Ref. Ares(2019)6878010 - 06/11/2019

EUCALC

Explore sustainable European futures

WP4 – Land, land use, minerals, water and biodiversity input spreadsheets for calculator model

D4.1

11/2019

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 730459.

Project Acronym and Name	EU Calculator: trade-offs and pathways towards sustainable and low-carbon European Societies - EUCalc
Grant agreement number	730459
Document Type	Deliverable
Work Package	WP4
Document Title	Land, land use, minerals, water and biodiversity input spreadsheets for calculator model
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Release date	November 06th, 2019
Distribution	*All involved authors and co-authors agreed on the publication.*

Short Description

This report describes the resources module input spreadsheets, including agriculture, land, land use, minerals, water and biodiversity, while specifying their scientific background and rationales.

Quality check

Name of reviewer	**Date**
Boris Thurm	31/07/2019

Statement of originality:
This deliverable contains original unpublished work except where clearly indicated otherwise.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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List of Abbreviations

APS - Alternative Protein Sources

Aichi Targets – The biodiversity targets set by the CBD members for 2020 at the CBD meeting in Aichi. These are the current global targets for biodiversity conservation; proposed 2030, and potential 2050 targets are now included

BtL – Biomass to Liquid

CBD - Convention on Biological Diversity

CAP – Common Agricultural Policy

CBD – Convention on Biological Diversity

COP-21 – Conference of the Parties 21

CSA – Climate-Smart Agriculture

CSF – Climate-Smart Forestry

DDGS - Dried Distillers Grains

EEA - European Environmental Agency

EFI – European Forest Institute

ESA-CCI – European Space Agency Climate Change Initiative

EU – European Union

EU-28 – The 28 EU Member States as of 1 July 2013

EU28+1 - The 28 EU Member States as of 1 July 2013, plus Switzerland

FAO - Food and Agriculture Organization

FAWS - Forest Available for Wood Supply

GHG – Greenhouse gases

HVO - Hydrotreated Vegetable Oil

IDDRI - Institut du développement durable et des relations internationales

IEA – International Energy Agency

INDC - Intended Nationally Determined Contributions

IPCC - Intergovernmental Panel on Climate Change

IPIFF - International Platform of Insects for Food and Feed

IUCN – International Union for the Conservation of Nature

JRC – Joint Research Center

LSU – Livestock Unit

LULUCF – Land-Use, Land-Use Change and Forestry

NGO – Non-Governmental Organization

RCP - Representative Concentration Pathway
RESEDA - Réseau pour la sécurité et la qualité des denrées animales
TWh – Terawatt per hour
TYFA - Ten Years For Agroecology in Europe
UCO – Used Cooking Oil
UNFCCC - United Nations Framework Convention on Climate Change
WDPA – World Database on Protected Areas

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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] (2017). 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.

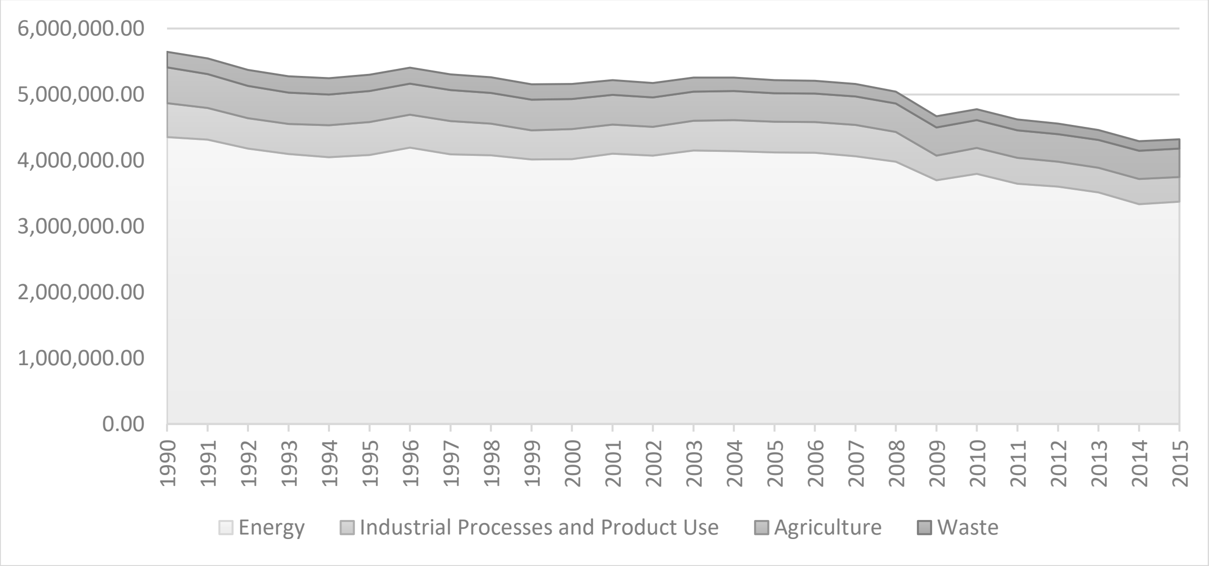

Figure 1 - GHG emissions per sector without LULUCF in the European Union (ktCO₂ equivalent)[4]

The agriculture, land-use, land-use change and forestry, biodiversity, water and mineral modules of the European Calculator (EUCalc) aim at modelling these challenges associated with the sustainable use of natural resources.

