc.)?
- ✓ (possibly) How may insect-based meals production contribute to waste valorisation?
- ✓ How may insect-based meals production contribute to the use of organic fertilizer?

Lever setting – Observed data

Figure 37 presents the current feed consumption per type, excluding grazing, for each member states and Switzerland.

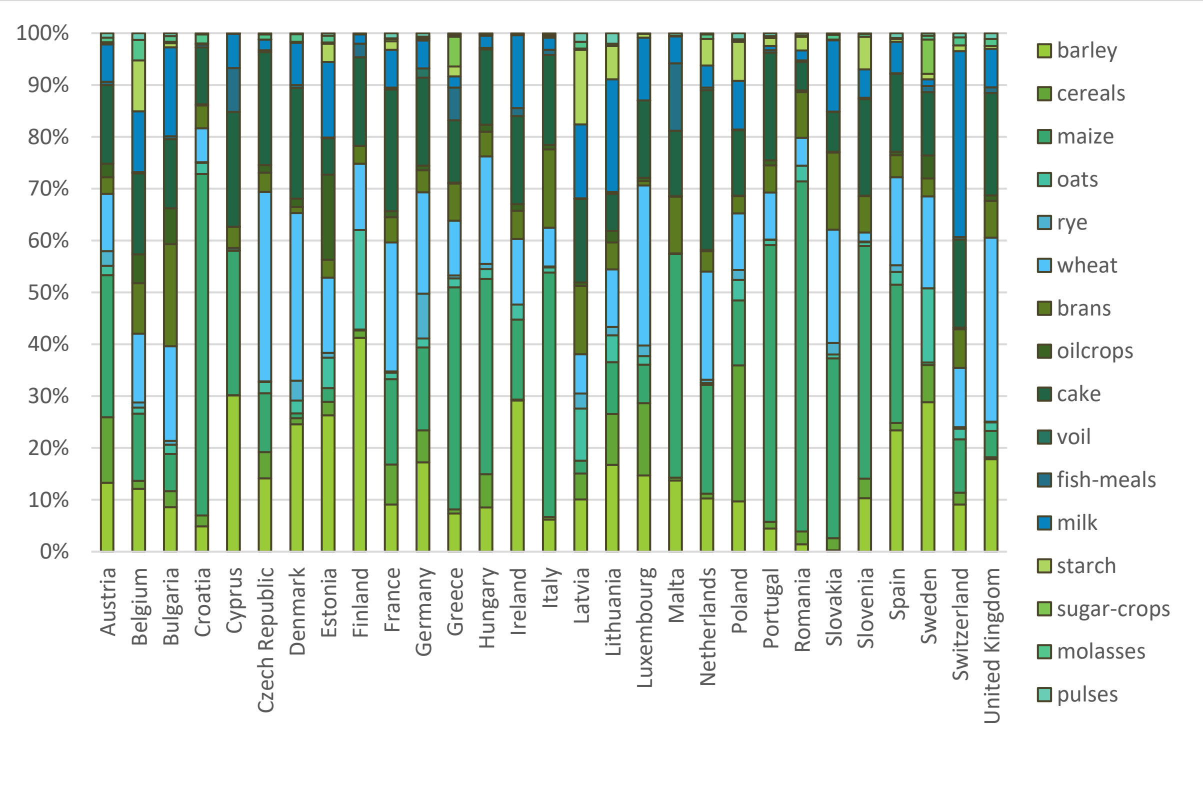

Figure 37 – Feed consumption by type and by country in the EU28+1 (2015)[53]

[53] FAOSTAT, Commodity Balances - Crops Primary Equivalent - Livestock and Fish Primary Equivalent

Neither insect nor algae meals are currently significantly used in Europe.

Insect-based meals: the European production of insect in 2018 is estimated to be about 2 kt, mainly consumed through fish feed and pet food. The production is expected to take off up to 200 kt by 2020 and 1200 kt by 2025 (IPIFF, 2018).

Algae-based meals: microalgae biorefinery are currently limited to the production of high-value products but niche markets for chemical, pharmaceutical, and human food markets. Algae production for food market is estimated to be about 15 kt (EUMOFA, 2018).

Lever setting – Ambition levels

Insect-based meals: although the current microalgae production volumes exceed the insect ones, a fast take off is expected for insects. Although at an early stage of deployment, the insect farming sector is already producing at an industrial scale for the purpose of animal feed. According to the International Platform of Insects for Food and Feed (IPIFF), the European insect production is expected to strongly increase over the next years.

Algae-based meals: Algae production for feed and bioenergy is still missing critical milestone to grow from small scale production for high-value product markets to large industrial scale for low-value product markets (EUMOFA, 2018). Given these missing milestones, we consider that large scale microalgae biorefinery cannot be widely deployed before 2030 at best (Baudry et al., 2018a).

Table 25 presents the ambition level for insect and microalgae-based feed contribution to the typical livestock diet by 2050 across the 4-ambition levels (Madeira et al., 2017; Sánchez-Muros et al., 2014):

Table 25 – Alternative protein sources for livestock

Animal type /Algae meals	Level 1	Level 2	Level 3	Level 4
Ruminants	0%	3%	5%	10%
Pigs	0%	5%	15%	25%
Poultry	0%	1%	3%	5%
Aquaculture	0%	10%	20%	30%
Animal type / Insect meals	**Level 1**	**Level 2**	**Level 3**	**Level 4**
Pigs	0%	10%	20%	33%
Poultry	0%	10%	20%	30%
Aquaculture (carnivore)	0%	10%	20%	40%

Basically, the ambition levels range between the non-large-scale deployment of insect-farming and microalgae biorefinery, and the maximum share of their livestock typical ration that is recommended for each livestock type.

direct link: http://www.fao.org/faostat/en/#data/BC / http://www.fao.org/faostat/en/#data/BL

Lever setting – Disaggregation method

Given the lack of a country specific database, the data presented in Table 26 is applied homogeneously across the European countries, following the approach detailed for food wastes and losses.

4.1.2.5. Biomass hierarchy

Lever rationales

The move towards a more biosourced and circular economy already involves competition between different uses. Through climate smart agriculture practices, FAO recommend the use of low-carbon inputs which includes industrial byproducts such as livestock wastes (FAO, 2013)that can be used as feedstock for compost, fertilizer, biogas, electricity and heat, biodiesel, oleochemicals, pet food, meat meals, and other minor markets. A similar analysis could be done for agriculture and forestry residues that can be used for a wide range of uses that all contribute to bioeconomy, but through different ways.

Table 26 – Food waste most preferable option hierarchy in the EU (EU, 2010)

Hierarchy		Description
1	Prevention	reducing wastes
2	Prevention	Redistribution to people
3	Prevention	Send to animal feed
4	Recycling	anaerobic digestion, biogas and digestate production
5	Recycling	compost
6	Recovery	Incineration with energy recovery
7	Disposal	Incineration without energy recovery
8	Disposal	Landfill
9	Disposal	Sewer

Following the European Union approach to waste management, a hierarchy can be set for the use of the available biomass between different valorisation pathways. It is worth mentioning that some member states consider anaerobic digestion as recycling while other consider it recovery.

Lever description

The agriculture module is considering a wide range of industrial byproducts, wastes and residues across the modelling framework. The objective of the biomass use hierarchy lever is to drive these biomasses towards a set of possible uses including animal feed, bioenergy by type, fertilizer, and other uses (aggregated).

Table 27 presents in brief the parameters and variables that will be driven by the biomass-use hierarchy lever.

Table 27 – Sub-lever list included in the biomass hierarchy lever

#	Sub-lever…	… in brief	Unit
1	Alcoholic beverages by-product-use	Sets the share of alcoholic beverage industry byproducts driven towards feed, fertilizer and bioenergy-uses	%
2	Livestock-based by-products	Sets the share of livestock industry byproducts driven towards feed, fertilizer and bioenergy-uses	
3	Crop residues split use	Sets the share of agricultural residues driven towards feed, fertilizer and bioenergy-uses	%
4	Forestry residues split use	Sets the share of forestry residues driven towards feed, fertilizer and bioenergy-uses	%
5	Wood wastes split use	Sets the share of wood industry byproducts driven towards feed, fertilizer and bioenergy-uses	
6	Bioenergy technology & feedstock mix	Sets the bioenergy technology and feedstock mix assuming that the development of technology first relies on feedstock availability	

The biomass-use hierarchy lever is driving the following feedstock towards different uses:

Alcoholic beverage industry is generating significant volumes of byproducts through the brewery and distilleries. Brewery mainly yield yeast and cereal meals which are mostly used as animal feed. Distilleries mainly produce cereal meals, lees and marc as byproducts, which can be used as bioenergy, biochemical, and fertilizers (Réséda et al., 2017).

Livestock slaughter industry is yielding skin, blood, fats, bones, leather and offal, that are processed and used as animal feed, fertilizer, bioenergy and biochemical feedstock. In a lower extent, milk and eggs byproducts are currently not modelled in the agriculture module, but one may also consider these industry's wastes that can be used as feed, fertilizer or bioenergy feedstock (Réséda et al., 2017).

Crop residues: are the share of the plant left on cultivated land after the harvesting stage, which represents roughly half the crop in volume (Searle and Malins, 2015). These residues can be used for improving soil quality by increasing the content of organic matter, reducing erosion and evaporation, and fixed CO_2 in the soil (Liang et al., 2012). Agricultural residues can also be used as bioenergy feedstock for biogas, ethanol, biodiesel and biojetfuel.

Forestry residues: consist of small trees, branches, tops and wood left in the forest after the cleaning, thinning or final felling of forest stands according to the European Biomass Industry Association. Forestry residues can be used as bioenergy through different forms, such as biomass to liquid biodiesel, solid bioenergy for heating and power generation.

Wood wastes: stem from wood product processing by the Industry, which can be used as bioenergy feedstock, such as the previously mentioned forestry residues.

Bioenergy technology mix: assuming that the biomass availability will drive the bioenergy technology mix, the lever will set the share of bioenergy technology. Table 28 presents the bioenergy technology considered in the agriculture module. It is worth remembering that biomass-based power and heating are considered in the energy supply module.

Table 28 – Bioenergy conversion pathways in the agriculture module

Type	Conversion pathway	Feedstock
Biodiesel	Esterification	vegetable oil, UCO, animal fats, algae oil, insect oil, energy crop
Biodiesel	Hydrotreated Vegetable Oil	vegetable oil, UCO, animal fats, algae oil, insect oil, energy crop
Biodiesel	Biomass To Liquid	agricultural residues, forestry-residues, energy crops
Jetfuel	Hydrotreated Vegetable Oil	vegetable oil, UCO, animal fats, algae oil, insect oil, energy crop
Jetfuel	Biomass To Liquid	agricultural residues, forestry-residues, cellulosic energy crop
Ethanol	Fermentation	sugar crop, cereal, energy crops
Ethanol	Enzymatic	agricultural residues, forestry-residues, cellulosic energy crop
Biogas	Anaerobic digestion	Manure, biowastes, energy crop
Solid bioenergy	-	agricultural residues, forestry-residues, wood fuel

<u>Bioenergy technology mix, feedstock buffer:</u> In the modelling framework, the use of residues and wastes is prioritized. However, when the setting does not enable the supply to meet the demand, the biomass hierarchy lever sets what way will be used to fill the gap, including imports and energy crops. The model also enables one to disable the use of both imports and crops for bioenergy. In such case, a warning is sent when the setting involves a resource limit.

Feedback from the stakeholder consultations

The biomass hierarchy was the most challenged lever. Stakeholders debates led to consider residues retention for soil quality in the respective climate smart cropping system and climate smart forestry levers (not as a biomass-use hierarchy), while the split for the different uses in the present lever only concerns the available residue share considering the retention rates set by the climate smart levers. The experts also reinforced our thinking in terms of including settings that allow the users to explore scenarios that enable or disable the use of dedicated energy crops, food-crop and imports.

Scenarios to explore & addressed issues

- ✓ How may the biomass-use hierarchy affect the GHG emissions?
- ✓ How may the biomass-use hierarchy affect the resource availability for bioenergy?
- ✓ Is it possible to meet bioenergy demand without imports, food crop-based feedstock or dedicated energy crops?

Lever setting – Observed data

<u>Industrial byproducts:</u> To the best of our knowledge, there is no database that provides the valorisation of industrial products per industry and per country. Consequently, the data that has been used for observed data are estimation based on the available literature.

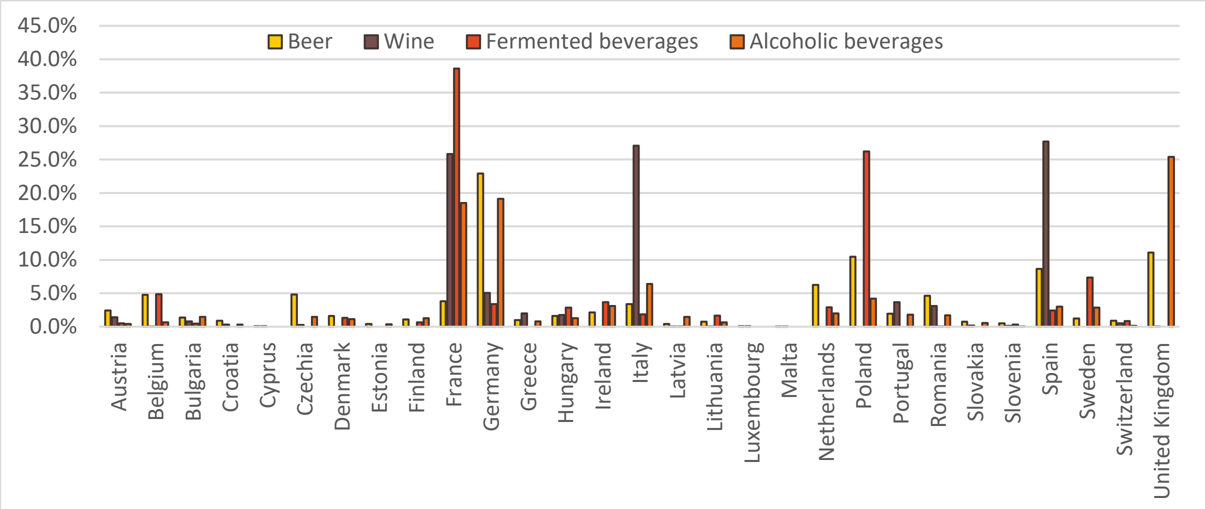

Figure 38 – Share of beer and wine production in the EU28+1[54]

Alcoholic beverages: Focusing on alcoholic beverages, the major producers are France, Germany, Italy, Poland, Spain, and the United Kingdom, for which the potential for byproducts is wider. Given the lack of country specific data, the byproducts flows are based on RESEDA report (Réséda et al., 2017) – the network for food security and quality – that provides the byproducts flow from agri-food industry towards the different markets (see Table 29). Given the common European food-waste hierarchy, we consider best compromise to apply a common pattern of byproducts valorisation across the European member states, based on the available data.

Table 29 – Alcoholic beverages yields in kcal/kcal

Beverage	Wine	Beer	Alcoholic	Fermented
Cereal demand	-	94.5	-	290
Marc supply	137	-	-	-
Lees supply	20.6	-	-	-
Distillers Dark Grains (DDGS)	-	96.6	-	296
Yeast supply	-	21.7	-	-
Fruit demand	113.6	-	288	-

Wine byproducts are used as feedstock for the ethanol industry in a large extent (90% for grape marc, and 93.5% for lees), and for compost, and bioenergy (biogas, combustion) in a much lower extent. Brewery (including malting process) involves the by production of cereal meals and yeasts that is almost exclusively used for livestock (97%), while the rest is allocated to bioenergy and compost. Distilleries yields byproducts used as animal feed (50%), fertilizer (31%), and bioenergy (13.5%), and the rest for other industry (e.g. pharmaceutical).

Animal slaughter industry: animals byproducts represents almost equivalent volume compared with meat, which represent a large pool of potential feedstock for the industry.

[54]FAOSTAT, Commodity Balances - Crops Primary Equivalent
direct link: http://www.fao.org/faostat/en/#data/BC

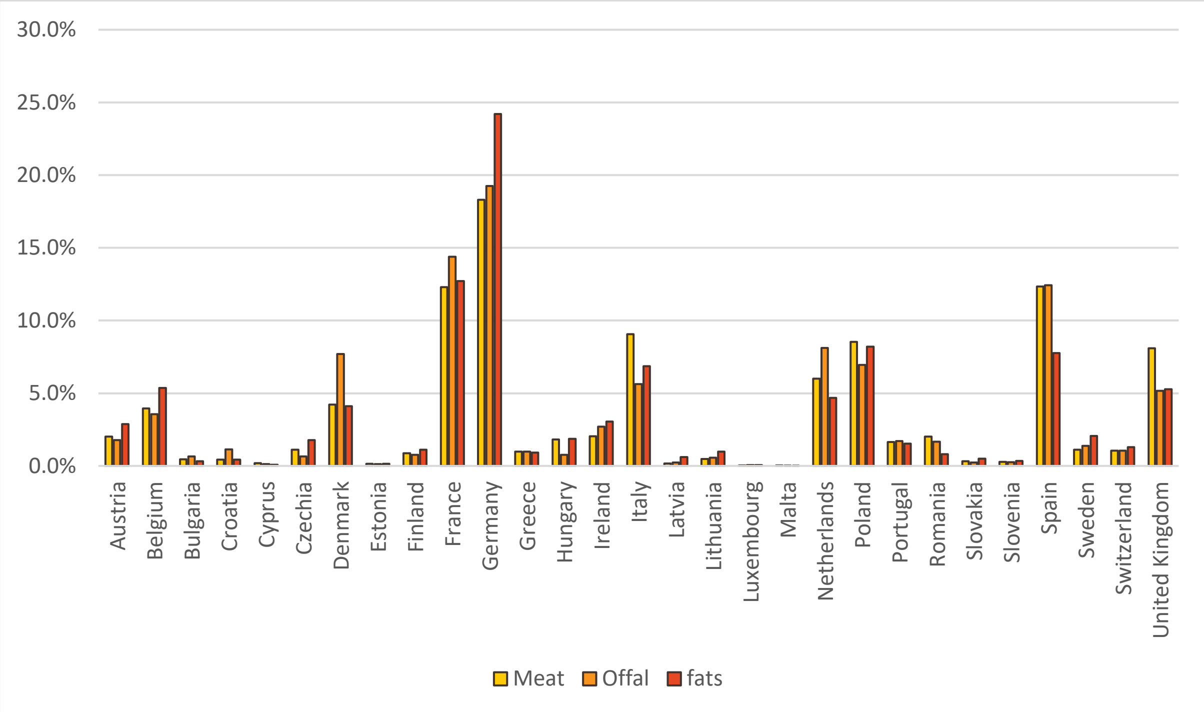

Figure 39 – Share of meat, offal and fats production in the EU28+1[55]

Germany, France, Spain, Italy, the Netherlands and the United Kingdom represents 2/3 of the meat, offal and animal fat European production. Following the alcoholic beverage logic, it is assumed that animal based byproducts are mainly valorised as pet food (46%), biogas (12%), biodiesel (10%), animal feed (9%), and the rest is used for oleochemical and food industry.

<u>Wood processing byproducts:</u> wood chips, residues and agglomerates represented 120 Mm^3 in 2017 in the EU28+1, as presented by

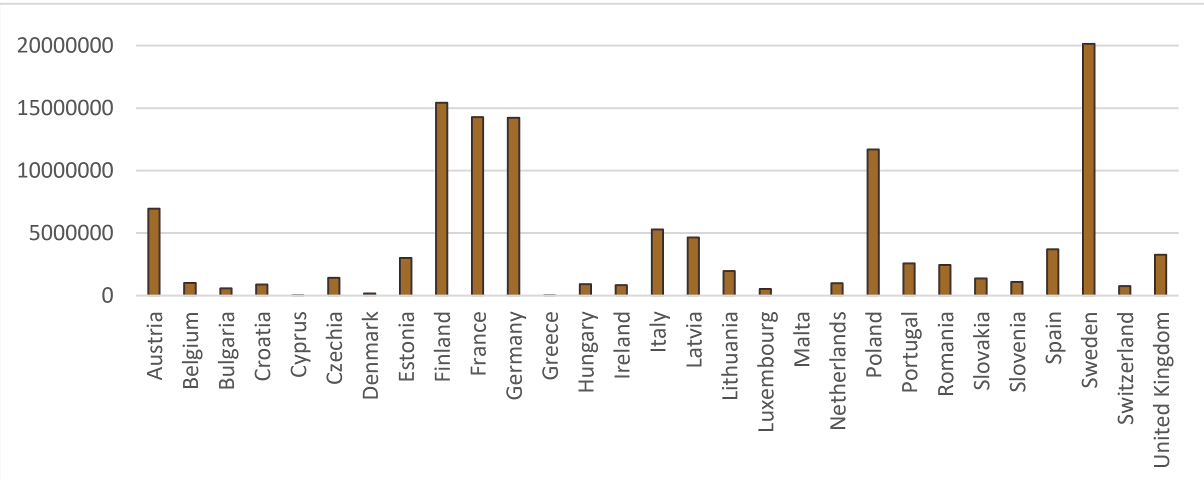

Figure 40 – Wood processing byproducts in the EU28+1(2017)[56]

55 FAOSTAT, Commodity Balances - Livestock and Fish Primary Equivalent
direct link: http://www.fao.org/faostat/en/#data/BL
56 FAOSTAT, Forestry production & trade

Sweden, Finland, France, Germany, Poland and Austria have the most important wood processing byproducts volumes. Wood processing byproducts are used for pulping, boards production, and as a fuel.