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[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

At the European level, the agriculture sector only represents about 9% of GHG emissions, variating by +/- 1% since 1990 (Figure 1). When focusing on land-use, land-use change and forestry associated emissions - usually shortened 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 sustainable development of the complex human-based system.

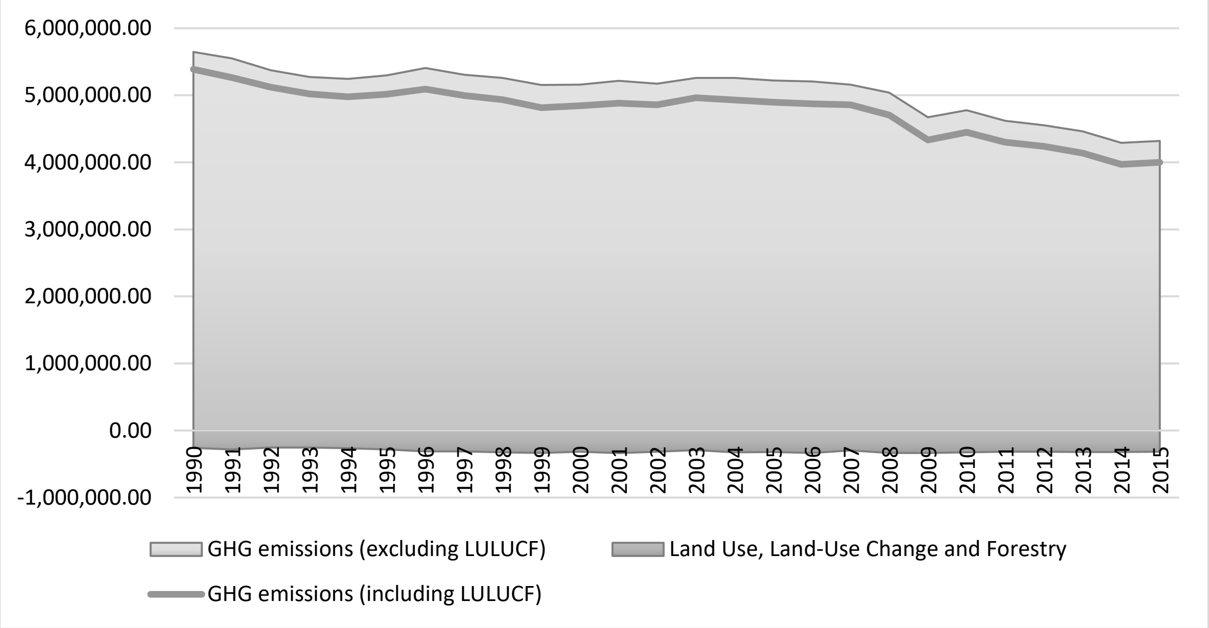

Figure 2 – GHG emissions from LULUCF in the European Union ($ktCO_2$ equivalent)[5]

Although Figure 2 presents 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 is mainly dependent 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.

Protected areas can play a major role in the preservation of biodiversity. The proper siting of new protected areas can play a role in mitigation either through protecting existing carbon sinks, or through the development of new sinks via reforestation/afforestation in restoration efforts. This preservation or restoration can potentially be in direct competition with demand from agriculture for cropland and forests.

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[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

From the Bronze Age to Lithium-ion batteries, mineral resources usage has transformed human societies. Though plentiful for centuries, recent economic development and transitions have had considerable impacts on world-wide resources. In addition, the threat posed by climate change challenges decision makers since cleaner solutions are primarily mineral resource intensive. Are current reserves enough to sustain economic development and sustainable transitions? Recent publications have demonstrated that resource extraction has more than tripled since 1970, deeply affecting current mineral resources (International Resource Panel 2019). The European Union is one of the leading mineral consumers through its numerous industrial sectors. If the EU is a major producer of industrial minerals (see Appendix II) for which it is a net exporter, the union is deeply dependent on imports for metallic minerals (Schüler, et al. 2017) (University of Leoben 2004). Yet, the latter support the current effort for cleaner energy technologies (including batteries). Therefore, it seems important to demonstrate not how European mineral extraction is consequential to the environment, but how Europe's current transitions and lifestyles impact global resources.

Water is a vital substance for human life but also a critical input for agriculture, industries, energy production and households. A reduction in water availability can for instance have a significant impact on food production and cooling of power stations, thus jeopardizing the proper functioning of our societies. In EUCalc, we explore pathways that would allow EU countries to mitigate their impacts on climate and aim for low-carbon societies. Reaching ambitious low-carbon objectives can have important benefits regarding water security since climate change is projected to extend water shortage periods and increase the frequency and intensity of extraordinary events such as droughts or floods. Rise in water demand is also likely to continue, putting even more pressure on these changing water resources. Assessing the water impacts of these pathways is then crucial to help policy makers make the right adjustments in order to keep European countries on a sustainable path.