Crop & forestry residues are obviously associated with the forestry and agriculture activity. Thus, France, Germany have by far the most important resources in terms of agricultural residues. As shown by Table 30, Finland, Sweden and France have the most important resources in terms of forestry residues. Table 30 presents the volumes and the current use of residues. Uses of residues is shared between bioenergy and mostly livestock/fertilizer uses for agricultural residues, whereas forestry residues are mostly used for bioenergy purposes (Searle and Malins, 2016).

Table 30 – Agricultural & forestry residues uses

Country list	Agricultural residues	soil retention	heat, power & biogas	other uses	Forestry residues	heat & power	soil retention
Austria	5.4	87%	5.6%	7.4%	1.71	23%	77%
Belgium	3.4	76%	5.9%	17.6%	0.62	21%	79%
Bulgaria	10.5	98%	0.0%	1.9%	0.92	12%	88%
Croatia	3.5	97%	0.0%	2.9%	1.06	7%	93%
Cyprus	0.1	100%	0.0%	0.0%	0	0%	100%
Czech	8.7	95%	2.3%	2.3%	1.52	12%	88%
Denmark	8.4	45%	26.2%	28.6%	0.28	39%	61%
Estonia	1.1	73%	27.3%	0.0%	0.99	8%	92%
Finland	3.6	94%	0.0%	5.6%	11.43	10%	90%
France	69.8	94%	0.6%	5.2%	8.62	10%	90%
Germany	47.6	95%	0.0%	5.5%	5.85	19%	81%
Greece	4.8	83%	6.3%	10.4%	0.24	33%	67%
Hungary	15	95%	2.7%	2.0%	1.16	9%	91%
Ireland	1.7	35%	0.0%	64.7%	0.2	10%	90%
Italy	19.4	90%	1.0%	8.8%	1.37	31%	69%
Latvia	2	95%	0.0%	5.0%	1.8	11%	89%
Lithuania	4.4	95%	0.0%	4.5%	1.03	10%	90%
Luxembourg	0.2	50%	0.0%	50.0%	0.04	0%	100%
Malta	0	100%	0.0%	0.0%	0	0%	100%
Netherlands	2.6	23%	11.5%	65.4%	0.13	69%	31%
Poland	28.1	83%	9.6%	7.1%	4.21	49%	51%
Portugal	1.2	42%	33.3%	25.0%	1.87	6%	94%
Romania	21.7	94%	0.0%	5.5%	2.74	15%	85%
Slovakia	4.1	98%	0.0%	2.4%	1.14	4%	96%
Slovenia	0.5	80%	0.0%	20.0%	0.46	13%	87%
Spain	23.1	85%	4.3%	10.4%	2.53	14%	86%
Sweden	4.9	67%	26.5%	6.1%	14.77	26%	74%

direct link: http://www.fao.org/faostat/en/#data/FO

Technology and feedstock mix: The following Figures present the technology and feedstock mix for biogas, liquid bioenergy and solid bioenergy (wood-based):

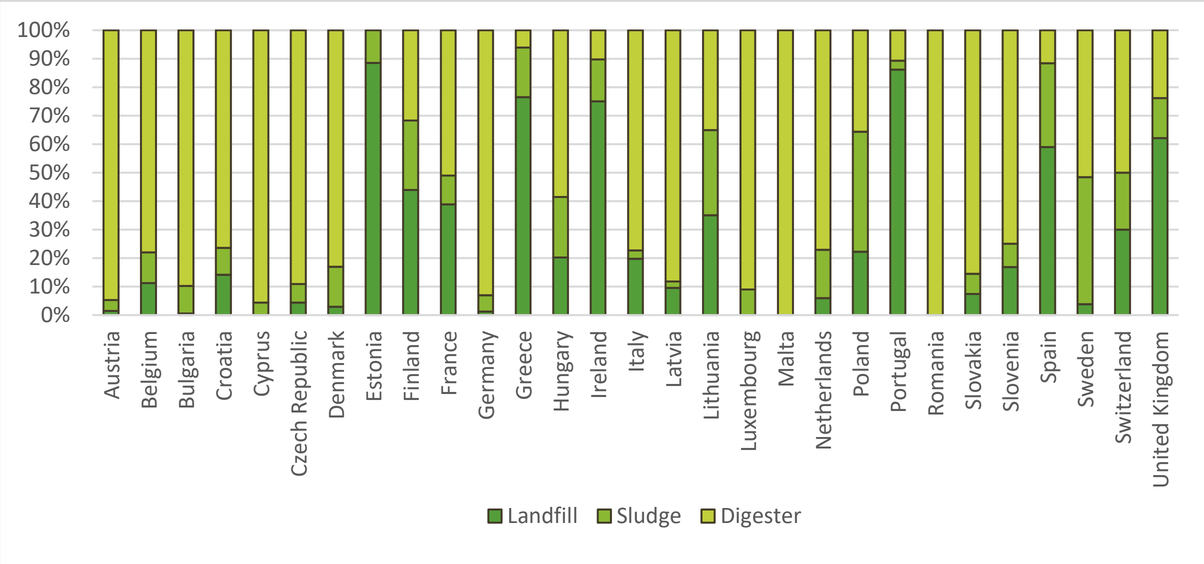

Figure 41 – Biogas technology mix in the EU28+1(2017)[57]

Since 2011, the biogas production rose from 752 GWh to 17,264 GWh in 2016. The agriculture module only considers the biogas produced through digesters, which is the main pathway used in Europe. The feedstock mix for biogas production is highly heterogeneous between the member states (Figure 42). The biowastes and manure represents the most important share of the feedstock mix although some countries massively use dedicated energy crops (e.g. Finland, Latvia), usually green maize.

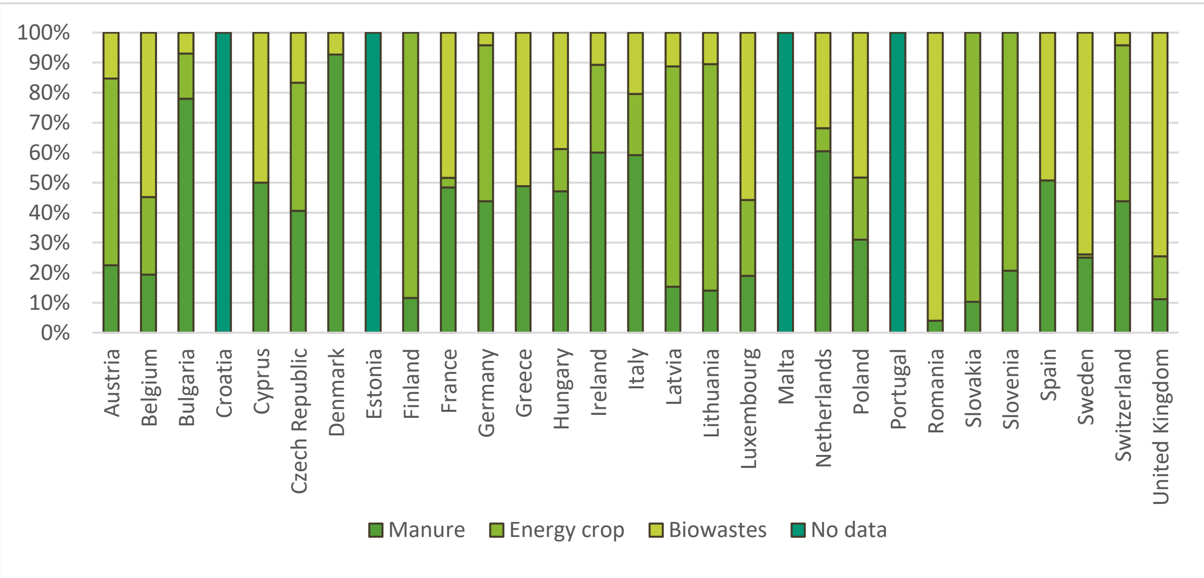

Figure 42 – biogas feedstock mixes in the EU28+1(2015)

[57] EUROSTAT: Primary production - all products - annual data (dataset: nrg_109a), Direct link: https://ec.europa.eu/eurostat/data/database

Given the lack of detailed database providing the feedstock mixes at the level of EU28+1 in a yearly basis, we considered the present mixes per country as a constant over the years.

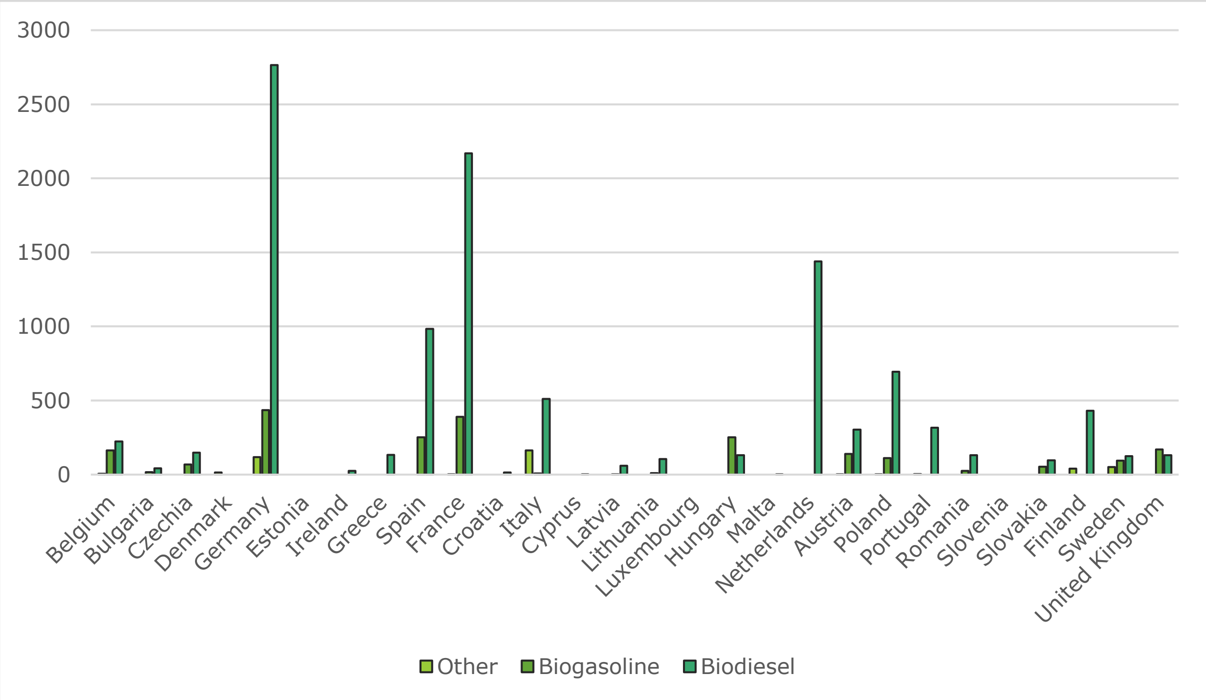

Figure 43 – Liquid biofuel production in the EU28(2015)[58]

In terms of liquid biofuels, the European production is highly concentrated in Germany, France and Netherlands (HVO, hydrotreated vegetable oil), which represent 25%, 19% and 11% of the total European production. Biodiesel is produced in a much larger extent with 81% of the liquid biofuel production. Most of the production currently relies on food crop for both biodiesel and ethanol:

[58] EUROSTAT: Primary production - all products - annual data (dataset: nrg_109a), Direct link: https://ec.europa.eu/eurostat/data/database

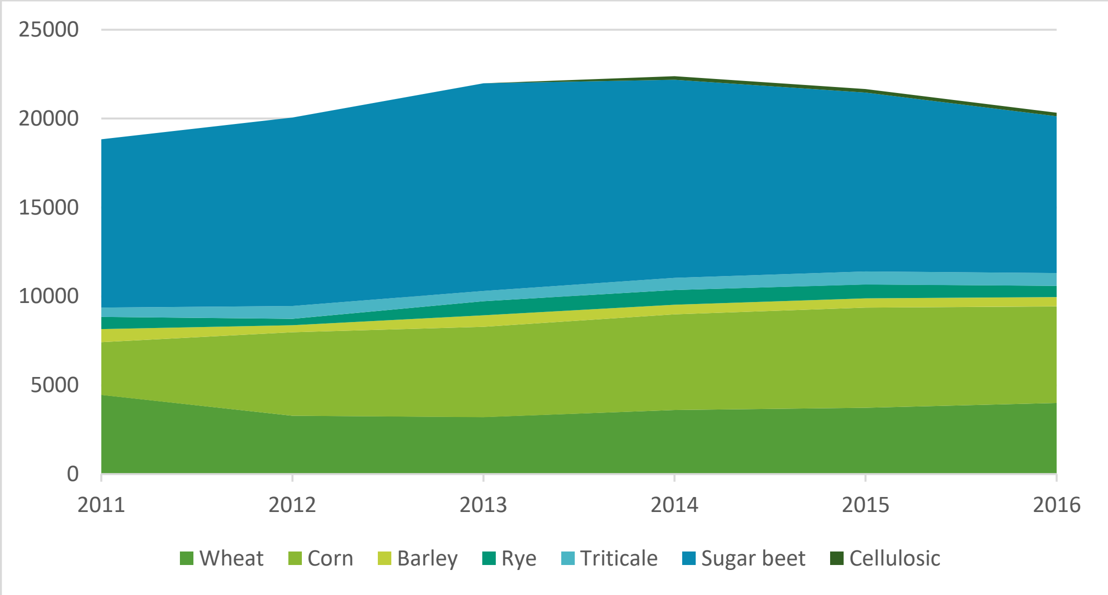

Figure 44 – Ethanol production in the EU28 (Flach et al., 2017)

Ethanol production is mostly produced from sugar beet and cereal through fermentation pathways. Advanced technology using cellulosic feedstock and enzymatic production pathways does not even represent 1% of the Biogasoline production.

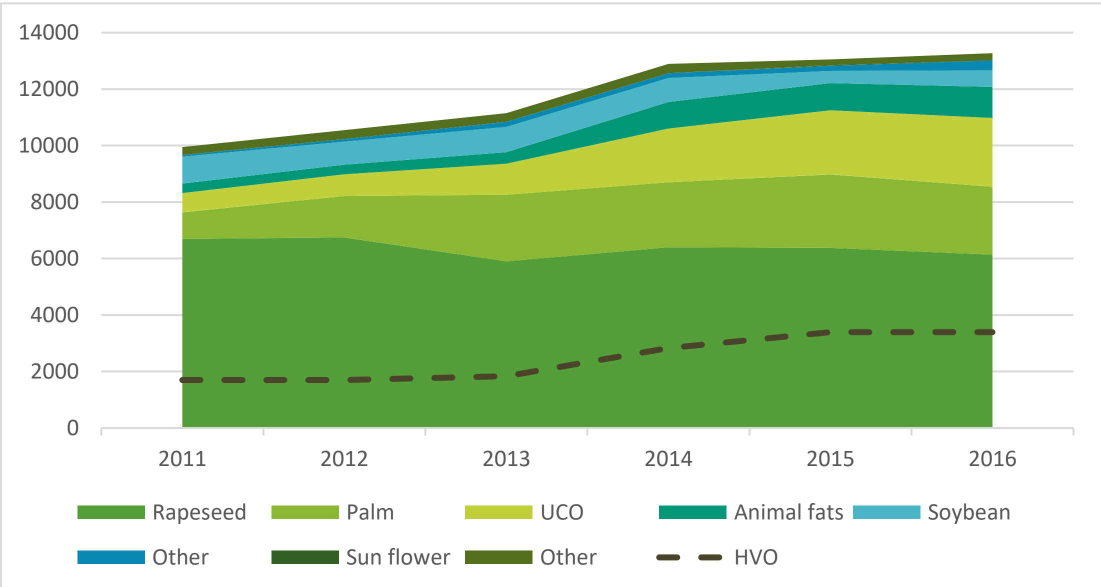

Figure 45 – Biodiesel production in the EU28 (Flach et al., 2017)

Biodiesel feedstock mix is also mostly composed of food crop-based materials. Nevertheless, a significant share of feedstock does not compete directly with food, namely animal fats and UCO (used cooking oil). Biodiesel are mostly produced through esterification pathways, but a significant share of biodiesel is produced through HVO pathway, which is a drop-in biofuel (i.e. totally fungible in fossil-based diesel).

Solid biomass: The production of solid bioenergy is less heterogenous than the other energy types across the EU member states as shown by figure 46.

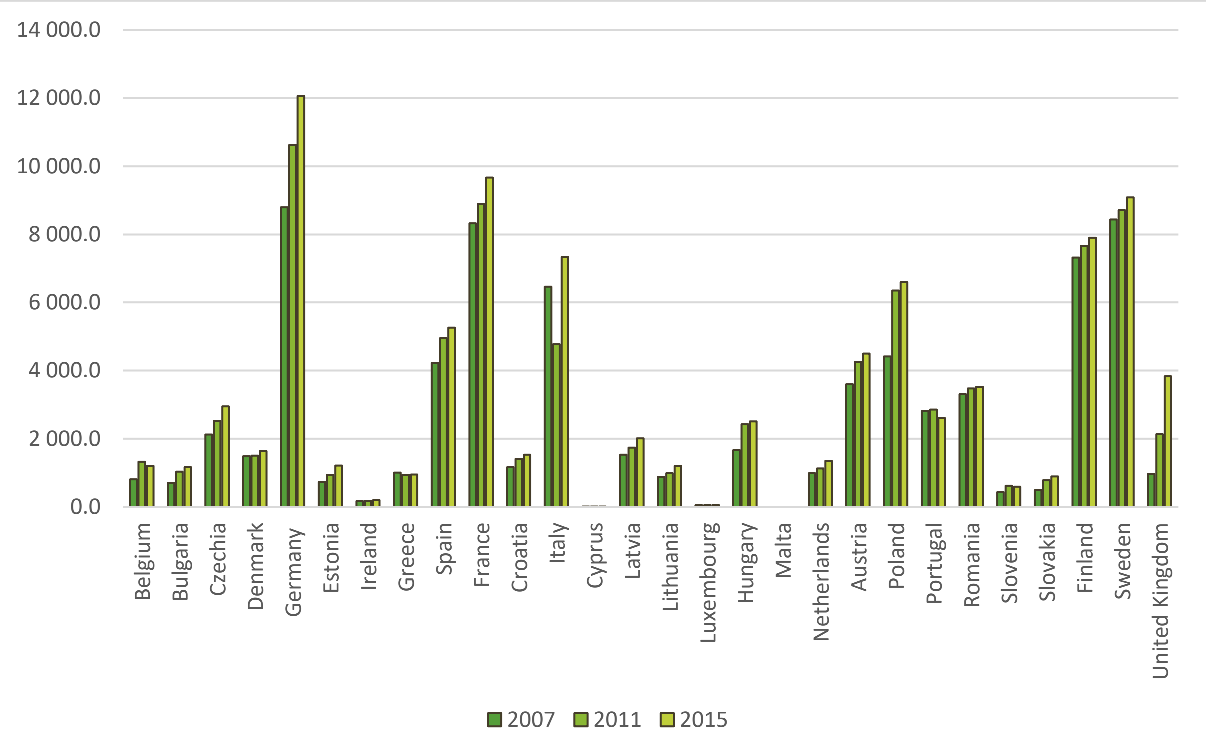

Figure 46 – Solid bioenergy production in the EU28[59]

According to the FAO[60], the woody biomass use as bioenergy is composed of wood fuel, chips, residues and pellets. The European member states present a common increasing trend for solid bioenergy production for the most part. Solid biomass mainly includes wood fuel, pellets, chips and other wood aggregates.

Lever setting – Ambition levels

It is widely acknowledged that policy and subsidies schemes are driving the biomass towards the different markets. Thus, we considered the waste hierarchy framework as a strong policy driver to drive the byproducts and residues towards the different markets and thus uses.

Technical issues: Table 31 present how can the feedstock be used from a technical perspective. Focusing on the animal slaughter industry, main of the byproducts are considered through their processed form, for example through animal meals or animal transformed protein, fatty acids, etc. The category 'Other' usually includes food, pet-food, oleochemical and pharmaceutical industries.

[59] EUROSTAT: Primary production - all products - annual data (dataset: nrg_109a), Direct link: *https://ec.europa.eu/eurostat/data/database*
[60] FAOSTAT, Forestry production & trade direct link: *http://www.fao.org/faostat/en/#data/FO*

Table 31 – Technical possible uses for alcoholic beverage industry byproducts (Réséda et al., 2017)

Uses	Other	Animal feed	Biogas	Fertilizer	Ethanol	Biodiesel	Combustion
Alcoholic beverages industry							
Hierarchy	*Prevent*		*Recycling*		*Recovery*		
Marc	x		x	x	x		x
Lees	x		x	x	x		x
DDGS		x					x
Yeast		x			x		x
Pulps	x	x	x	x	x		x
Animal slaughter industry							
Hierarchy	*Prevent*		*Recycling*		*Recovery*		
Fats	x	x	x	x		x	x
Offals	x	x	x	x			x
Blood	x	x	x	x			x
Bones	x	x	x	x			x
Leather	x	x	x				x
Other residues and byproducts							
Hierarchy	*Prevent*		*Recycling*		*Recovery*		
Agricultural residues	x	x	x	x	x	x	x
Forestry residues	x				(x)*	x	x
Wood wastes	x					x	x
Wood fuel	x					x	x
UCO	x	x				x	

*forestry residues for ethanol is technically possible but less efficient due to important lignin ratio.

Feedstock use: the feedstock availability for recovery and recycling uses depends on le lever settings. Table 32 presents how the biomass-use hierarchy lever is driving the feedstock towards different technology.

Table 32 – Biomass-use in the different ambition level settings

Feedstock group	Technology	Level A	Level B	Level C	Level D
Imports	Conventional	x			
Food-crops		x	x		
Energy-crops			x	x	
Residues & byproducts	Advanced	x	x	x	x

As previously mentioned, we consider that the biomass availability and hierarchy framework send a strong economic signal that (waste hierarchy, subsidies schemes) is driving the associated technology deployment. For example, driving the cellulosic biomass towards liquid biofuel will enable cellulosic based technology to be deployed. Through this lever, one can explore the impacts of enabling or disabling the use of imports, energy-crops and food-crops.

As energy production is considered as a 'recovery', we consider no hierarchy among the bioenergy types. The modelling framework only computes the total feedstock demand. For level D setting, one may design pathways in which residues and byproducts are not produced enough to supply the bioenergy demand. In such case, a warning informs the user of the pathway inconsistency.

Lever setting – Disaggregation method

The setting is common to all the countries.

4.1.3.Outputs towards the other modules

The Section is detailing the scope of the agriculture module outputs and how they are considered in the overall modelling framework.

4.1.3.1.Synthetic fertilizer demand

Given the demand for crops to supply bioenergy, biosourced materials, food and animal feed products, the agriculture module is computing the demand for fertilizer. Fertilizers can be supply through 4 main sources: (1) synthetic nitrogen; (2) manure application; (3) symbiotic fixation through crop rotation;(4) digestate application (Poux and Aubert, 2018). The extent of each fertilizer contribution relies on the actual deployment of climate-smart practices, either intensive or extensive. The synthetic fertilizer demand is supplying the mineral fertilizer industry (i.e. included in the industry module), expressed in metric tons.

Table 33 – Nitrogen balance in the EU28

Nitrogen source	EUCalc module	Main drivers in EUCalc
Synthetic fertilizers	Output - Industry	Intensive agriculture practices
Manure	Internal variable	Livestock population, agriculture practices
Symbiotic fixation	Internal variable	Extensive agriculture practices
Atmospheric position	Internal variable	Grassland management
Others	Not modelled	/

Such as the other industrial products, the industry module is computing the resources requirement to supply synthetic fertilizers, while considering a set of production pathways – lever dependant – that will drive a demand for gas, biogas and hydrogen.

4.1.3.2.Land-use, land-use change and forestry module

Given the demand for bioenergy, biosourced materials, food and animal feed products, the agriculture module is computing the demand for agriculture lands, including cropland and grassland. The cropland demand is driven by the demand for food, feed, bioenergy and biosourced material. The demand for grassland depends on the ruminant livestock population. The extent of the cropland and grassland demand, expressed in ha (hectare) thus rely on the other modules demand for biomass and food, and on the choice for agriculture practices (lever dependent).

Table 34 – Land demand from the agriculture module

Land	EUCalc module	Main drivers in EUCalc
Grassland	Output for LULUCF	Diets, climate smart livestock, livestock population
Cropland…	Output for LULUCF	Diets, biomass demand
…dedicated to human food	Output for the TPE	Diets
…dedicated to livestock feed	Output for the TPE	Diets, Livestock production practices
…dedicated to bioenergy	Output for the TPE	Biomass demand (transport, building, industry, lifestyle)
…dedicated to non-food	Output for the TPE	Alcohol beverages demand, biomass demand (industry)

Beyond the land demand, the agriculture module also computes the demand for wood expressed in roundwood equivalent in million cubic meter (Mm3). The wood demand is coming from the solid biomass demand. The scope of the LULUCF module is further detailed in the next sections.

4.1.3.3. Energy module

Given the demand for agricultural commodities, the module is computing the demand for energy by carrier, expressed in TWh.

Table 35 – Energy demand from agriculture

Energy carrier	Main drivers in EUCalc
Diesel	Agriculture practice, net-import, food/biomass demand
Gasoline	Agriculture practice, net-import, food/biomass demand
Natural gas (including LNG, LPG)	Agriculture practice, net-import, food/biomass demand
Fuel oil	Agriculture practice, net-import, food/biomass demand
Coal	Agriculture practice, net-import, food/biomass demand
Electricity	Agriculture practice, net-import, food/biomass demand
Total	Agriculture practice, net-import, food/biomass demand

The sectoral energy demand is added up in the electricity & oil refinery module, which enables the modelling framework to compute the energy and power unit capacity as well as the GHG emissions from energy consumption.

Such as the other sectoral energy demand, the electricity & oil refinery module is adding up the energy demands and computes the resources requirement. The electricity mix is lever dependant, which set the power unit capacity. Given the balancing and typical electricity consumption patterns, the electricity carbon footprint can be computed and allocated to each of the sector respectively.

Through the climate smart agriculture practice, the supply of biogas may exceed the demand that is triggered through the other modules, namely building, industry, and transport. It is thus assumed that this extra biogas is used by the energy supply module for an upgrade and injection in the gas network. Similarly, climate smart forestry lever set the harvest rate that is enabling us to use extra harvested wood – when the supply exceeds the demand – as biomass-based electricity feedstock or exports.

4.1.3.4. Water management

The water management module requires activity data to assess the water demand associated with the crop and livestock-based production. Using water intensity factors, and given the global temperature, the water module is computing the irrigation needs for the production of crops, livestock and biomass.

Table 36 – Activity data sent to the water module

Activity data	Production	Unit	Main drivers in EUCalc
Livestock population	Bovine	lsu	Agriculture practice, net-import, food/biomass demand
	Pig	lsu	Agriculture practice, net-import, food/biomass demand
	Poultry	lsu	Agriculture practice, net-import, food/biomass demand
	Sheep	lsu	Agriculture practice, net-import, food/biomass demand
	Hens	lsu	Agriculture practice, net-import, food/biomass demand
	Milk	lsu	Agriculture practice, net-import, food/biomass demand
	Other animals	lsu	Agriculture practice, net-import, food/biomass demand
Crops	Cereal	kcal	Agriculture practice, net-import, food/biomass demand
	Oil crop	kcal	Agriculture practice, net-import, food/biomass demand
	Pulses	kcal	Agriculture practice, net-import, food/biomass demand
	Starchy roots	kcal	Agriculture practice, net-import, food/biomass demand
	Sugar crops	kcal	Agriculture practice, net-import, food/biomass demand
	Fruits	kcal	Agriculture practice, net-import, food/biomass demand
	Vegetables	kcal	Agriculture practice, net-import, food/biomass demand
	Energy crops	t	Biomass-use hierarchy, bioenergy demand, resource availability, alternative protein sources
	Cellulosic energy crops	t	Biomass-use hierarchy, bioenergy demand, resource availability, alternative protein sources
Other	Insect biomass	t	Alternative protein sources, livestock population
	Algae biomass	t	Alternative protein sources, livestock population

4.1.3.5. Employment

Such as the water module, the employment module requires the activity data stemming from the agriculture module.

Table 37 – Activity data sent to the employment module

Energy carrier	TWh	Unit	Main drivers in EUCalc (not exhaustive)
Energy demand	Diesel	TWh	Agricultural practices, food, biomass demand
	Gasoline	TWh	Agricultural practices, food, biomass demand
	Natural gas	TWh	Agricultural practices, food, biomass demand
	Fuel oil	TWh	Agricultural practices, food, biomass demand
	Coal	TWh	Agricultural practices, food, biomass demand
	Electricity	TWh	Agricultural practices, food, biomass demand
Bioenergy supply	Liquid bioenergy	TWh	Bioenergy demand (transport, industry, building)
	Solid bioenergy	TWh	Bioenergy demand (transport, industry, building)
	Biogas	TWh	Bioenergy demand (transport, industry, building)
Fertilizer	Crop based	t	Agricultural practices, food, biomass demand
	Animal based	t	Agricultural practices, food, biomass demand
	Mineral based	t	Agricultural practices, food, biomass demand
Feed production	Processed crop based	kcal	Practices, alternative protein, food demand
	Unprocessed crop based	kcal	Practices, alternative protein, food demand
	Processed animal based	kcal	Practices, alternative protein, food demand
	Unprocessed animal based	kcal	Practices, alternative protein, food demand
Net-import balance	Processed crop based	%	Self-sufficiency, alternative protein, food demand
	Unprocessed crop based	%	Self-sufficiency, alternative protein, food demand
	Processed animal based	%	Self-sufficiency, alternative protein, food demand
	Unprocessed animal based	%	Self-sufficiency, alternative protein, food demand

The employment module uses inputs from the sectoral modules (e.g. Lifestyles, Buildings, Transport, Industry, Agriculture, Electricity) to reproduce the scenario defined by the user but through a macroeconomic model, in order to compute the employment impacts per economic sector and per educational attainment of workers of this scenario. Using these sectoral inputs, the modelling framework indicators of transition are computed to compare against a reference scenario simulated using the Computable General Equilibrium model GEMINI-E3. The indicators of transition are used to shock the reference scenario and reproduce the scenario defined by the user to deliver the employment impacts.

4.1.3.6.Climate

The module is feeding the climate module with the non-CO_2 GHG emissions. The climate module is computing the CO_2 emission equivalent from CH_4 and N_2O.

4.1.3.7.Transition Pathway Explorer (TPE)

The Pathway Explorer enables the user to display the modelling framework output, which consists in the following regarding the agriculture module:

Direct GHG emission: As shown by Table 38, the agriculture module provides the direct GHG emissions per activity and by gas type, including CH_4, N_2O and CO_2.

Table 38 – TPE, direct GHG emissions

Direct emissions		Unit
CH_4 emission	Enteric fermentation	Mt
	Rice cultivation	Mt
	Manure treatment	Mt
	Crop residues	Mt
N_2O emission	Manure treatment	Mt
	Manure applied to soil	Mt
	Manure left on pasture	Mt
	Crop residues	Mt
CO_2 emission	Energy use, diesel	Mt
	Energy use, gas	Mt
	Energy use, fuel-oil	Mt
	Energy use, gasoline	Mt
	Energy use, coal	Mt

The GHG emissions from electricity consumption is computed by the energy supply module. These additional GHG emissions are computed by the TPE interface.

Food carbon leakage (non-implemented yet): will display the embedded GHG emissions associated with the food imports, through a range from the most optimistic to the most pessimistic for the major crop and livestock food groups.

Activity data: the agriculture model is providing the activity data to the PTE, namely, the livestock population and the crop production.

Table 39 – TPE, activity data

Activity data	Production	Unit
Livestock population	Bovine	lsu
	Pig	lsu
	Poultry	lsu
	Sheep	lsu
	Hens	lsu
	Milk	lsu
	Other animals	lsu
Crops	Cereal	kcal
	Oil crop	kcal
	Pulses	kcal
	Starchy roots	kcal
	Sugar crops	kcal
	Fruits	kcal
	Vegetables	kcal
Other	Insect biomass	kcal
	Algae biomass	kcal

Crop consumption per use: the agriculture module keeps track of the crop-uses and provides the TPE with the use-split including food, feed, non-food and bioenergy uses.

Livestock feed consumption given the agriculture practices and the use of alternative protein sources; the agriculture provides the feed consumption by type.

Bioenergy feedstock mix & feedstock mix: the agriculture modules provides the TPE with the bioenergy mix and the feedstock mix of the designed pathways.

Table 40 – Bioenergy conversion pathways in the agriculture module

Type	Conversion pathway	Feedstock
Biodiesel	Esterification	vegetable oil, UCO, animal fats, algae oil, insect oil, energy crop
Biodiesel	Hydrotreated Vegetable Oil	vegetable oil, UCO, animal fats, algae oil, insect oil, energy crop
Biodiesel	Biomass To Liquid	agricultural residues, forestry-residues, energy crops
Jetfuel	Hydrotreated Vegetable Oil	vegetable oil, UCO, animal fats, algae oil, insect oil, energy crop
Jetfuel	Biomass To Liquid	agricultural residues, forestry-residues, cellulosic energy crop
Ethanol	Fermentation	sugar crop, cereal, energy crops
Ethanol	Enzymatic	agricultural residues, forestry-residues, cellulosic energy crop
Biogas	Anaerobic digestion	Manure, biowastes, energy crop
Solid bioenergy	-	agricultural residues, forestry-residues, wood fuel

4.2. Scope of the land-use module

The land-use, land-use change and forestry -LULUCF- module aims at computing the land associated impacts of the explored pathways. Such as its name indicates, it computes the land-use, land-use changes and associated GHG emissions and carbon storage in the soil.

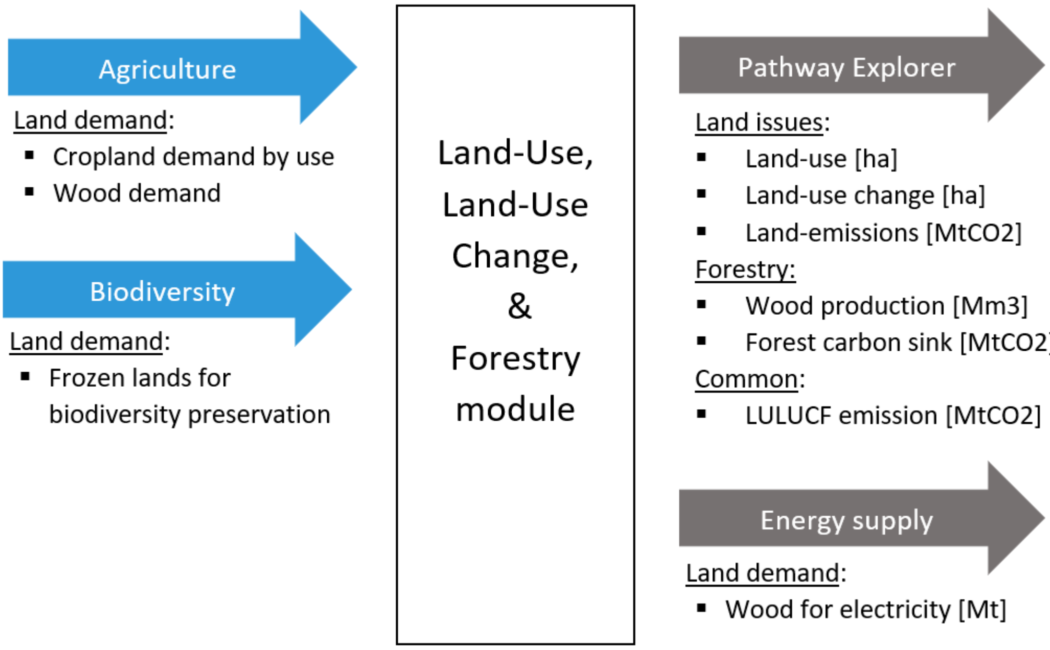

Figure 47 – Land-use, land-use change & forestry module in brief

The next sections present and detail the inputs and outputs of the LULUCF module following the structure of the agriculture module.

4.2.1.Input from the other modules

The land-use module only received direct inputs from the agriculture and biodiversity modules.

4.2.1.1.Agriculture

See Section 5.1.3.2.

4.2.1.2.Biodiversity

The biodiversity module partly set the ambition levels for conservation and preservation based on the Aichi targets framework. The twenty Aichi Biodiversity Targets are organized under five strategic goals[61]:

'Strategic Goal A: Address the underlying causes of biodiversity loss by mainstreaming biodiversity across government and society;

Strategic Goal B: Reduce the direct pressures on biodiversity and promote sustainable use;

Strategic Goal C: To improve the status of biodiversity by safeguarding ecosystems, species and genetic diversity;

[61] Aichi Biodiversity Targets - Convention on Biological Diversity;
Direct link: https://www.cbd.int/sp/targets/

Strategic Goal D: Enhance the benefits to all from biodiversity and ecosystem services;

Strategic Goal E: Enhance implementation through participatory planning, knowledge management and capacity building;'

The module is tackling biodiversity from a habitat preservation perspective, as the only quantifiable way. Concretely, the biodiversity module computes the land that needs to be frozen for biodiversity preservation, given a set ambition level, which cannot be used for another economic activity.

4.2.2. Land-use, land-use change and forestry levers

The LULUCF module includes 2 levers, one focusing on land management, and the other one focusing on forestry. The forestry lever has been developed under a climate smart approach, such as the cropping and livestock production systems levers.

4.2.2.1.Land management

Lever rationales

LULUCF is a key pillar to enable net-zero emission pathways as one cannot completely emit 0 emissions. Thanks to the natural carbon cycle, the oceans, lands and forests constitutes major natural carbon sinks that can offset CO_2 emissions and thus enabling to reach net-zero emission pathways. Figure 48 illustrates through the Sweden example, how LULUCF contributes to offset CO_2 emissions. The extent of this carbon sequestration relies on the forestry dynamics, as mentioned in the previous section, but also on the land dynamics through the soil carbon sequestration.

By definition, the soil carbon sequestration is a process in which CO_2 is removed from the atmosphere and stored in the soil carbon pool. The land cover and use are nevertheless affecting the extent of which the soil can store carbon. For instance, arable lands can store about 43tC/ha in the 0-30 cm of soil, compared with 70 for forests and grasslands in Europe[62]. Moreover, the land-use intensity will itself contribute to lower or increase the land capacity to store carbon, for example through the tree cover. Thus, the land use and cover are critical driver of the carbon natural sequestration.