[redacted] Trends and evolution of the sectors

The section presents in brief the trends and past evolution of the agriculture; land-use, land-use change and forestry; biodiversity; water; and mineral 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.

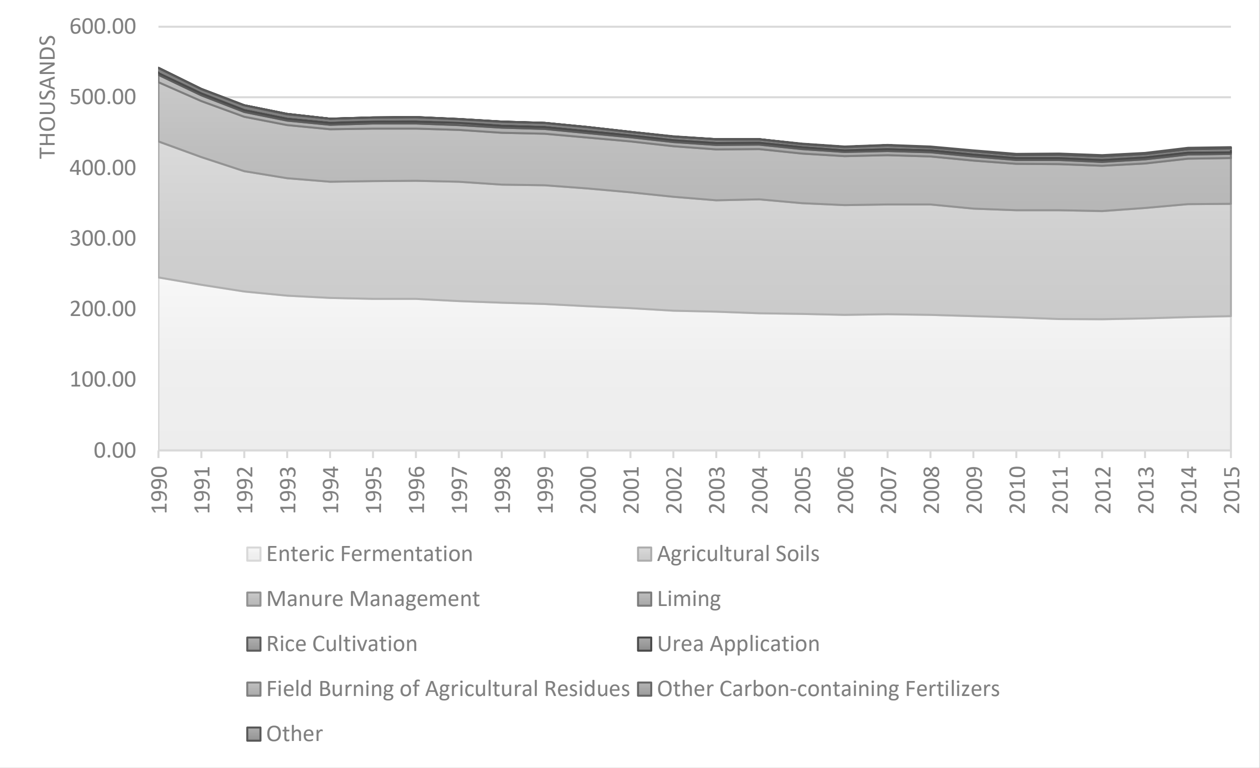

Figure 3 – GHG emissions in Agriculture in EU28 (2015)[6]

As shown by Figure 3, the European domestic agriculture associated GHG emissions decreased by about 18% since 1990. According to the European Union, the two main drivers 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 they are not considered in the official GHG inventory (Peters and Hertwich, 2008).

1.1.2 Land-use, land-use change & forestry (lulucf)

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

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[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