[62] INRA (French national Institute for Agricultural Research), Contribution à la lutte contre l'effet de serre : stocker du carbone dans les sols agricoles de France ?, 2013 ; Direct link: http://institut.inra.fr/Missions/Eclairer-les-decisions/Expertises/Toutes-les-actualites/Stocker-du-carbone-dans-les-sols-agricoles-de-France

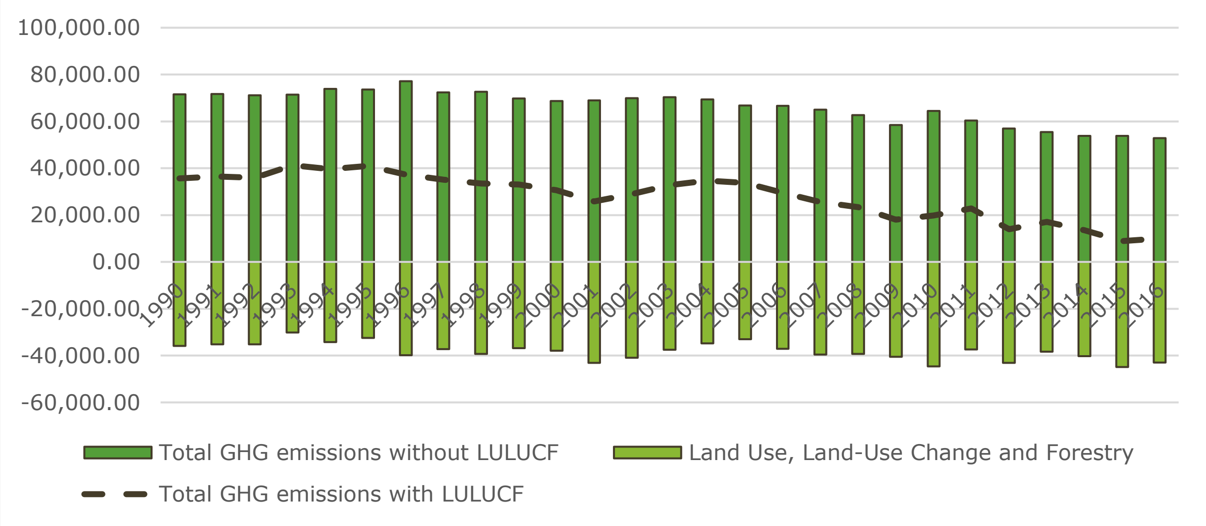

Figure 48 – Sweden GHG inventory and LULUCF balance[63]

Beyond the land use and cover, the land-use change patterns is in itself a key driver of the carbon dynamics (Figure 49):

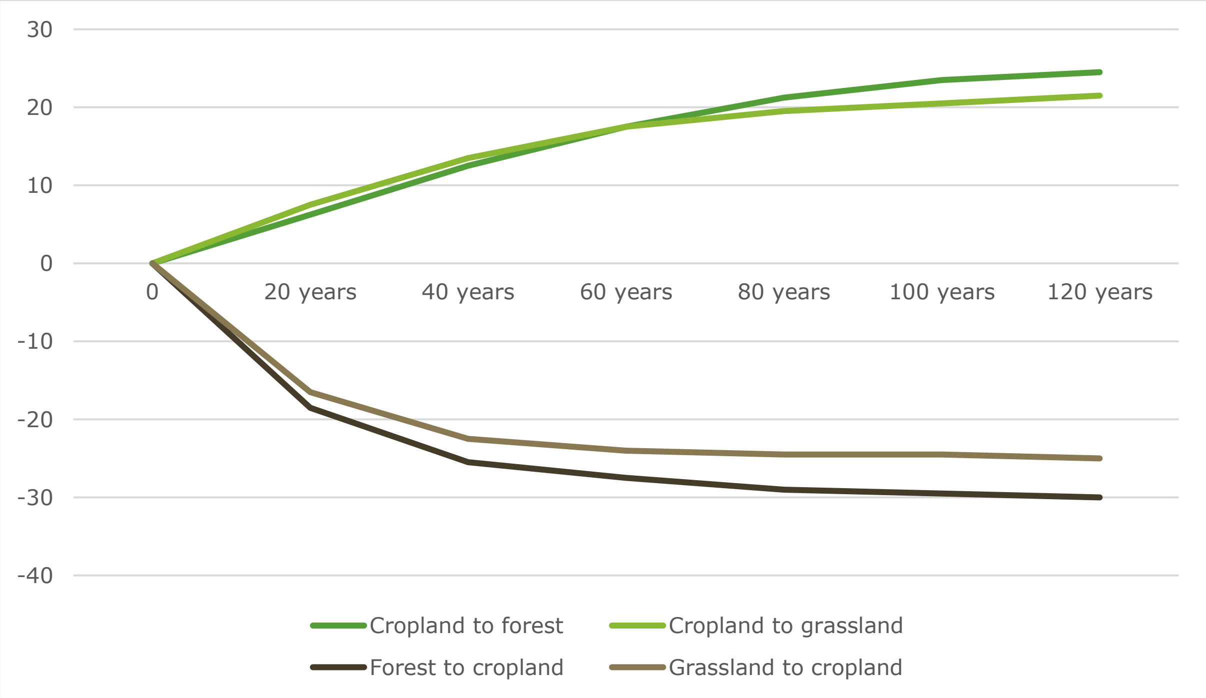

Figure 49 –Illustrative land-use change and its associated carbon-dynamics[64]

Converting a carbon sink such as forests and grassland to cropland will for example lead to net GHG emissions over the years until the new carbon balance of the soil

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[63] United Nations Framework Convention on Climate Change (UNFCCC), Greenhouse Gas Inventory Data - Detailed data by Party, Land Use, Land-Use Change and Forestry, European Union (Convention); Direct link: https://di.unfccc.int/detailed_data_by_party

[64] INRA (French national Institute for Agricultural Research), Contribution à la lutte contre l'effet de serre : stocker du carbone dans les sols agricoles de France ?, 2013 ; Direct link: http://institut.inra.fr/Missions/Eclairer-les-decisions/Expertises/Toutes-les-actualites/Stocker-du-carbone-dans-les-sols-agricoles-de-France

is reached (Figure 49, forest to cropland). At the opposite, converting croplands to forest land increase in a large extent the soil capacity to store the carbon. Thus, the way lands are allocated are critical to enable the carbon sink potential.

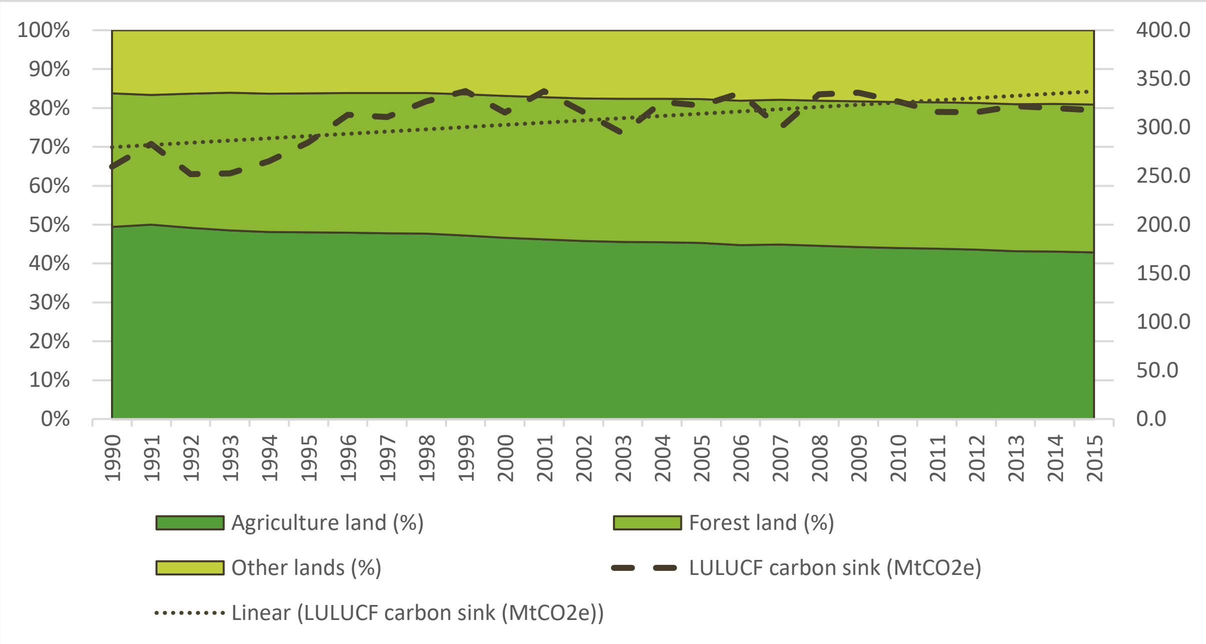

Figure 50 –Evolution of the LULUCF in the EU since 1990[65]

As shown by Figure 50, the LULUCF has been increasing over the years in the EU, partly because of the extension of forest areas that substituted former croplands. In EUCalc, the modelling framework allows one to explore of wide range of key socio-economic, environmental and technical drivers that will affect the demand for land in a large extent over the future years.

The 'land management' lever will enable the users to allocate the freed lands towards different uses and covers. At the opposite, land scarcity can be managed through 3 option: the self-sufficiency lever for food products (i.e. through the trade balance, but inducing GHG emission leakages), the biomass-use hierarchy for non-food products (i.e. enable/disable energy crops and imports, but inducing GHG emission leakages), and finally, deforestation is use as a buffer variable by default, inducing direct GHG emissions impacts, not to mention other negative sustainability impacts.

Lever description

Table 41 presents the sub-levers that will be driven by the land management lever:

[65] United Nations Framework Convention on Climate Change (UNFCCC), Greenhouse Gas Inventory Data - Detailed data by Party, Land Use, Land-Use Change and Forestry, European Union (Convention); Direct link: https://di.unfccc.int/detailed_data_by_party ; Food and Agriculture Organization (FAO), FAOSTAT, Land use; Direct link: http://www.fao.org/faostat/en/#data/RL

Table 41 – Sub-lever list included in the land-management lever

#	Sub-lever…	… in brief	Unit
1	Unmanaged land	Sets the share of freed lands that are allocated to unmanaged lands	%
2	Natural prairies	Sets the share of freed lands that are allocated to natural prairies	%
3	Forest	Sets the share of freed lands that are allocated to forest land	%
4	Settlement	Sets the settlement land share	ha
5	Wetlands	Sets the settlement land share	ha
6	Other lands	Sets the settlement land share	ha

Allocation of freed lands: the reallocation of abandoned lands is critical for land management decisions in the EU. The model includes the following settings:

- Unmanaged lands are lands that are abandoned whenever they are not used anymore. In the FAO scenarios, lands can be abandoned due to degradation. Nevertheless, the current situation shows that abandoned farmlands are already widespread in the EU, including lands that are perfectly suitable for farming, especially in central and eastern Europe[66].
- Natural prairies are prairies that are mainly dedicated to biodiversity and ecosystems preservation such as water and soil quality issues. Prairies also enable to sequester carbon in the soil.
- Afforestation and reforestation can be used as a strategy to increase the carbon sink by converting abandoned croplands to forest (See the climate smart forestry section).

Other land dynamics: settlements, wetlands and other lands dynamics over the years is set through the land management lever that are still under development.

Feedback from the stakeholder consultations

The land-management lever was highly challenged by the stakeholders, as land 'surplus' were considered theoretical, even if EU already have a wide range of abandoned farmlands. Nevertheless, the technical needs of the model require to allocate land-use for freed land, and we considered best for user to set the priorities rather than adding pathways by default. As a compromise, we added an 'abandoned land' setting. Finally, stakeholders recommended to set the ambition level setting between ecosystems and economic uses of the freed lands. Nevertheless, given that the model is demand driven, adding extra production would be inconsistent with the self-sufficiency and multiple levers that drives the demands (except for forestry products). Consequently, the land management lever has been set to allocate freed lands towards forests, prairies, and unmanaged lands.

Scenarios to explore & addressed issues

- ✓ How may land allocation affect the carbon dynamics and carbon sink potential?
- ✓ How may LULUCF contribute to reach net-zero pathways?

[66] EU, Science for environment Policy, Abandoned farmland widespread in central and eastern Europe; Direct link: http://ec.europa.eu/environment/integration/research/newsalert/pdf/355na3_en.pdf

- ✓ How can self-sufficiency ratio affect the demand for land and enable reallocation of lands?
- ✓ How may the deployment of new forest affect the availability of wood and forestry residues?
- ✓ How may land demand lead to deforestation?

Lever setting – Observed data

Allocation of freed lands: Figure 51 presents the dynamics of artificial lands, cropland, grassland, and forests in Europe over the years.

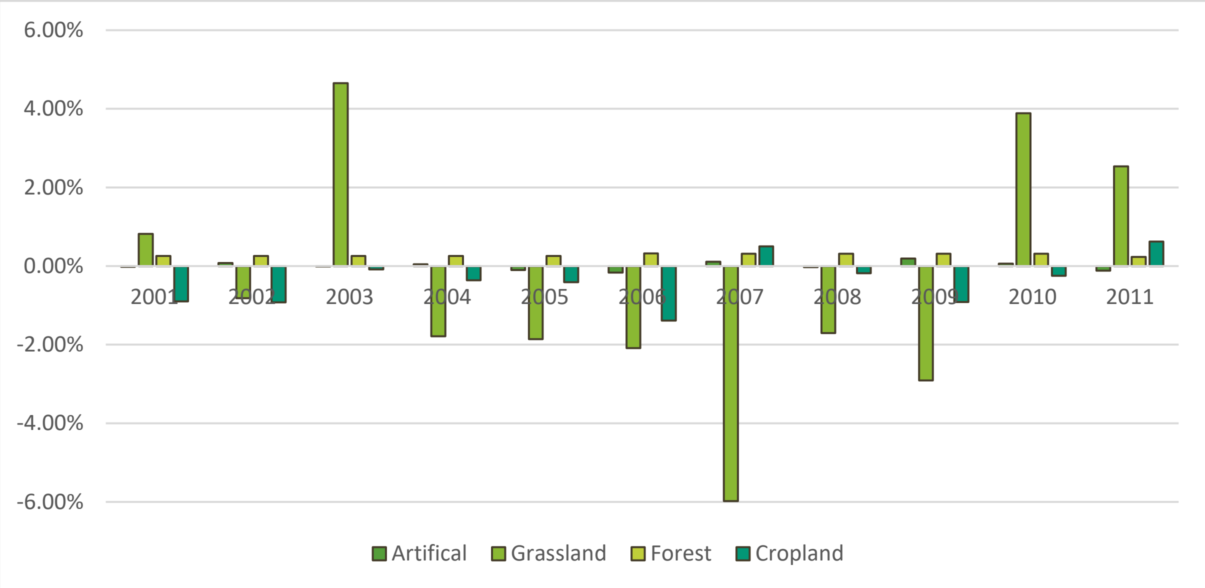

Figure 51 –Land-use change in the European Union between 2000-2011 (%)[67]

At the European scale, the agriculture land including both the grassland and cropland have been decreasing over the years. As shown by Figure 51, grassland is the land cover that is presenting the most important variation, both positively and negatively, acting like an adjustment variable. Based on FAOSTAT, the lands are mostly converted towards forests and in a much lower extent, settlements. Nevertheless, none open-access databases allow us to clearly track the land dynamics in a level of details that would enable to account for the carbon dynamics.

Lever setting – Ambition levels

The land management lever is building on the former 'land surplus' lever developed in the context of the Land-Use Futures model for Europe (Strapasson et al., 2016). The objective of the lever was to allocate uses to the freed lands. Nevertheless, the lever has been upgraded to address wider issues in terms of land management decisions. For instance, the lever management allows one to explore future in

[67] Food and Agriculture Organization (FAO), FAOSTAT, Land-Use, European Union (total); Direct link: http://www.fao.org/faostat/en/#data/RL

which lands are just left abandoned. The land management lever is set under the 1-4 level ambition scale, which means that higher levels will always higher GHG mitigation, or else limit the extent of GHG emissions (such as lands converted to settlements).

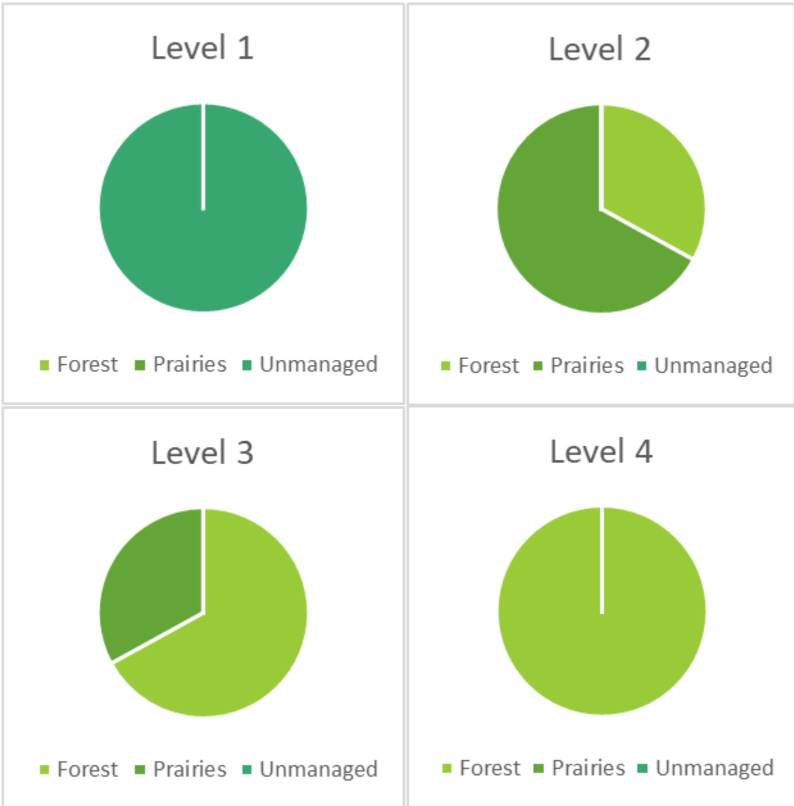

Figure 52 –Land-use allocation set by the land management lever

The lever allows one to use additional lands as forests, prairies or to remain freed lands unmanaged, which will affect the carbon sequestration potential. As shown by Figure 52:

<u>Level 1</u> assumes that all land remains unmanaged and highlights the situation in which there is neither support nor policy to enable lands to be valorised. As an example, it is estimated to reforestation costs is about 5k€ per ha.

<u>Level 2</u> assumes that priority is given to the deployment of natural prairies free of economic activity that is turned towards biodiversity and ecosystems conservation. Two third of the lands are allocated to prairies, one third to reforestation and afforestation.

<u>Level 3</u> assumes the symmetry of level 2, two third of the lands are allocated to reforestation and afforestation, and one third is allocated to deploy natural prairies.

<u>Level 4:</u> assumes that all freed lands are converted into forests, which represents the highest ambition in terms of carbon sequestration but not necessarily in terms of other sustainability issues.

Lever setting – Disaggregation method

The land management lever will be applied following the patterns presented in Figure 52 regardless to the country concerning the allocation of the freed lands.

4.2.2.2. Climate smart forestry

[not fully implemented in the KNIME framework yet]

Lever rationales

According to the UNFCCC inventory[68], forests enabled capturing 419 $MtCO_2e$ in 2016 in the EU 28+1, which represents almost 8% of the GHG emissions (Figure 53).

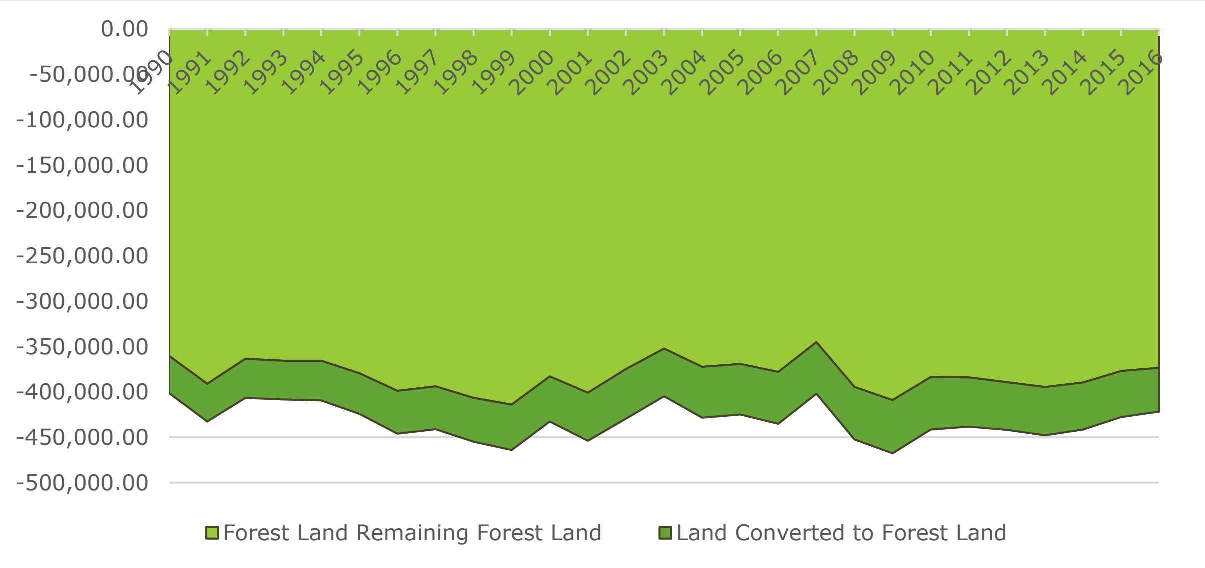

Figure 53 – GHG emissions stored by Forests in the EU since 1990 (%)

According to the European forest institute, the forest carbon pool consists of the carbon stored in the soil (54.1%), in the biomass above ground (28.5%), in the litter (9%), in the biomass below ground (7.1%), and in dead wood (1.2%). It is worth mentioning that although deadwood does not represent a large carbon sequestration pool, it is pillar of the forest ecosystems as an important substrate for a large number of forest species, both fauna and flora, and it contributes to the structural stability and the retention of organic matter, carbon, nitrogen and water.

According to the (EC, 2018), the forest carbon sink results from an imbalance in a dynamic forest system, which in turn represents the net absorptions of CO_2 from the atmosphere in above-ground biomass. In other words, the forest biomass growth (gross annual increment, reforestation, afforestation) is larger than the quantity of biomass which is taken (i.e. natural mortality, disturbances, harvesting, and other human activities). The extent of the carbon sink depends on

[68] United Nations Framework Convention on Climate Change (UNFCCC), Greenhouse Gas Inventory Data - Detailed data by Party, Land Use, Land-Use Change and Forestry, European Union (Convention);
Direct link: *https://di.unfccc.int/detailed_data_by_party* ;

this imbalance which results from the forest management practices, as well as the afforestation, reforestation and deforestation. The later are tackled through the land-management lever detailed in the previous section. Consequently, the present lever will focus on the forest management practices.

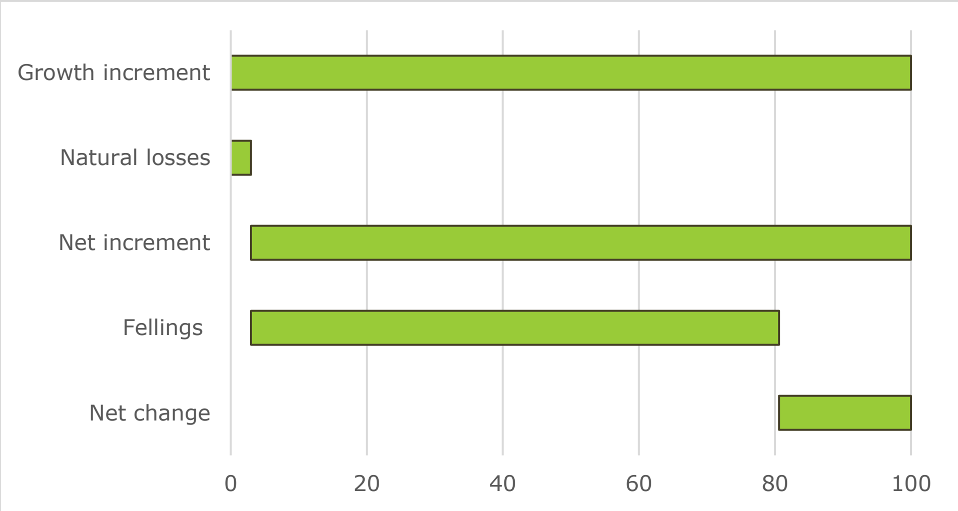

Figure 54 – Illustration of the forest system (EFI & FAO, 2015)

Through the deployment of Climate Smart Forestry (CSF) management practices (Nabuurs et al., 2017), the imbalance of the dynamic forest system (Figure 54) can be enhanced to sequester more carbon, by limiting natural losses through more resilient forests; by increasing the biomass stock growth increment through the implementation of faster growing species; by maximizing the use of the sustainably available harvested wood products; By extending the forest areas, and the biomass density in the forests.

Lever description

Following the approach developed for the agriculture sector through livestock and cropping production systems, the forestry module will follow a "Climate Smart" approach. According to the FAO (2018) and to (Nabuurs et al., 2017), CSF can be understand as:

> *"a more climate-oriented approach compared to the Sustainable Forest Management paradigm. CSF should not be understood as a concept which seeks to replace the sustainable forest management concept, but rather as a more targeted approach or strategy to increase the climate benefits from forests and the forest sector in a way that creates synergies with other needs related to forests. CSF considers the whole value chain from forest to wood products and energy and illustrates that a wide range of measures can be applied to integrating climate objectives into the forest and forest sector framework. CSF is more than just storing carbon in forest ecosystems; it builds upon three main objectives, including (1)*

reducing and/or removing greenhouse gas emissions; (2) adapting and building forest resilience to climate change; and (3) sustainably increasing forest productivity and incomes. These three CSF objectives can be achieved by tailoring policy measures and actions to regional circumstances in Member States forest sectors".

The following Table presents the forest management practices that will be driven by the climate smart forestry lever. The latter have been identified based on (Nabuurs et al., 2017).

Table 42 – Sub-lever list included in the CSF lever (Nabuurs et al., 2017)

#	Sub-lever…	… in brief	Unit
1	Coppice	Sets the share of coppice sprouting use for forest regeneration, and how it affects the growing stock	m^3/ha
2	Enhanced productivity	Sets the surplus of level of the growing stock through enhanced productivity management	m^3/ha
3	Reduced natural disturbances	Sets the level of losses limited by the implementation of more resilient and climate adapted species	m^3/ha
4	Reserves	Sets the level of forest reserved (included in the biodiversity module)	ha
5	Harvest rate	Sets the harvest rate for the forest under CSF management	m^3/ha

According to (Calfapietra et al., 2015; Schelhaas et al., 2007), the forest carbon pool could provide an additional sequestration benefits of approximately 170 Mt CO_2/year by 2050:

<u>Full grown coppice</u>: annual afforestation and regeneration is classified by the EFI as natural, planting and/or seeding and coppice sprouting. According to Nabuurs and al. (2017), regenerate full-grown coppice forest areas with more productive and climate adapted species would enable one to unlock an additional stem wood volume growth by 1.5 m3/ha year where the measure is applicable (35Mha). Moreover, it would contribute to bioeconomy and unlock more potential for bioenergy production.

<u>Enhanced productivity:</u> forest productivity and biomass density could be developed through enhanced thinning of stands, regrowth with new species, planting of more site-adapted species, and regeneration using faster growing species. Through these measures, Nabuurs and al. (2017) estimates an additional increased of stem wood growth of about 1m^3/ha/year. Nevertheless, the authors also specify that the regeneration of old forest using more productive mixed deciduous and coniferous forests should only be done in areas with low biodiversity. Which is in line with our biodiversity lever that enables one to freeze forest areas for biodiversity conservation up to a level that complies with the Aichi targets.

<u>Harvested wood products</u>: the wood biomass can sequester carbon in the forest but also by being used as a substitute for fossil and mineral based materials and bioenergy (e.g. wood against steel and concrete in the construction sector, wood against oil and gas for power and heat, or else liquid biofuels). The following

dynamics is cross-lever and cross-module in the EUCalc modelling framework as detailed in the model inputs/outputs interfaces sections.

Reduced natural disturbances: forests natural disturbances damage forest areas, involving direct GHG emissions (e.g. fire) and hampering the growing stock dynamics (e.g. pests). Forest damaged areas represents 3.1% of the forest land in Europe (EFI & FAO, 2015). Regardless to human disturbances (0.5%), damaged areas are caused by wildlife and grazing (1.40%), insects and diseases (1.20%), storm wind and snow (0.5%), fires (0.3%) and other unspecified causes (0.2%). Forest management can improve the forest resilience and thus reduce the extent of the damaged areas. For instance, introducing more adapted species could significantly reduce fire risk. Nabuurs and al. (2017) assume that 2/3 of the damaged areas associated emissions can be avoided by increasing forest relicense (i.e. ~35 Mt CO_2 year at the European scale).

Reserves: currently cover 2% of European forests and could be further extended, leading to additional CO_2 sequestration. The reserve areas in fare driven by the biodiversity lever has mentioned previously. Nabuurs and al. (2017) assume forest reserves to increase up to 7%, corresponding to an additional 64 Mt CO_2/year sequestration. The authors also mention that NGOs would even recommend 10% of set aside forests. Reserves will affect the FAWS in the model, i.e. the Forest Available for Wood Supply.

Harvest rate: represent the ratio between the net increment and the fellings expressed in m^3/ha in the forest available for wood supply.

Feedback from the stakeholder consultations

Given the feedbacks for climate smart agriculture, we applied a common pattern to set the 'climate smart forestry' lever, formerly the forest management lever. The first approach was – such as agriculture – to provide a wide range of lever to enable users to explore how forest management practices (e.g. harvest rate, harvest patterns) affect the forest carbon pool. Following the stakeholder suggestion, the unique climate smart forestry lever has been developed.

Scenarios to explore & addressed issues

- ✓ How may climate smart forestry can enhance the forestry carbon pool potential?
- ✓ How may climate smart forestry can enhance the harvested wood products for bioenergy and biosourced products? How may climate smart forestry can contribute to bioeconomy?
- ✓ How may climate smart forestry affect the growing stock patterns?

Lever setting – Observed data

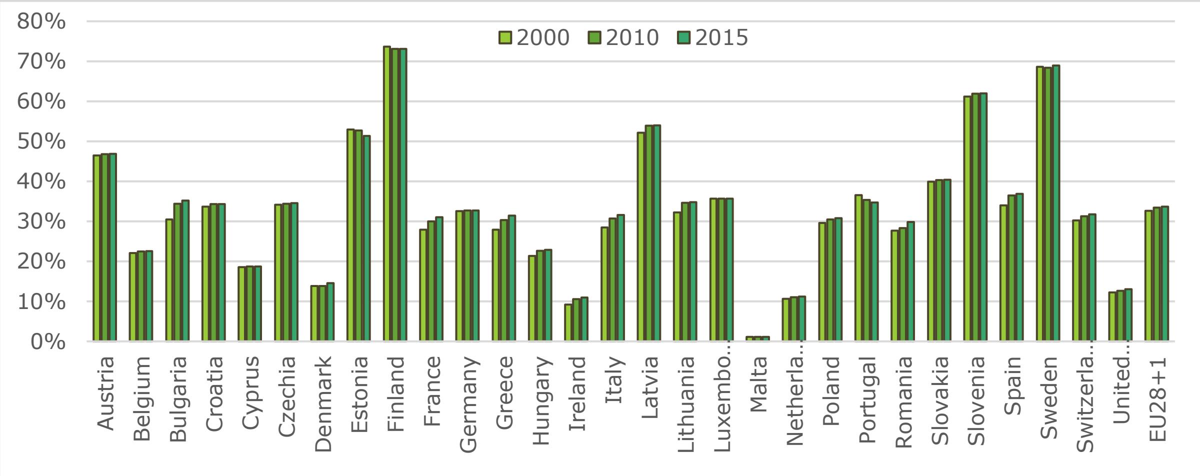

Figure 55 – GHG emissions stored by Forests in the EU since 2000 (%)[69]

As previously mentioned, forests are covering 38% of the EU 28+1 area at the overall level. Forest lands are increasing over the years for most of the European countries. As shown by Figure 55, the forest land shares in each country are highly heterogeneous, ranging from 1 to 73% for Malta and Finland respectively. In other words, the climate smart forestry lever potential impacts will widely vary from a country to another.

<u>Coppice as regeneration management</u>: Figure 56 presents the observed data for the EU28+1 in 2010 regarding the share of forest area generated through coppice sprouting.

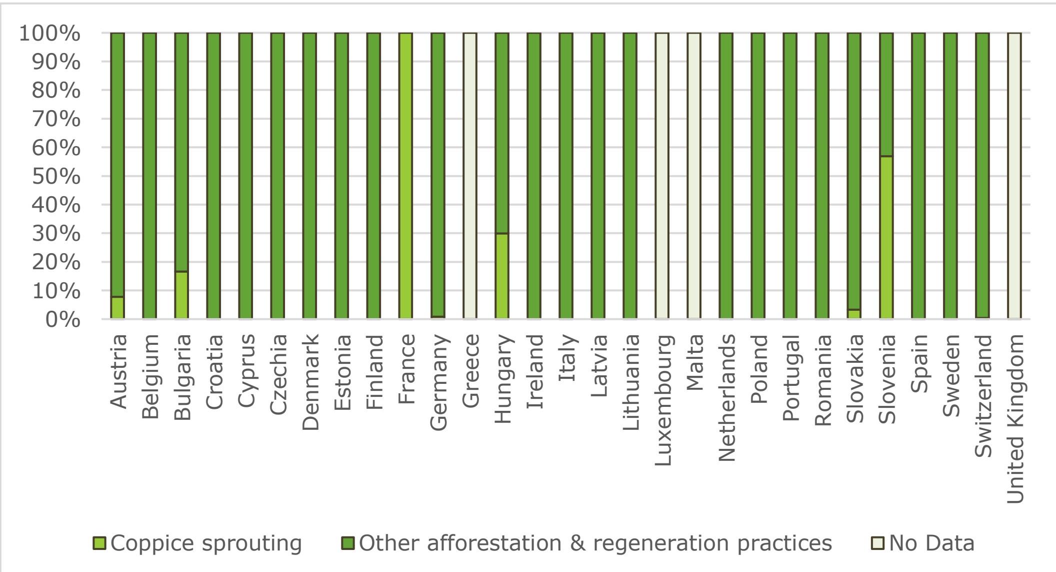

Figure 56 – Share of forest area by regeneration types in Europe, 2010 (EFI & FAO, 2015)

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69 United Nations Framework Convention on Climate Change (UNFCCC), Greenhouse Gas Inventory Data - Detailed data by Party, Forestry, European Union (Convention);
Direct link: https://di.unfccc.int/detailed_data_by_party ;

The annual afforestation and regeneration through coppice sprouting is limited and only represents 2% of the regenerated forests area in the EU28 (EFI & FAO, 2015).

Enhanced productivity: additional growth can be obtained through improved forest management practices. A higher growing stock means that higher harvesting is possible while keeping the annual fellings at the recommended 70% sustainability rate. Figure 57 presents the mean growing stock density by country in the EU28+1 in 2015.

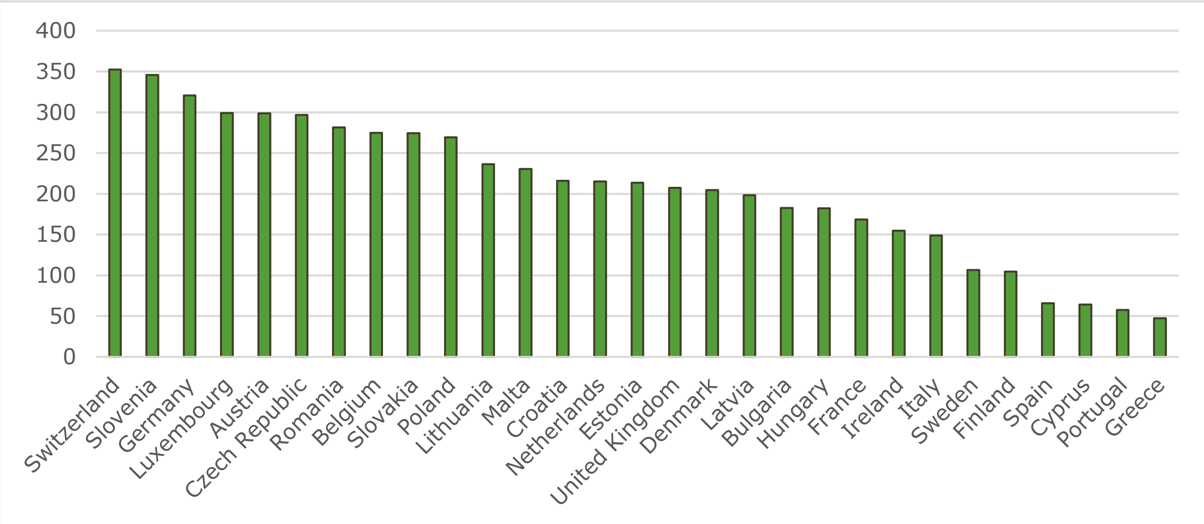

Figure 57 – Mean growing stock density by country in the EU28+1, 2015[70]

Harvest rate: At the EU28+1 level, the annual feelings rate is about 70%[71], which is the recommended to ensure the sustainable management of forests (EFI & FAO, 2015). Nevertheless, the county's contexts are highly heterogeneous, with countries exceeding the sustainable harvest rate levels, such as Austria, Belgium and Czech Republic. Some countries even exceed the net increment of biomass, leading to decrease the growth stock through negative net changes, such as Switzerland (Figure 58).

[70] European Environment Agency, Forest: growing stock, increment and fellings, 2015; Direct link: https://www.eea.europa.eu/data-and-maps/indicators/forest-growing-stock-increment-and-fellings-3/assessment

[71] European Environment Agency, Forest: growing stock, increment and fellings, 2015; Direct link: https://www.eea.europa.eu/data-and-maps/indicators/forest-growing-stock-increment-and-fellings-3/assessment

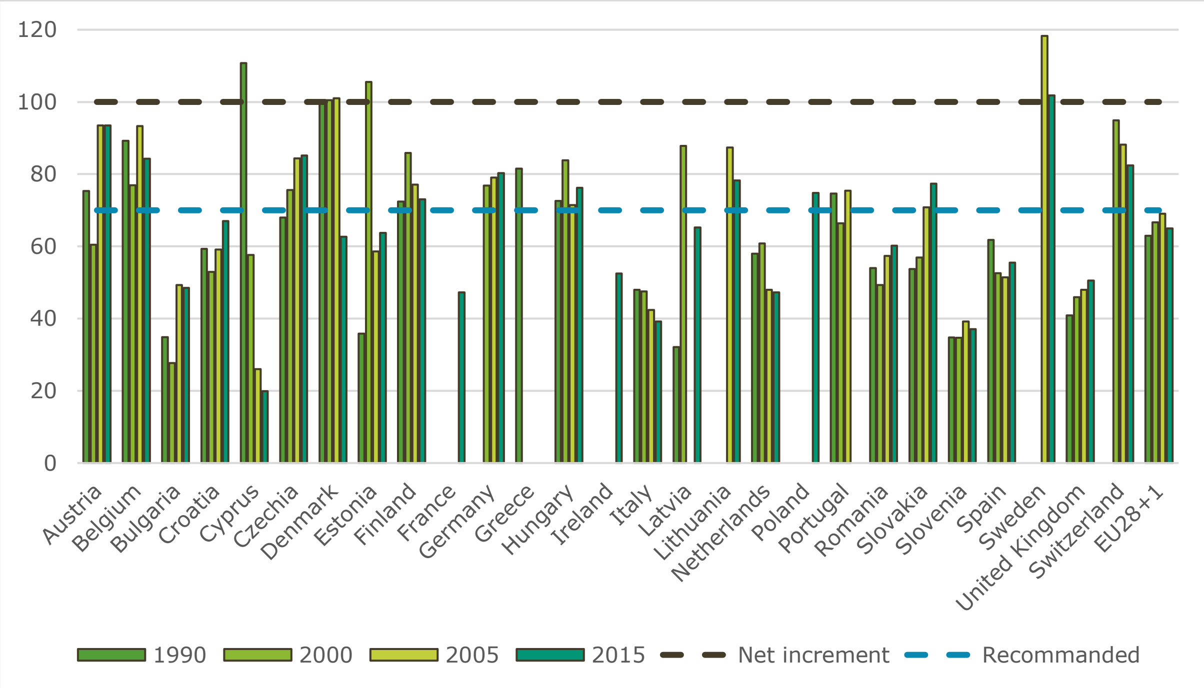

Figure 58 – Annual fellings in the EU28+1 since 1990 *(EFI & FAO, 2015)*

<u>Production from the forestry sector:</u> wood production is shared between wood fuel, and industrial wood, including both saw logs and wood pulp. The European forestry sector's production has been increasing since 1990 (Figure 59).