[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

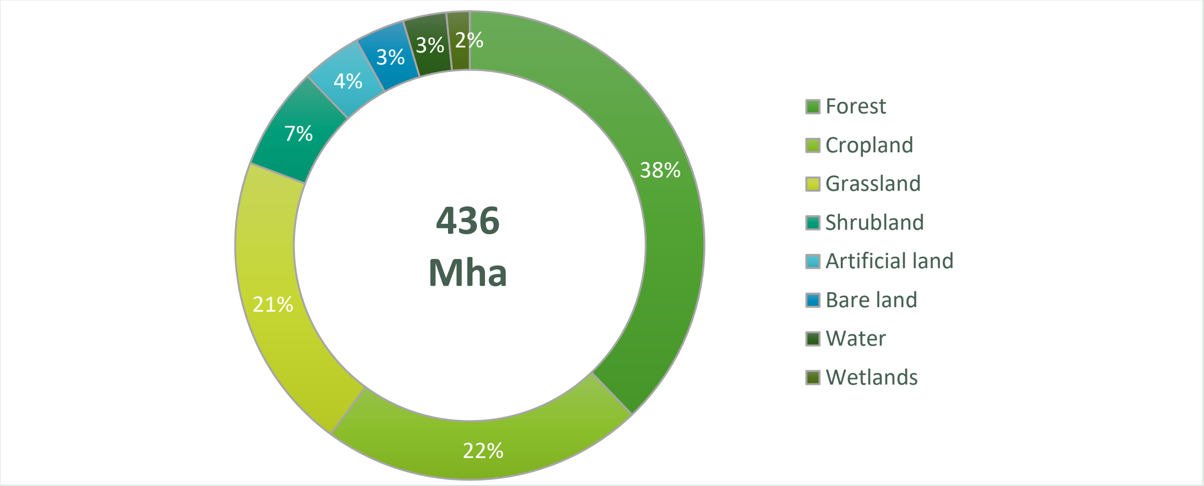

Figure 4 - Land cover overview in the EU in 2015 (ha)[8]

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 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 global and yearly CO_2 emission[9]. These good practices include grassland advanced management practices that could increase the carbon soil storage ability by 0.1-0.5 tC/ha/year. [10] 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.

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[8] EUROSTAT: land-cover (dataset: an_lcv_ovw), Direct link: https://ec.europa.eu/eurostat/data/database

[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

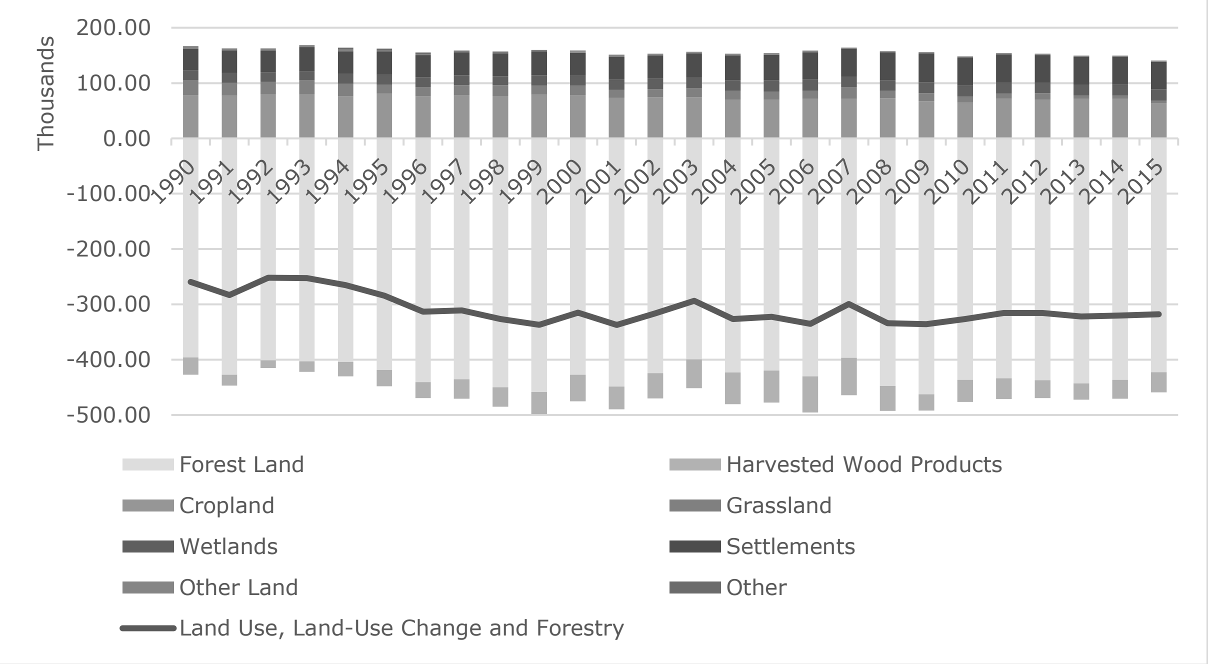

Figure 5 – GHG emissions from LULUCF by source in the European Union (ktCO₂ equivalent)[11]

1.1.3 Biodiversity

The long-term decline of global terrestrial biodiversity is well established. Land-use changes are the main driver behind increasing rates of species loss, but the situation has been further exacerbated by climate change. Of 1886 species in Central and Western Europe around 13% were classified as threatened in 2015 and 0.2% already considered extinct (IPBES, 2018).

To counteract further biodiversity declines, the EU committed to an ambitious conservation strategy, aiming to halt biodiversity loss by 2020. Part of this strategy was to fulfill Aichi Target 11, which requires member states to cover at least 17% of their terrestrial extent (CBD, 2010). Additionally, member states of the EU are subject to the EU Habitats Directive (European Council Directive 92/43/EEC; The Council of the European Communities, 1992) and the Birds Directive (Directive 2009/147/EC; European Parliament, 2010). These directives require the member states to establish designated areas for biodiversity protection to form the Natura 2000 network - the backbone of the EU's long-term conservation strategy.

Since the EU Habitats Directive was established in 1992 the network of conservation areas has continuously expanded. Covering roughly 10.7% of the terrestrial extent in 1992 it reached 25% coverage in 2015, suggesting that the EU already reached Aichi Target 11 (IPBES, 2018). However, coverage within member states varies widely and ranges from 10% to 53% (numbers calculated from UNEP-WCMC and IUCN, 2019).

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[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

There is thus further need for expansion to reach the target on a per member base. Furthermore, many of these protected areas are not being managed for biodiversity. For example, many protected areas still have agriculture, and even villages, embedded within them. Additionally, the areas are not in 'ideal' condition (see below) and this limits their usefulness as carbon sinks and for biodiversity benefits.

The protection of areas for biodiversity has benefits beyond the pure conservation of species. Managing areas for conservation requires the upkeep of natural habitat and even restoration of degraded land. It provides society with nature for recreation and tourism but also actively contributes to the reduction of GHG emissions (IPBES, 2018). Expanding the network of protected areas nearly tripled the sink in GHG emissions between 1990 and 2015 (Figure 6). The areas thus contribute significantly to the EU's long-term goal to cut GHG emissions by 80-95% of its levels in 1990 by 2050. However, note that there has been a levelling off of this benefit in recent years.

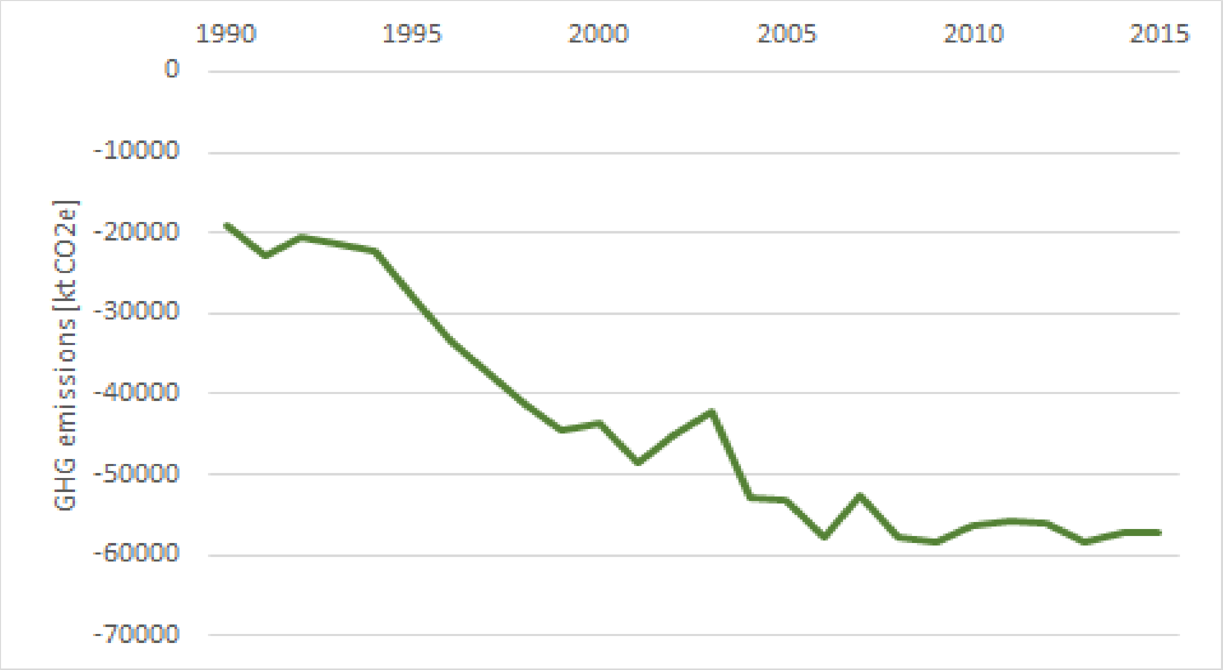

Figure 6 - Total GHG emissions from protected areas in EU28 and Switzerland (Calculated based on data from UNEP-WCMC and IUCN, 2019 and UNFCCC, 2019)

The future of European biodiversity depends on the EU's ambitions to halt biodiversity loss and to drastically reduce GHG emissions. Committing to the CBD's recent potential ambitions for increased biodiversity protection in 2050 would require member states to further invest into the upkeep and expansion of their protected area network but could indeed slow biodiversity loss down (IBPES, 2018). However, only the drastic reduction of GHG emissions will ultimately reduce the pressures that species are expected to face from climate change in the decades to come.

1.1.4 Water

1.1.4.1 Water availability

Water availability (or water resources) refers to the freshwater available for use in a territory and include surface waters (lakes, rivers and streams) and groundwater.[12] Renewable water resources are calculated as the sum of internal flow (which is precipitation minus actual evapotranspiration) and external inflow. Freshwater availability in a country is primarily determined by climate conditions and transboundary water flows (in other words, external flows).

Large spatial and temporal differences in the amount of water available are observed across Europe.[13] Water availability problems appear in areas with low rainfall, high population density, intensive irrigation and/or industrial activity.

Recent studies have shown that water resources are increasingly stressed by population growth and climate change, thus contributing to higher scarcity risks (Gosling et al., 2016). Water scarcity emerges when a low water availability is combined with water demand levels exceeding the supply capacity of the natural system. Figure 7 illustrates the high variability of water resources in response to climate change.