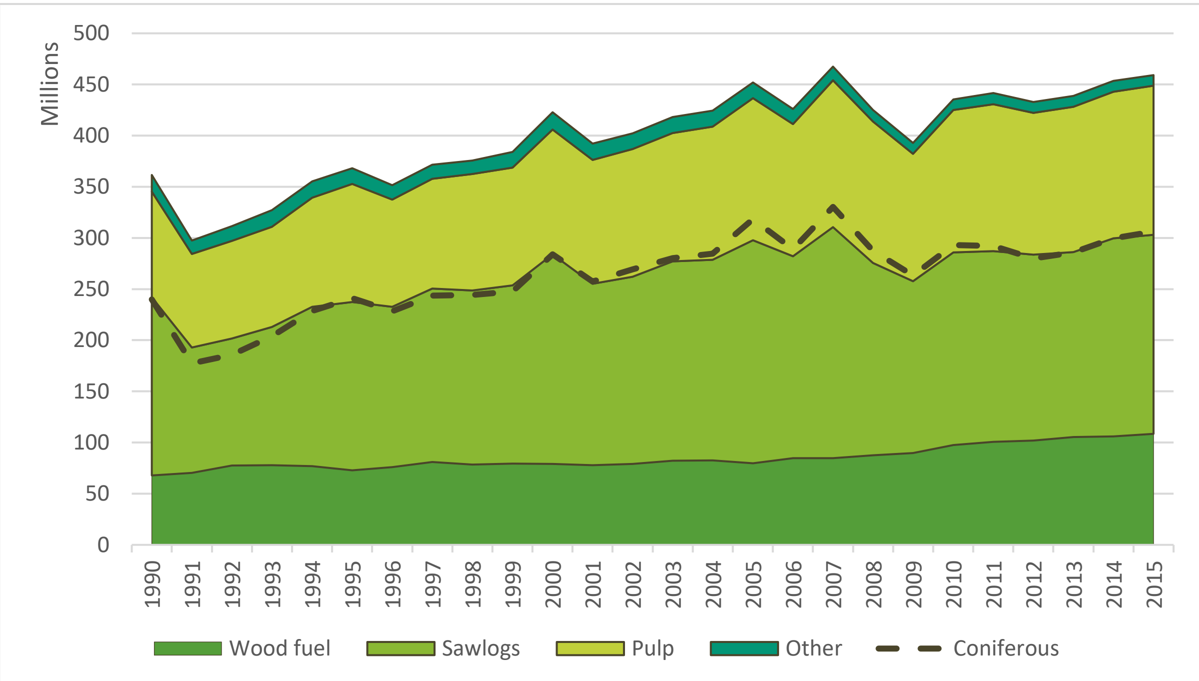

Figure 59 –Wood production in EU since 1990 (Mm^3)[72]

[72] FAOSTAT, Forestry Production and Trade
Direct link: http://www.fao.org/faostat/en/#data/FO

Reduced natural disturbances: Damaged forest areas are widely heterogeneous across the European countries (Figure 60).

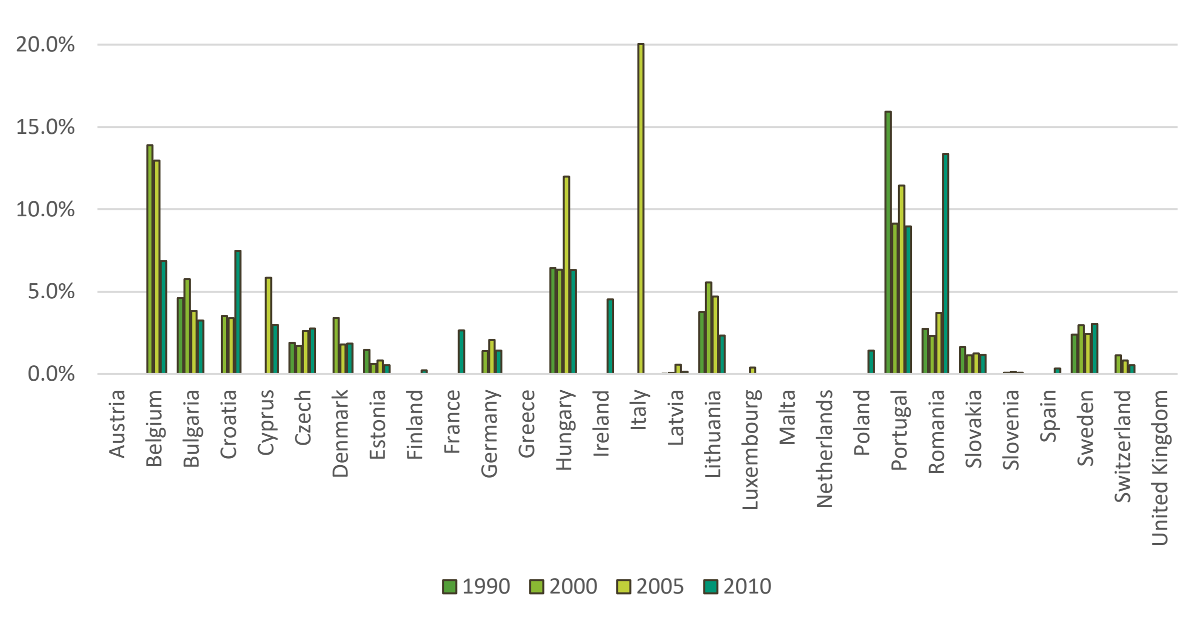

Figure 60 – Damaged forest areas in the EU28+1[73]

Beyond the extent of damaged areas, the causes are also heterogenous, shared between wildlife and grazing, insects and diseases, storm wind and snow, fires and other unspecified causes. Nevertheless, pests and diseases represent the most important loss cause.

Lever setting – Ambition levels

About 70% of the European forests are under a sustainable management plan, with an average growth of 1% per year since 1990. Considering the current trend, it would lead to have nearly 100% under a sustainable management plan by 2050.

Table 43 – Match between EUCalc and alternative future patterns for the agri-food system in Europe by 2050

Variables & parameters from...	Level 1	Level 2	Level 3	Level 4
Business as usual	x			
CSF 40% public owner only		x		
CSF baseline			x	
CSF 100%				x

The 4 ambition levels are based on the CSF scenarios as detailed bellow. The most recent data for forestry inventory is 2015, we thus assumed a linear trend between 2015 and 2020. Then, the deployment of CSF practices is assumed linear such as presented by Nabuurs and al. (2017).

Level 3: the CSF deployment pathways proposed by Nabuurs and al. (2017) is adapted and considered as the third ambition level of the EUCalc climate

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smart forestry lever. The scenario assumes that CSF can only be deployed on the EU forests own by states (40% of European forests); and another 30–35% that are in the hands of large industry or large private owners, which are assumed to respond to regulations and price incentives.

Level 1: The level 1 will follow the current trends.

Level 2: Building on the level 3 rationales, the second ambition level will consider that CSF deployment only occurs in the forest own by states, i.e. 40% of the European forests, following each country specificity thanks to the EFI database.

Level 4: Building on the level 3 rationales, the most ambition level will consider that CSF deployment occurs in all forest, whatever their ownership, which assumes very incentive forest management programmes and that all European forest will be covered by sustainable forestry management plans.

Coppice surplus (m^3/ha): Figure 61 presents the yearly biomass increment surplus according to the ambition level, and thus to the deployment of coppice sprouting in European forest.

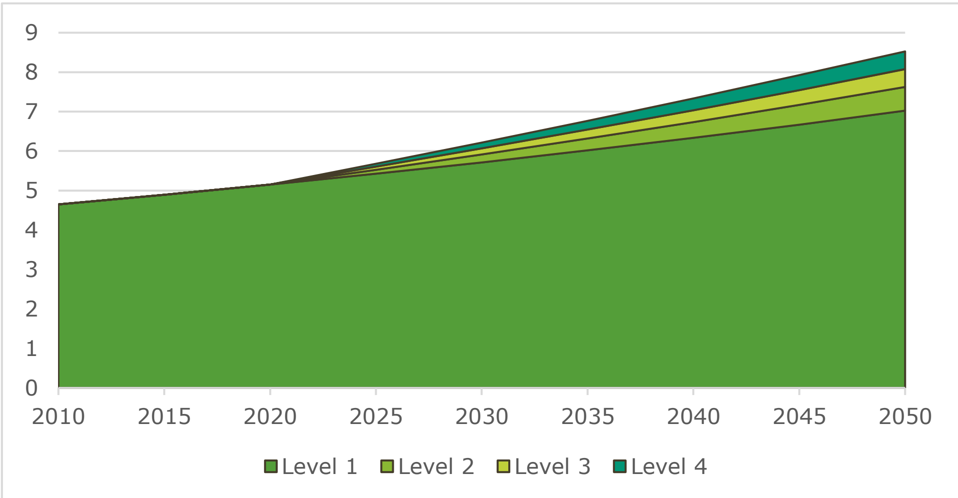

Figure 61 –Gross increment through coppice sprouting deployment (m^3/ha)

As mentioned previously and based on (Nabuurs et al., 2017), coppice sprouting enables the forest to yield up to 1.5 m^3/ha extra biomass at the European level, applied on areas under CSF practices that ranges between none to 100%.

Enhanced productivity (m^3/ha): following the same patterns, Figure 62 presents the yearly biomass increment surplus that stem from the deployment of enhanced productivity management practices in European forest.

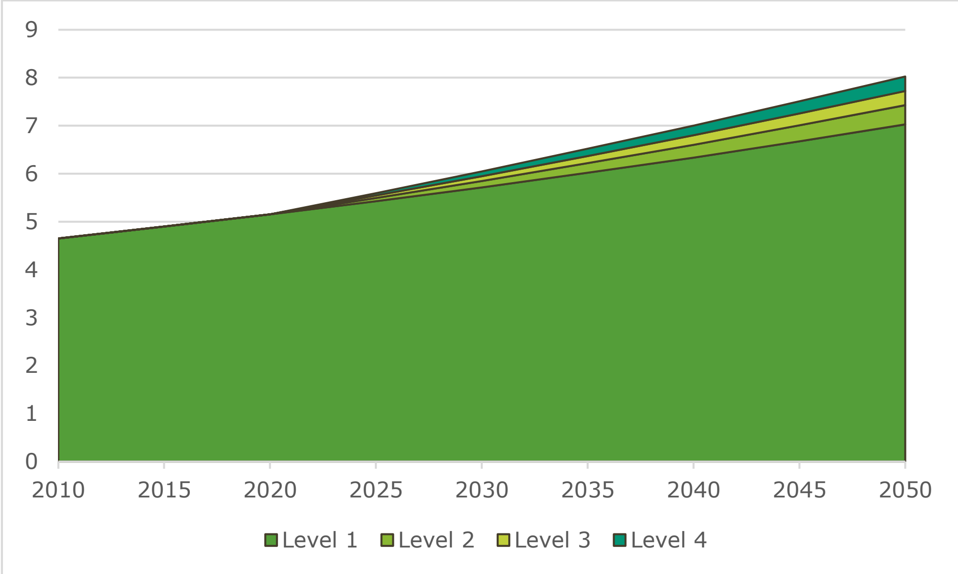

Figure 62 –Gross increment through improved management practices (m³/ha)

Following the same patterns, enhanced productivity management practices enables the European forest to yield up to 1 m³/ha extra biomass on areas under CSF practices Nabuurs et al. (2017).

Natural disturbances (m³/ha): Natural disturbances trends are currently considered constant across the years given the complexity involved with climate change / forest damaged areas patterns (3.1%/year, (EFI & FAO, 2015). Through enhanced management practices, Nabuurs et al. (2017) assumes that two third of the natural disturbances can be avoided (Figure 63).

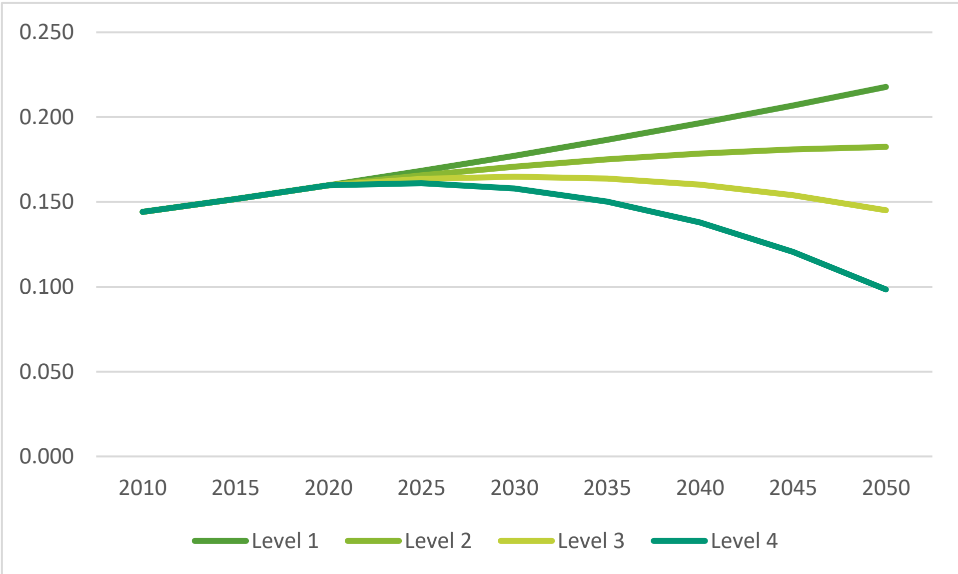

Figure 63 – Natural losses assumption through improved management practices (m³/ha)

Annual fellings (m3/ha): are assumed to converge towards 70% for forests under CSF management, and to follow the linear trends otherwise. Thus, it is assuming that some countries will reduce their harvest rate while others will increase it in order to maximize the carbon pool of the forest under the CSF patterns that is proposed in the model. The balance between demand and supply is ensured and tracked through trades.

Lever setting – Disaggregation method

The extent of the CSF management practices per county is following the patterns presented in Table 43, with respect of each country's characteristics. When data are missing for a specific country/parameter, the average regional value is used to fill the gap according to the granularity set by the EFI.

4.2.3.Outputs from the land-use module

4.2.3.1.Pathway Explorer

The land-use module provides the GHG emissions associated with LULUCF, expressed in tCO_2e (tons of CO_2 equivalent). The model aims at delivering the level of details that is included in UNFCCC inventories regarding GHG emissions from LULUCF. In terms of forestry, the model aims at delivering the level of detail that is included in the European long-term strategy.

Land-use: the model enables to track the land-use and cover that are covered by the UNFCCC inventories, namely: the cropland, grassland, forests, wetlands, settlements, and other lands:

Table 44 – Land demand

Land	Unit	Description
Grassland	ha	Total grassland cover
	ha	… under low pressure
	ha	… under medium pressure
	ha	… under high pressure
Cropland	ha	Total cropland
	ha	…dedicated to human food
	ha	…dedicated to livestock feed
	ha	…dedicated to bioenergy
	ha	…dedicated to non-food
Forest	ha	Total forest
	ha	… frozen for biodiversity conservation
	ha	… forest available for wood supply
	ha	… other forests
Settlements	ha	Total settlement areas
Wetlands	ha	Total wetland areas
Other lands	ha	Total other lands (glaciers, barren lands, etc.)

LULUCF emissions

The land module computes the GHG emissions associated with land-use and land-use change, possibly with the following level of detail, based on the UNFCCC inventories:

Table 45 – Emission associated to land

Land	Unit	Description
Grassland	$MtCO_2$	Emission associated with grassland remaining grassland
	$MtCO_2$	Emission associated with land becoming grassland
Cropland	$MtCO_2$	Emission associated with cropland remaining cropland
	$MtCO_2$	Emission associated with land becoming cropland
Forest	$MtCO_2$	Emission associated with forest remaining forest
	$MtCO_2$	Emission associated with land becoming forest
Settlements	$MtCO_2$	Emission associated with settlement remaining settlement
	$MtCO_2$	Emission associated with land becoming settlement
Wetlands	$MtCO_2$	Emission associated with wetland remaining wetlands
	$MtCO_2$	Emission associated with land becoming wetland
Other lands	$MtCO_2$	Emission associated with other lands remaining other lands
	$MtCO_2$	Emission associated with land becoming other lands
Net LULUCF	$MtCO_2$	Balance of LULUCF emissions

<u>Forestry production:</u> the activity data of the forestry module production presents the forestry products trade:

Table 46 – Emission associated to land

Item	Unit	Description
Wood fuel	Mm^3	Production of wood fuel in roundwood equivalent, stemming from bioenergy demand
Pulp wood	Mm^3	Production of pulp wood in roundwood equivalent, stemming from industry demand
Forestry residues	Mm^3	Production of forestry residues and other aggregates in roundwood equivalent, stemming from bioenergy demand
Sawlogs	Mm^3	Production of sawlogs in roundwood equivalent, stemming from industrial wood demand
Wood import	Mm^3	Trade balance of wood products, use as a buffer variable in the model
Wood export	Mm^3	Trade balance of wood products, use as a buffer variable in the model

<u>Forest carbon dynamics:</u> given the demand for wood products, the forest management practices, and the land-use and land-use change dynamics, the modelling framework is providing the forest carbon dynamics:

Table 47 – Emission associated to land

Item	Unit	Description
Harvested wood products	$MtCO_2$	CO_2 emissions stored through the use of wood products
Afforestation	$MtCO_2$	CO_2 emissions captured by the development of new forest areas
Deforestation	$MtCO_2$	CO_2 emissions stemming from the deforestation
Forest management	$MtCO_2$	CO_2 emissions captured thanks to climate smart forestry management
Item	**Unit**	**Description**
Dead wood	$MtCO_2$	CO_2 emissions stored in deadwood
Forest litter	$MtCO_2$	CO_2 emissions stored in the forest litter
Biomass increment	$MtCO_2$	CO_2 emissions captured though the forest growth
Biomass removal	$MtCO_2$	CO_2 emissions stemming from biomass removal

4.3. Detailed calculation trees

In EUCalc, the successive computation that makes the input-output model are called '*calculation tree*'. The modelling framework is developed under a KNIME environment. Each of the computation is performed simultaneously for each country and each year independently, with the exception of computation that requires stock and flows dynamics. Typically, the carbon dynamics involves inter-year computation. The following sections present the calculation tree breakdown of the agriculture and land-use modules by following the same patterns that is used in the KNIME documentation (Figure 64).

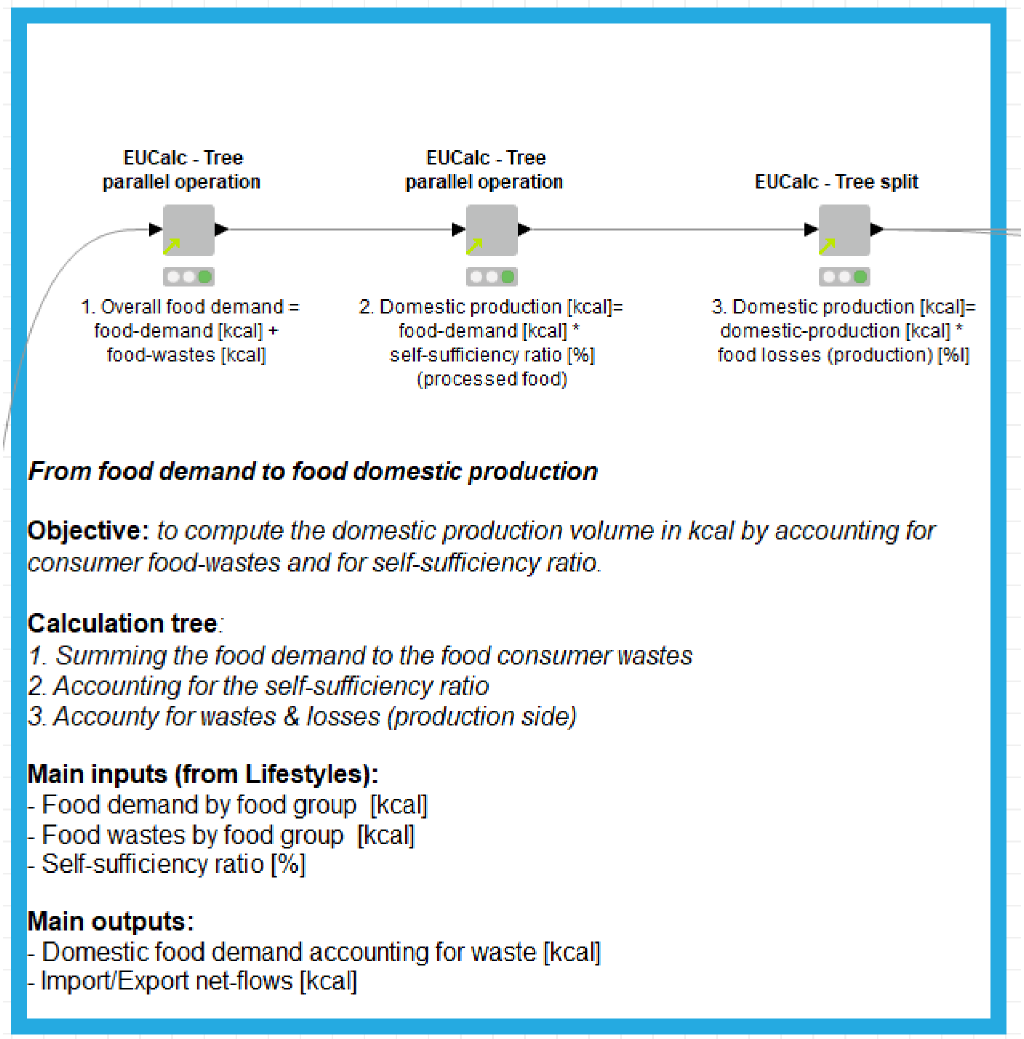

Figure 64 –Illustration of the KNIME documentation

Similarly, the present document and the KNIME documentation (Figure 64) present for each step of the calculation tree: (1) the brief objective & (2) logic of the calculation tree breakdown; (3) the variables that are computed; (4) the equation of the computation that is made; (5) the main outputs.