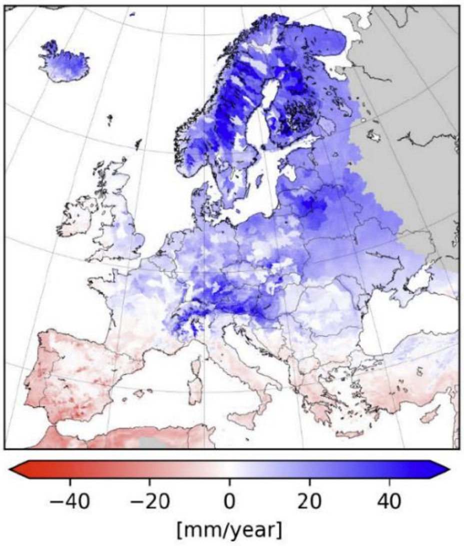

Figure 7 - Impact of 2 degrees climate change on groundwater recharge, as compared to the 1981-2010 climate (Bisselink et al., 2018)

These changes in water availability have an impact not only on food security (Rijsberman, 2006) but also on power generation cooling capacities (Tobin et al., 2018). Figure 8 shows spatial and temporal impacts of water scarcity.

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[12] Eurostat, Water statistics. Direct link: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Water_statistics&oldid=421073#Water_as_a_resource

[13] European Commission, Environment. Direct link: http://ec.europa.eu/environment/water/quantity/about.htm

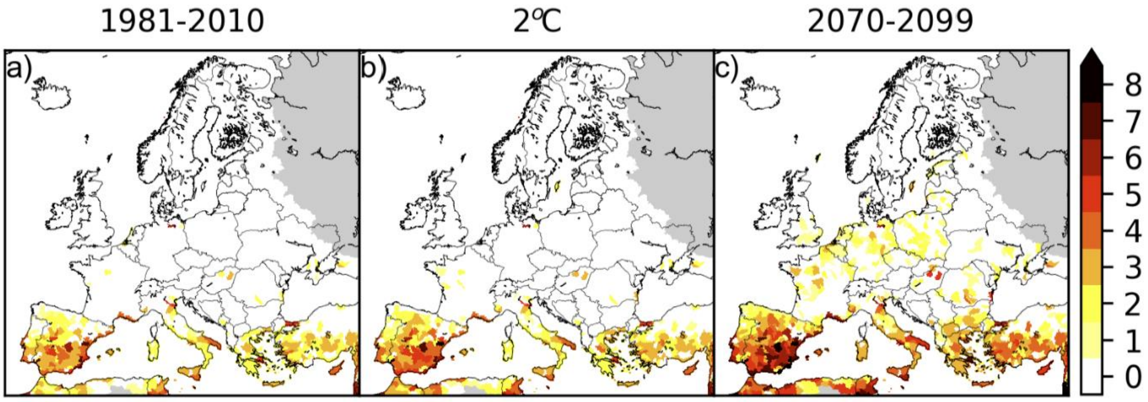

Figure 8 - Number of months in a year with high scarcity risk for different projections (Bisselink et al., 2018)

1.1.4.2 Water demand

During the last century, worldwide water demand has been largely driven by population and economic growth. However, water efficiency improvements, structural change and increasing water supply costs slightly decoupled water use from population and income increase (Duarte et al., 2014). Generally, water demand is divided as follows:

- Agriculture water demand which includes livestock water use and irrigation.
- Industry water demand which includes industrial manufacturing water use and electricity production cooling demand.
- Domestic water demand which includes household water use and other water uses related to services (hotels, restaurants, hospitals, schools, …).

The water demand is linked to two main water flows: water withdrawal and water consumption. The water withdrawal can be defined as the water removed from the ground or diverted from a surface-water source for a specific use. The water consumption, on the other hand, corresponds to the part of water withdrawn that is evaporated, transpired, incorporated into products or crops, consumed by humans or livestock, and that is not available for immediate use. Water returned to a different watershed than the point of withdrawal (interbasin transfer) is not considered a consumptive use.[14]

In EU countries, the European Environmental Agency (EEA) estimated that in 2015 the most water intensive sector was agriculture (with around 40% of all withdrawals), followed by electricity production (28%), mining and manufacturing (18%) and

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[14] USGS water definitions: https://www.usgs.gov/mission-areas/water-resources/science/water-use-terminology?qt-science_center_objects=0#qt-science_center_objects

households domestic use (11%) (EEA, 2018). Figure 9 illustrates the percentage distribution of water withdrawals by sector for each European country.