4.3.1.Agriculture calculation trees

4.3.1.1. From food demand to domestic production (livestock-based products)

Objective

Livestock based products requires animal feed inputs but also yields valuable byproducts that are feedstock for food, feed, bioenergy and biosourced material markets. The modelling framework first enables us to compute the domestic production for livestock-based products, including:

Table 48 – Variables computed in the module

# food group	sub-group	variables
Livestock based products	Meat	Bovine meat
		Sheep meat
		Pig meat
		Poultry meat
		Other meat
	Other animal based products	Eggs
		Milk
		Animal fats
		Offal

Food demand accounting for waste

The total food demand is computed by summing up the food demand by group (e.g. cereal, bovine meat) with the wastes and losses from the consumer and distribution stages, expressed in kcal:

Equation 1: $food\ demand\ accounting\ for\ wastes\ [kcal] = food\ demand\ [kcal] + food\ wates\ [kcal]$

Both input variables are driven by the lifestyle patterns, but the amount of wastes has to be considered individually to keep track of wastes & losses as feedstock for other uses such as used cooking oil (UCO) as biofuel feedstock.

Self-sufficiency & trade balance

Given the food demand – accounting for wastes & losses – and the self-sufficiency pattern, the modelling framework computes the domestic production for livestock-based food (lbf) groups, expressed in kcal:

Equation 2: $lbf\ domestic\ production\ [kcal] = lbf\ demand\ [kcal].self\ sufficiency\ ratio\ [\%]$

The output enables to set domestic production level and the trade balance. Self-sufficiency input depend on the food self-sufficiency lever. A self-sufficiency ratio ranging between 0 and 1 – excluding one - implies a net-import trade balance for a country. At the opposite, a self-sufficiency ratio greater than 1 involves a net-export trade balance.

Livestock based food domestic production, accounting for waste& losses

The total food domestic production is computed by multiplying the domestic production with the wastes and losses ratio from the agriculture, postharvest handling and storage, processing and packaging stages, expressed in percentage (%):

$$\text{Equation 3: } lbf\ domestic\ production\ accounting\ for\ wastes\ [kcal] = lbf\ domestic\ production\ .\ lbf\ losses\ and\ wastes\ ratio\ [\%]$$

The level of food wastes and losses of livestock-based food products is set by the climate smart livestock production system lever.

4.3.1.2. From trade balance to carbon leakages (livestock & beverages)

[not fully implemented in the KNIME framework yet]

Objective

Given the trade balance, the carbon leakages are computed to keep track of the embedded GHG emissions in the food product trades, expressed in CO_2e.

Trade balance

Given the consumption and domestic production levels, the import and export flows are computed:

$$\text{Equation 4: } lbf\ trade\ balance\ [kcal] = lbf\ consumption[kcal] - lbf\ domestic\ production[kcal]$$

An additional computation is made to rename negative values as imports and positive values as exports.

$$\text{Equation 5: } if: lbf\ trade\ balance\ [kcal] < 0\ then: lbf\ trade\ balance\ [kcal] = imports\ [kcal]$$

$$\text{if: lbf trade balance [kcal]} > 0 \text{ then: lbf trade balance [kcal]} = \text{exports [kcal]}$$

Food associated carbon leakages, livestock-based products

Exports embedded GHG emissions are computed at the very end of the calculation tree to consider the carbon footprint of the country agri-food system. Imports enables to assess the embedded GHG emissions in livestock-based products by using typical emission intensity by food product type.

$$\text{Equation 6: } embedded\ GHG\ emission\ [CO2e] = lbf\ imports[kcal].\ lbf\ emission\ intensity\ [CO2e/kcal]$$

Given that imports are not spatially explicit and considering the high uncertainty regarding the future emission factors, the potential embedded GHG emissions are provided as a range rather than a unique value, bounded by the most optimistic and pessimistic values found in the FAOSTAT data base.

Limits

Using self-sufficiency ratio, only net-trade flows are considered, which may include a bias as one can be self-sufficient while importing and exporting goods, which affects the GHG embedded emissions.

4.3.1.3. From meat domestic production to livestock population and byproducts

Objective

Given the livestock-based products demand and the set of livestock production system patterns, the modelling framework is computing the livestock population, expressed in livestock unit (lsu), for each animal type including bovines (non-dairy), sheep, pigs, poultry, other animals, dairies, laying hens. Given the livestock population being slaughtered, byproducts are being computed and expressed in kcal.

Livestock being slaughtered

The livestock yields are set through the production system patterns. The yields enable us to compute the livestock population that is slaughtered:

Equation 7: $$livestock\ being\ slaughtered\ [lsu] = lbf\ domestic\ production\ [kcal]/livestock\ yield\ [kcal/lsu]$$

Livestock population

The slaughtering age of each livestock type is set through the production system patterns, and enable us to compute the livestock population from the livestock being slaughtered:

Equation 8: $$livestock\ population\ [lsu] = livestock\ being\ slaughtered\ [lsu]/slaughter\ rate\ \ [\%]$$

Livestock-based byproducts

Given the livestock being slaughtered, the modelling framework is computing the by-production of animal fats and offal for each livestock type, expressed in kcal.

Equation 9: $$livestock\ byproducts\ [kcal] = livestock\ being\ slaughtered\ [lsu] * byproducts\ yields\ \ [kcal/lsu]$$

The animal fat and offal are used as feedstock for food, feed, fertilizer, bioenergy and other uses later on in the calculation tree.

Equation 10: $livestock\ byproducts\ for\ non-food\ uses\ [kcal] = livestock\ byproducts\ production\ [kcal] - byproducts\ food\ demand\ [kcal]$

The livestock byproducts implicitly supplies the food demand, and only the remaining share can be used for non-direct human consumption (e.g. animal based meals, biodiesel).

4.3.1.4. From livestock population to feed demand

Objective: the modelling framework is computing the feed requirement given the livestock population.

Feed requirement

The feed requirement is computed given the livestock population by type and the energy efficiency of meat and livestock-based products production (Alexander et al., 2016):

> *'The energy efficiency of meat and livestock-based products production is defined as the percentage of energy (caloric) inputs as feed effectively converted to animal product. An efficiency of 25% would mean 25% of calories in animal feed inputs were effectively converted to animal product; the remaining 75% would be lost during conversion'*

The following Figure presents the energy efficiency that are being used in the agriculture module (Alexander et al., 2016):

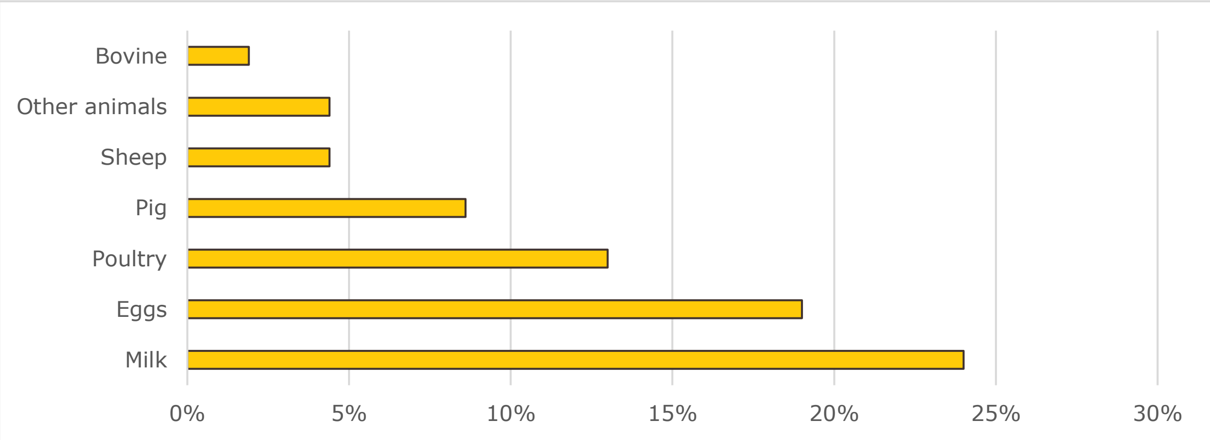

Figure 65 – Energy efficiency of meat and livestock-based products production

Equation 11: $feed\ requierment\ [kcal] = livestock\ poulation\ [lsu].\ energy\ efficiency\ ratio\ [kcal/kcal]$

The total feed requirement is then computed from the requirement for each livestock type (bovine, sheep, poultry, and so on):

Equation 12: $total\ feed\ requierment\ [kcal] = Sum\ (feed\ requierment\ by\ livestock\ type)$

The feed typical ration depends on both the livestock production system patterns (e.g. extent of the pastureland contribution), the alternative protein source deployment (e.g. share of insect-based meal) and the use of industrial based products, which are computed later on in the calculation tree.

4.3.1.5. From alcoholic beverages production to by-products supply

Objective

The modelling framework enable us to compute the demand for crops as well as the byproduct supplies from the alcoholic beverage production, and to drive the byproducts feedstock towards different uses.

Table 49 – Variables computed in the beverage's module

# food group	variables
Alcoholic beverages	Wine
	Beer
	Alcoholic beverages
	Fermented beverages
Alcoholic beverage byproducts	DDGS
	Yeast
	Lees
	Grape marc

Alcoholic beverages biorefinery

Given the domestic production of beverages, the demand for cereals (beer, fermented alcohol) and fruits (wine, distilled alcohol) is computed. The byproducts of wine and beer are also computed. Given the production small volume, the byproducts stemming from distilled and fermented alcohol are not considered.

Equation 13:

$$beverages\ byproducts\ [kcal] = beverage\ domestic\ production\ [kcal].\ byproducts\ yields\ [kcal/kcal]$$

$$crop\ demand\ [kcal] = beverage\ domestic\ production\ [kcal].\ yields\ [kcal/kcal]$$

Table 50 – Alcoholic beverages yields in kcal/kcal

Beverage	Wine	Beer	Distilled alcohol	Fermented alcohol
Cereal demand	-	94.5	-	290
Marc supply	137	-	-	-
Lees supply	20.6	-	-	-
Cereal meals	-	96.6	-	-
Yeast supply	-	21.7	-	-
Fruit demand	113.6	-	288	-

Given the lack of data at the country scale, the beverages yield data is based on the French report for the byproduct resource and availability in the agri-food industry (Réséda et al., 2017), presented in Table 50. For example, for each kilocalorie of beer produced, 0.945 kcal of cereals is required, and 0.966 kcal and 0.217 kcal of cereal meals and yeast are generated as byproducts.

Alcoholic beverages byproduct uses

Given the beverages byproducts supply, and the biomass-use hierarchy setting, the byproducts are driven towards animal feed, bioenergy, fertilizer and other-uses. Other uses mainly include pet food and oleochemical industry which are currently not taken into account, but which are still considered to avoid multiple counting issues regarding the biomass availability.

Equation 14: $beverages\ byproducts\ per\ use[kcal] = beverages\ byproducts\ [kcal].hierarchy - uses\ [\%]$

Computation are then enabling the model to keep track of byproducts uses for land-use allocation, but for formatting purposes. For instance, summing the wine and beer byproducts used as fertilizer, bioenergy and so on:

Equation 15: $beverages\ byproducts\ use\ as\ fertilizer[kcal] = Sum(byproducts\ used\ as\ fertilizer)$

4.3.1.6. *Alternative Protein Sources for livestock (APS)*

Objective

The APS computation enables us to consider the deployment of insect farming and microalgae biorefinery. Moreover, the demand for APS for feed will also drive the biomass availability for bioenergy and fertilizer through their byproducts (e.g. microalgae oil, insect manure). It is also worth mentioning that the framework has been developed to enable adding extra APS easily.

Equation 16: $APS\ meals\ demand\ [kcal] = feed\ requierment\ by\ livestock\ type\ [kcal].APS\ share\ by\ type\ and\ livestock\ type[\%]$

The microalgae and insect-based meals demands are computed by multiplying the share of APS in the total feed intake for each livestock type. It is worth mentioning that the maximum share of APS corresponds to the highest share that is considered healthy for each animal type (Madeira et al. (2017) and Makkar et al., (2014). The overall microalgae and insect-based meals demand are then summed up to enable computing the byproducts supplies:

Equation 17: $microalgae\ meals\ demand\ [kcal] = Sum(microalgae\ meals\ demands)$[74]

Equation 18.1: $Byproduct\ supplies\ [TWh, t] = microalgae\ meals\ demand\ [kcal].byproduct\ yields[TWh, t/kcal]$

Equation 19.2: $Resource\ demand\ [TWh, t] = microalgae\ meals\ demand\ [kcal].resource\ yields[TWh, t/kcal]$

The resource demand includes the microalgae biomass and insect requirement, but the specific energy and water demand remain to be implemented in Equation 18.

[74] Same computation for insect-based meals

The yields for insect farming and microalgae biorefinery are based on Baudry et al., (2018), and Wang et al., (2017).

Table 51 – APS yields in kcal/kcal

Beverage	Insect farming	Microalgae biorefinery
Animal feed meal	100	100
Biomass input	130	150
Oil	27	50
Biowastes & residues	3500	/
Bio-organic fertilizer	1700	/

4.3.1.7.From liquid bioenergy production, to crop demand

Objective

The modelling framework is computing the bioenergy technology mix, feedstock mix and the demand for crops given the bioenergy demand, while considering the availability of wastes, and industrial byproducts supplies.

Technology mix

First the technology mix is set based on the observed data for the period 1990-2015 and given the biomass-use hierarchy lever setting for the future time series. The implicit assumption here is that the biomass availability is driving the technology bioenergy mix. For example, if the lever setting does not allow food crop-based feedstock to supply the bioenergy sector, it is considered that advanced biofuels that use cellulosic feedstock will be deployed.

Equation 20: $Liquid\ bioenergy\ production\ per\ technology\ [TWh] = liquid\ bioenergy\ production\ [TWh].\ technology\ mix[\%]$

Feedstock type requirement

Given the technology mix and associated yields, the demand for biomass feedstock type is computed, including demand for vegetable oil, cellulosic feedstock, sugar plants (including cereals and sugar):

Equation 21: $Biomass\ demand[TWh] = Liquid\ bioenergy\ production\ per\ technology\ [TWh]$

$$* Technology\ yields[t, kcal/TWh]$$

Cellulosic feedstock is expressed in metric tons while food crop-based feedstock is expressed in kcal.

Vegetable oil balance

Given the vegetable oil demand and byproducts/wastes supplies, the demand/supply balance is computed:

Equation 22: $vegetable\ oil\ remaining\ demand\ [kcal] = vegetable\ oil\ demand\ [kcal] - byproducts\ supply\ [kcal]$

Depending on the biomass hierarchy setting, the supply/demand balance can be ensure either through imports or food crop based oil.

4.3.1.8. Typical livestock ration

Objective

The modelling framework is computing the livestock typical ration given the biomass hierarchy and climate smart livestock production systems. First, the grass, APS, and industrial byproducts allocated to animal feed uses are summed up. Then, the remaining feed share is computed, expressed in kcal. Finally, the remaining feed requirement is split.

Table 52 – Variables computed in the beverage's module[75]

# food group	variables
Crop-based	Cereal
	Oil crop
	Sugar crop
	Pulses
	Vegetables
	Fruits
	Starch
	Cakes
	Molasse
	Oil
Livestock-based	Animal meals
	Fish-meals
APS	Insect meals
	Algae meals

Total low-carbon feed

According to the FAO, low carbon feed includes feed crop produced through low-carbon agriculture practices, from lands that are not recently been forests or grasslands, and it includes agri-food industry byproducts.

Equation 23: $Total\ low\ carbon\ feed\ [kcal] = Sum(alternative\ feed\ supply)[kcal]$

Remaining feed demand

Given the alternative feed sources, the remaining feed demand is computed.

[75] FAO, Climate Smart Agriculture, Source Book, 2013 (http://www.fao.org/docrep/018/i3325e/i3325e.pdf, consulted the 26/12/2018)

Equation 24: $remaining\ feed\ demand\ [kcal] = total\ feed\ requierement[kcal] - \ total\ low\ carbon\ feed\ [kcal]$

Typical feed ration

The remaining feed per type is computed assuming the feed mix in each country remains relatively constant for the other feed groups.

Equation 25: $remaining\ feed\ demand\ by\ group\ [kcal] = \ remaining\ feed\ demand[kcal] * \ feed\ split\ [kcal]$

4.3.1.9.From livestock population to manure and enteric fermentation emissions

Objective

The modelling framework is computing the livestock associated GHG emissions expressed in N_2O and CH_4, coming from enteric fermentation and manure management.

Enteric fermentation emission

Enteric fermentation emissions are computed by multiplying the livestock population expressed in lsu with the enteric fermentation emission factors expressed in $MtCH_4/lsu$, specific to each livestock type.

Equation 26: $enteric\ emission\ [MtCH4] = \ livestock\ popultaion[lsu] * enteric\ fermentation\ emission\ factor\ [MtCH4/lsu]$

Manure volume

The manure volumes expressed in nitrogen content are computed by multiplying the livestock population expressed in lsu with the manure generated by each livestock type expressed in MtN/lsu.

Equation 27: $Manure\ [MtN] = livestock\ popultaion[lsu] * \ manure\ yiels\ [MtN/lsu]$

Manure management practices

The manure management per practices are computed by multiplying the manure volumes for each livestock type, with the split of manure management practices expressed in %. The manure management practices include manure treatment, manure applied to soil, and manure left on pasture.

Equation 28: $manure\ management\ per\ practices[MtN] = \ manure\ [MtN] * manure\ management\ practices\ split\ [\%]$

Manure CH_4 emission

The CH4 emission that stem from manure are computed by multiplying the manure volumes to the emission factors expressed in MtCH4/MtN, specific to each management practice.

$$\text{Equation 29: } manure\ CH4\ emission\ [MtCH4] = manure\ management\ per\ practices[MtN] * emission\ factors\ per\ practices\ [MtCH4/MtN]$$

Manure N_2O emission

The N_2O emission that stem from manure are computed by multiplying the manure volumes to the emission factors expressed in MtN_2O/MtN, specific to each management practice.

$$\text{Equation 30: } manure\ N2O\ emission\ [MtN2O] = rmanure\ management\ per\ practices[MtN] * emission\ factors\ per\ practices\ [MtN2O/MtN]$$

4.3.1.10.From processed crop-based products to crop demand

Objective

The demand for processed food and feed commodity, including vegetable oil, oil crop cakes, sugar, and sweeteners are converted in crop equivalent, expressed in kcal.

$$\text{Equation 31: } crop\ demand\ [kcal] = processed\ crop\ food\ demand[kcal] * conversion\ factors\ [kcal/kcal]$$

$$\text{Equation 32: } crop\ demand\ [kcal] = processed\ crop\ feed\ demand[kcal] * conversion\ factors\ [kcal/kcal]$$

4.3.1.11.From food demand to crop domestic production

Objective

The model is computing the summing up the crop demand for the different use and computes the crop domestic production expressed in kcal, with the exception of energy crops expressed in tons (t).

Total food crop demand

The food crop demand driven by the food, feed, bioenergy and biosourced materials is summed up, expressed in kcal.

$$\text{Equation 33: } food\ crop\ demand\ [kcal] = Sum(foodcrop\ demand\ per\ use)\ [kcal]$$

Self-sufficiency & trade balance

Given the food demand – accounting for wastes & losses – and the self-sufficiency pattern, the modelling framework computes the domestic production for crop-based food groups (cbf), expressed in kcal:

$$\text{Equation 34: } cbf\ domestic\ production\ [kcal] = cbf\ demand\ [kcal].\ self\ sufficiency\ ratio\ [\%]$$

The output enables to set domestic production level and the trade balance. Self-sufficiency input depend on the food self-sufficiency lever. A self-sufficiency ratio ranging between 0 and 1 – excluding one - implies a net-import trade balance for a country. At the opposite, a self-sufficiency ratio greater than 1 involves a net-export trade balance.