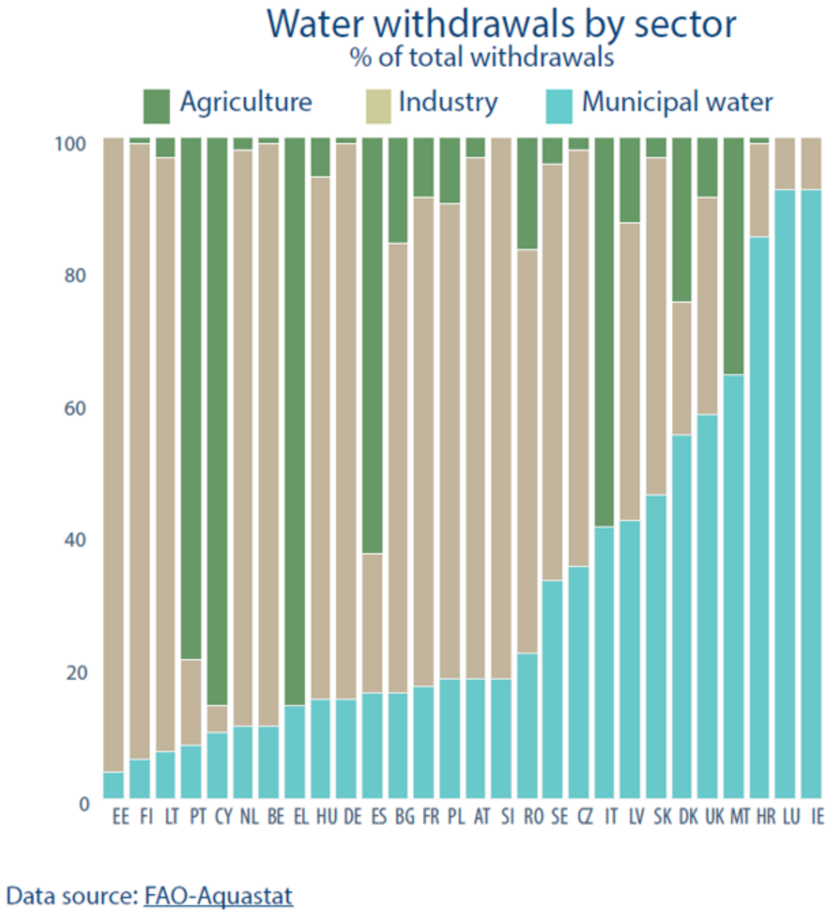

Figure 9 – Water withdrawals in Europe by sector (Source: EPRS, 2016)

More specifically, Figure 10 and Figure 11 show respectively the economic sub-sectors that have withdrawn and consumed most water in the EU over the period 1990-2011. On the one hand, the most water intensive sub-sectors are mainly the electricity productions from coal, nuclear, gas and petroleum, which are abstracting substantial amounts of water for cooling purposes.

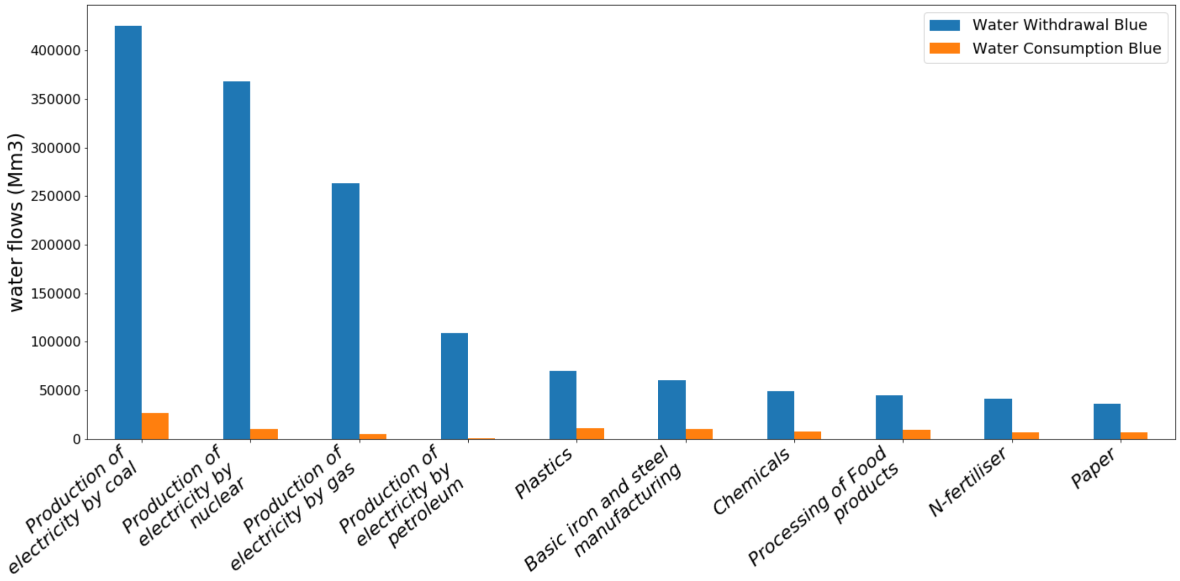

Figure 10 – Water flows from the most water withdrawing sub-sectors in EU over the period 1990-2011 (based on EXIOBASE data[15])

On the other hand, the most water consumptive items are typically related to agriculture, such as the cultivation of fruits and vegetables, cereal grains and crops, due to irrigation needs.