Food crop-based food domestic production, accounting for waste& losses

The total food domestic production is computed by multiplying the domestic production with the wastes and losses ratio from the agriculture, postharvest handling and storage, processing and packaging stages, expressed in percentage (%):

$$\text{Equation 35: } cbf\ domestic\ production\ accounting\ for\ wastes\ [kcal] = cbf\ domestic\ production\ .\ lbf\ losses\ and\ wastes\ ratio\ [\%]$$

The level of food wastes and losses of livestock-based food products is set by the climate smart cropping production system lever.

4.3.1.12.From trade balance to carbon leakages (crops)

[not fully implemented in the KNIME framework yet]

Objective

Given the trade balance, the carbon leakages are computed to keep track of the embedded GHG emissions in the food product trades, expressed in CO2e.

Trade balance

Given the consumption and domestic production levels, the import and export flows are computed:

$$\text{Equation 36: } cbf\ trade\ balance\ [kcal] = cbf\ consumption[kcal] - cbf\ domestic\ production[kcal]$$

An additional computation is made to rename negative values as imports and positive values as exports.

$$\text{Equation 37: } if: cbf\ trade\ balance\ [kcal] < 0\ then: cbf\ trade\ balance\ [kcal] = imports\ [kcal]$$

$$\text{if: cbf trade balance [kcal]} > 0 \text{ then: cbf trade balance [kcal]} = \text{exports [kcal]}$$

Food associated carbon leakages, crop-based products

Exports embedded GHG emissions are computed at the very end of the calculation tree to consider the carbon footprint of the country agri-food system. Imports enables to assess the embedded GHG emissions in crop-based products by using typical emission intensity by food product type.

Equation 38: $embedded\ GHG\ emission\ [CO2e] = cbf\ imports[kcal].\ cbf\ emission\ intensity\ [CO2e/kcal]$

Given that imports are not spatially explicit and considering the high uncertainty regarding the future emission factors, the potential embedded GHG emissions are provided as a range rather than a unique value, bounded by the most optimistic and pessimistic values found in the FAOSTAT data base.

4.3.1.13. From crop production to residues

Objective

Given the crop domestic production, the volume of residues is computed for each crop type.

Crop residues

Based on Malins and Searle estimation, the volume of crop residues generated given the demand for crops is computed. The production ratio has been aggregated for each country based on the following assumption:

Table 53 – Crop residues production ratio in t/t (Searle and Malins, 2016)

Crop	production ratio
Barley	1.18
Maize	1.27
Oats	1.31
Rapeseed	1.08
Rice	1.59
Rye	1.37
Soybeans	3.5
Sunflower	1.77
Triticale	1.28
Wheat	1.18
Sugar beet	0.27

The production ratio refers to the ratio of residues to harvested crop. A ratio that is greater than 1 means that more residues is produced compared to the part of the crop that is used. Given the present ratio, Searle and Malins (2016) estimated the total residues available in the EU up to 367 Mt, regardless to soil quality preservation.

Equation 39: $$Residues\ production\ [Mt] = crop\ production\ [kcal].\ \text{residues production ratio}\ [\text{Mt}/kcal]$$

As a second step, the overall residue production is summed up:

Equation 40: $$Total\ residues\ production\ [Mt] = Sum\ (\text{residues production per crop}[\text{Mt}])$$

Crop residues per use

Depending on the lever setting, crop residues can be used for soil quality preservation, as nitrogen input, for bioenergy and for other uses.

Equation 41: $Residues\ per\ use\ [Mt] = Residues\ production\ [Mt] * use\ hierarchy\ [\%]$

4.3.1.14. From woody biomass demand to roundwood equivalent wood demand

4.3.1.15.Biogas module

Objective

The modelling framework is computing the biogas technology mix, feedstock mix and the demand for manure, wastes and energy crops given the biogas demand.

Technology mix

The technology mix is set based on the observed data for the period 1990-2015 and split between digestor, sludge and landfill biogas. The agriculture module only considers the digester technology as part of the agriculture sector.

Equation 42: $Biogas\ production\ per\ technology\ [TWh] = biogas\ production\ [TWh].\ technology\ mix[\%]$

Feedstock type requirement

The feedstock mix is set based on the observed data for the period 1990-2015 and split between biowastes, manure and energy-crops.

Equation 43: $Biomass\ demand[TWh] = biogas\ produced\ from\ digesters\ [TWh]$

4.3.1.16. Bioenergy balance

Objective

Depending on the lever setting, either energy crops or imports are used as a buffer variable when the biomass supply cannot meet the bioenergy demand, either gas or liquid.

Equation 44: $Total\ missing\ biomass[t] = Sum(missing\ biomass\ for\ bioenergy[t])$

Equation 45: $energy\ crop\ demand[t] = total\ missing\ biomass[t] * energy\ crop\ share\ [\%]$

However, the lever setting enables us to explore scenarios for which dedicated energy crops or imports are not allowed. In such case, a warning is sent that inform the user of resources limits, and thus inconsistent pathways.

4.3.1.17. From trade balance to carbon leakages (energy crops)

[not fully implemented in the KNIME framework yet]

Objective

Such as the other carbon leakages sections, the model will consider the embedded GHG emissions associated with the trade balance of energy crops.

4.3.1.18. Land allocated to cropland

Objective

Given the demand for crops and the climate smart agriculture production systems patterns, the land demand is computed.

Defining crop yields

[not fully implemented in the KNIME framework yet]

Given the climate change and temperature levels, production factor is affecting the crop yields.

Equation 46: $$Net\ copland\ demand[ha] = Cropland\ demand\ [ha] * cropping\ intensity\ factor\ [\%]$$

Cropland demand

Given the cropland demand and yields the cropland demand is computed:

Equation 47: $$Cropland\ demand\ [ha] = Crop\ demand\ [\mathrm{kcal}]\ /\ crop\ yield\ [kcal/ha]$$

Emission from rice cultivation

Given the emission factors for rice cultivation, expressed in MtCH4/ha, the CH4 emissions associated with rice cultivation are computed:

Equation 48: $$CH4\ emission\ (rice)[MtCH4] = Rice\ land\ [ha] * CH4\ emission\ factor\ [MtCH4/ha]$$

Land cropping intensity

Given the cropland intensity the cropland demand is adjusted:

Equation 49: $$Net\ copland\ demand[ha] = Cropland\ demand\ [ha] * cropping\ intensity\ factor\ [\%]$$

Overall cropland demand

The overall demand for cropland is summed up:

Equation 50: $total\ cropland[ha] = Sum(cropland\ per\ crop\ type[ha])$

4.3.1.19. Synthetic fertilizer-use & emissions

Objective

Synthetic fertilizer use is computed given the climate smart cropping systems patterns, the modelling framework is computing the demand for synthetic fertilizer expressed in t, and the associated emissions expressed in MtN_2O.

Synthetic fertilizer-use

Given the deployment of the climate smart cropping production system patterns, the fertilizer demand is computed by multiplying the agriculture land with the fertilizer-use expressed in t/ha.

Equation 51: $Synthetic\ fertilizerse[t] = agriculture\ land[ha].synthetic\ fertilizer\ use[t/ha]$

Fertilizer associated emissions

The N_2O emissions are computed from the fertilizer-use and the synthetic fertilizer emission factors.

$$N2O\ emission[MtN2O] = fertilizer\ use[t].emission\ factor[tN2O/\mathrm{t}]$$

4.3.1.20.Energy consumption

Objective

The modelling framework is computing the energy demand given the climate-smart agriculture production systems, the energy-demand is computed.

Energy-use by vector

The energy demand is computed by multiplying the energy use by hectare with the agriculture land [ha]. The energy demand is then split between the different energy types:

Equation 52: $energy - use[TWh] = agriculture\ land[ha].energy\ use[TWh/ha]$

Equation 53: $energy - use\ by\ type\ [TWh] = energy\ use[TWh] * energy\ mix\ [\%]$

Direct energy GHG emission

Direct CO_2 emissions are computing by multiplying the energy consumption [TWh] by energy emission factors [$MtCO_2e$/TWh]. Electricity associated emissions are computed in the energy module (WP5), given the lever setting for electricity mix.

Equation 54: $CO2\ emissions\ [MtCO2] = energy\ consumption\ by\ type\ [TWh] * emission\ factors\ [MtCO2/TWh]$

4.3.1.21.GHG emissions

Objective

The total emissions of the agriculture sector are summed up by gas type, including CO_2, CH_4, N_2O.

Equation 55: $CO2\ emissions\ [Mt] = Sum(CO2\ emission[Mt])$

Equation 56: $CH4\ emissions\ [Mt] = Sum(CH4\ emission[Mt])$

Equation 57: $N2O\ emissions\ [Mt] = Sum(N2O\ emission[Mt])$

4.3.1.22.Bioenergy costs

As previously mentioned, the technology and costs features are currently not fully implemented.

4.3.2.Land-use detailed calculation trees

The next section is detailing the calculation trees of the land-use, land-use change and forestry module.

4.3.2.1.Land dynamics over the years

Objective

Given the dynamics for land-demand: (1) lands being freed up have to be allocated to specific uses and covers; (2) in case of land scarcity, deforestation is considered as a buffer variable to imbalance land demand and supply; (3) in case land area is not large enough to meet the demand, a warning informs the user that the pathway is not consistent.

Land demand

The demand for agriculture land (cropland and grassland), frozen lands for biodiversity conservation, settlements, wetlands and other lands are summed up to compute the total land demand.

Equation 58: $land\ demand(year\ i)[ha] = Sum[land\ demand\ per\ use\ and\ cover\ (year\ i)]$

Land dynamics across the years

As previously mentioned, 3 settings can occur depending on the pathway:

Equation 59:

$$If: agriculture\ land\ demand\ (year\ i) > agricultureland\ (year\ i-1):$$

$$forest\ land\ (year\ i)[ha] = forest\ land(Year\ i-1)[ha] - additional\ land\ requiered[ha]$$

$$If: agriculture\ land\ demand\ (year\ i) < agricultureland\ (year\ i-1):$$

$$land\ reallocation(Year\ i)[ha] = freed\ lands[ha].\ land\ allocation\ share\ [\%]$$

New allocation for lands is set by the users through the land management lever, which includes unmanaged lands, forest lands, and natural prairies. If agriculture land demand is exceeding the country's land availability or if it involves important deforestation, a warning informs the user about the pathway inconsistency.

Finally, the new land allocation is computed (illustrated through the forest lands):

Equation 60: $$forest\ land\ (year\ i)[ha] = forest\ land(year\ i-1)[ha] + forest\ land\ (year\ i)[ha]$$

4.3.2.2.Forestry module

[not fully implemented in the KNIME framework yet]

Objective

The forest land area is set given the land dynamics, and the forestry management practices are set through the CSF lever. Given the lever setting, the forestry module aims at computing the gross biomass increment, the net biomass increment, and the fellings.

Forest available for wood supply (FAWS)

Depending on the biodiversity ambition level, forest land available for wood supply is computed:

$$\text{faws (year i)[ha]} = \text{forest land(year i)[ha]} - \text{frozen forest land (year i)[ha]}$$

Biomass increment per ha

Depending on the deployment of CSF practices, the dynamics of biomass increment is computed given the gross increment rate (equation 61), the extent of natural losses (equation 62), the felling rates (equation 63).

Equation 61:

$$\text{gross increment (year i)}[m^3/ha] = \text{standard gross increment (year i)}[m^3/ha] + \text{additional CSF gross increment (year i)}[m^3/ha]$$

Equation 62: $$\text{net increment (year i)}[m^3/ha] = \text{gross increment } [m^3/\text{ha}] * (1 - \text{natural losses } [m^3/\text{ha}])$$

Equation 63: $$\text{fellings (year i)}[m^3/ha] = \text{net increment (year i)}[m^3/ha] * harvest\ rate\ [\%]$$

Forest growing stock

Given the biomass increment and the fellings, the net change is computed to evaluate the growing stock dynamics per ha (Equation 64) and per country (Equation 65):

Equation 64: $\text{net change (year i)}[m^3/ha] = \text{net increment (year i)}[m^3/ha] - \text{ fellings (year i)}[m^3/ha]$

Equation 65: $\text{growing stock change (year i)}[m^3] = \text{net change (year i)}[m^3/ha] * forest\ lands\text{(year i)}[m^3]$

4.3.2.3. Wood trade balance

Objective

The CSF lever sets management practices for forests, which sets the harvest rate. In order to avoid lever inconsistency, the self-sufficiently ratio and thus trade balance are used to enable the supply to match the demand when the country cannot be self-sufficient. At the opposite, when supply is exceeding the demand, wood fuel is assumed to be consumed for power and heat generation, and industrial wood exported. It is worth mentioning that intensive imports may export deforestation, which is why the model keep track of the trade balance.

Equation 66: $\text{wood trade balance [Mm}^3] = \text{wood demand}[Mm^3] - \text{wood supply [Mm}^3]$

Equation 67:

$$if: \text{wood trade balance} > 0: \text{ wood import }[Mm^3] = -\text{wood trade balance [Mm}^3]$$

Else: $\text{wood import}[Mm^3] = 0$

$$if: \text{wood trade balance} < 0: \text{ woodfuel supply }[Mm^3] = \text{wood trade balance [Mm}^3] * \text{wood fuel share}$$

And: $\text{wood trade balance} < 0: \text{ wood export }[Mm^3] = \text{wood trade balance [Mm}^3] * \text{industrial wood share}$

4.3.2.4. LULUCF emissions

[not fully implemented in the KNIME framework yet]

Objective

Depending on the lever setting, land-use change will occur that will affect the carbon storage by the biomass and the soil. The objective is to compute the land carbon dynamics.

Equation 68: $Emisson[CO2] = LandUse[ha].EmissionFactor[CO2/ha]$

The emission factors are considering the land dynamics given the categories presented in Table 54, for the future time series. It is worth mentioning that such a granularity is not available for the historical data. Thus, the OTS will be based on the UNFCCC inventories LULUCF emissions that considers land use remaining the same land-use, and land converted to another use.

Table 54 – Expected land categories

Land Type	Dynamics
Forest Land	remaining Forest land [0-20 years]
	remaining Forest land [20-40 years]
	remaining Forest land [40+ years]
	going from [0-20] to [20-40]
	going from [20-40] to [40+]
Cropland	Converted to Forest Land [0-20]
	remaining Forest land [20-40 years]
	remaining Forest land [40+ years]
	going from [0-20] to [20-40]
	going from [20-40] to [40+]
Grassland	Converted to Forest Land [0-20]
	remaining Forest land [20-40 years]
	remaining Forest land [40+ years]
	going from [0-20] to [20-40]
	going from [20-40] to [40+]
Wetlands	Converted to Forest Land [0-20]
	remaining Forest land [20-40 years]
	remaining Forest land [40+ years]
	going from [0-20] to [20-40]
	going from [20-40] to [40+]
Settlements	Converted to Forest Land [0-20]
	remaining Forest land [20-40 years]
	remaining Forest land [40+ years]
	going from [0-20] to [20-40]
	going from [20-40] to [40+]
Other Land	Converted to Forest Land [0-20]
	remaining Forest land [20-40 years]
	remaining Forest land [40+ years]
	going from [0-20] to [20-40]
	going from [20-40] to [40+]

Moreover, the land type should be divided in sub-types including the specific emission factors associated to the different agriculture patterns (e.g. additional agroforestry sequestration, grazing intensity). For time computation issues, the modelling framework may possibly lead to limit the land types and sub-types to maintain a real time experience to the end-user.

5. Description of constant or static parameters

5.1. Constant list

In the EUCalc modelling framework, the constants refer to parameters that are neither country nor year dependent. The present section provides the constant details that are not already presented in the other sections of the document:

- Biofuel biorefinery byproducts yields (e.g. bionaphtha, biopropane, glycerine, and so on) is based on (Baudry et al., 2017);
- Agri-food byproducts yields (e.g. fatty acids, bones) are based on (Réséda et al., 2017);
- Food processing yields (e.g. cakes and vegetable oil) are based on (Pradhan et al., 2013);
- Food conversion in kcal/tons are based on FAOSTAT database[76] and FOASTAT composition tables[77];

5.2. Fixed assumptions

In the EUCalc modelling framework, the fixed assumptions refer to variables that are Country and Year dependent, but are independent from the levers' setting*:*

- Livestock enteric fermentation emission factors are based on FAOSTAT[78]
- The range of the food embedded CO2 emissions are based on FAOSTAT emissions intensity[79].

6. References

6.1.Historical database

The following table is presenting the main databases that have been used in the agriculture, land-use, land-use change and forestry modules.

Table 55 – Database for agriculture and land-use

Dataset	Description	Main sources	Data quality check	Hypotheses
Food self-sufficiency ratio [%]	Self-sufficiency per food group and implied net trade balance	FAOSTAT: Commodity Balances: ▪Crops Primary Equivalent; ▪Livestock and Fish Primary Equivalent; EUROSTAT: ▪Imports - renewables - annual data (nrg_126a) ▪Exports - renewables - annual data (nrg_126a)	FAOSTAT database limited to 1990-2013	Linear extrapolation for 2014 and 2015 (FAOSTAT)
Slaughter rates and yields [%]	Share of livestock population, average age of	FAOSTAT: ▪Livestock Primary	Data for some country is missing (e.g. Malta)	Average or comparable countries in terms of agricultural context are used to fill the missing data

[76] Food and Agriculture Organization (FAO), FAOSTAT, Food Supply - Crops Primary Equivalent / Livestock Primary Equivalent;
Direct link: *http://www.fao.org/faostat/en/#data/CC* / *http://www.fao.org/faostat/en/#data/CL*
[77] Food and Agriculture Organization (FAO), food composition tables;
Direct link: *http://www.fao.org/3/x9892f/x9892f0c.htm*
[78] Food and Agriculture Organization (FAO), enteric fermentation;
Direct link: *http://www.fao.org/faostat/en/#data/GE*
[79] Food and Agriculture Organization (FAO), emissions intensities;
Direct link: *http://www.fao.org/faostat/en/#data/EI*

	animal, carcass yields of animal being slaughtered	▪The future of food & agriculture, alternative pathways to 2050		
Feed ration by food group [kcal, %]	Animal feed consumption [tons, %]	FAOSTAT: Commodity Balances: ▪Crops Primary Equivalent; ▪Livestock and Fish Primary Equivalent;	FAOSTAT database limited to 1990-2013	Linear extrapolation for 2014 and 2015 (FAOSTAT)
Bioenergy feedstock mix [tons, %]	Feedstock mix used by country to produce bioenergy	EUROSTAT: ▪Primary production - all products - annual data [nrg_109a] Biogas technology & feedstock mix: ▪Optimal use of biogas from waste streams, CE Delft	EUROSTAT data available for 1990 – 2016 Biogas technology & feedstock mix: Only available for 2015	EUROSTAT No hypotheses needed Biogas technology & feedstock mix: Only available for 2015, fixed mix assumed
Forestry production [m^3, tons]	Production of wood, forest land net-balance	FAOSTAT: ▪Forestry Production and Trade ▪Land use	Data for some country is missing	Average or comparable countries in terms of agricultural context are used to fill the missing data
Manure [%, N_2O]	Stock and emissions associated with manure	FAOSTAT: ▪Manure Management (left on pasture, soil, treated)	Data for some country is missing	Average or comparable countries in terms of agricultural context are used to fill the missing data
Enteric emission [CH_4/head]	Emissions of ruminants	FAOSTAT: ▪Enteric Fermentation	Data for some country is missing	Average or comparable countries in terms of agricultural context are used to fill the missing data
Fertilizer [kg/ha]	Use of fertilizer in agriculture land	FAOSTAT: ▪Nutrient nitrogen N ▪Nutrient phosphate P_2O ▪Nutrient potash K_2O	Data for some country is missing	Average or comparable countries in terms of agricultural context are used to fill the missing data
Energy use by carrier [toe/ha]	Use of energy by type in the agricultural sector	FAOSTAT: ▪Energy-use	FAOSTAT database limited to 1990-2012	Linear extrapolation for 2012-2015
Yields [tons/ha]	Yields by crop type	FAOSTAT: ▪Crops ▪The future of food & agriculture, alternative pathways to 2050	FAOSTAT database 1960-2018	-
Land-use [ha, %]	Land-use by type	FAOSTAT: ▪Land-use	Data for some country is missing	Average or comparable countries in terms of agricultural context are used to fill the missing data
Feed composition	Feed compounds composition and energy content	INRA-CIRAD-AFZ Feed tables	-	-

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