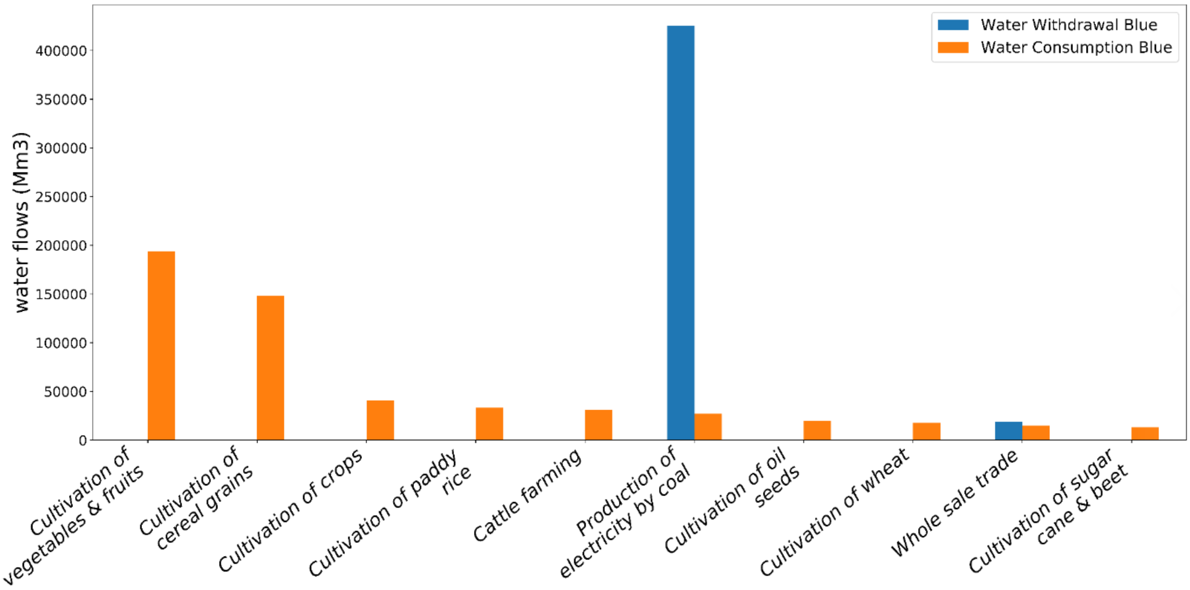

Figure 11 – Water flows from the most water consumptive sub-sectors in EU over the period 1990-2011 (based on EXIOBASE data)

The trends from 1990 to 2000 highlight a stunning 18-fold increase in industry and domestic water withdrawals, versus a mere five-fold increase in agriculture water withdrawal (Davies et al., 2012). Similar trends were also observed in water

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[15] Exiobase data download: https://www.exiobase.eu/index.php/data-download/exiobase3mon

consumptions. Indeed, as pointed out by Duarte et al. (2014), EU countries increasingly relied on agricultural imports, thus gradually substituting internal agricultural water use. This suggests that percentage distributions of water withdrawals and consumptions among sectors might evolve in the future. We can imagine a contraction in water demand for agriculture as irrigated land expansion stalls (Bruinsma J., 2009) and efforts are made to improve irrigation efficiencies (Gleick P.H., 2003), and a rapid increase in domestic and industrial water demands due to their close relation to population growth (Flörke et al., 2012).

1.1.5 Minerals

This section gives a short overview of the context and current trends in the mineral sector.

1.1.5.1 Mineral demand

1.1.5.1.1 International and European trends

During the last 70 years, the global society has experienced major transformations. Demographically, the human population grew from approximately 2.5 billion in 1950 to more than 7 billion in 2015 (United States Census Bureau 2011). It is further estimated that the world population will reach 9 to 10 billion human beings in 2050 (United Nations 2004). This demographic growth is coupled with the worldwide digital and energy transitions and the major economic development occurring in economies with large populations (e.g. China, India, Indonesia). Demographic growth, economic development, and the energy and digital transitions weigh heavily on the world mineral resources upon which they rely. All sectors directly or indirectly depend on them: potash in agriculture, limestone in the cement industry, lithium in digital appliances, copper for public transport, which indicates that mineral shortage could have consequences for the world economic development.

While the European Union mineral extraction has been stable in the last four decades (Figure 12), it satisfies its increasing demand by importing minerals from other continents (Schüler, et al. 2017). The mineral extraction sector in the European Union only represented 7% of worldwide extraction[16] in 1984 and 4% in 2017 demonstrating its feeble importance compared to global mineral extraction. Nonetheless, while it produces only 4% of mineral resources, the EU-28 and Switzerland remain one of the main consumers of minerals in the World (Rogich et Matos 2008).

Globally, the extraction practices have increased almost two folds between 1984 and 2017 (Figure 12), with the rate considerably increasing in the early 2000's, known as the '2000's commodity boom'. This *super cycle* is mainly driven by the BRIICS (Brazil, Russia, India, Indonesia, China, South Africa) economic development (Canuto 2014). Demand per annum will continue during the 21st century to rise as development is

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[16] The minerals taken into accounts are Aluminium, Antimony, Arsenic, Asbestos, Baryte, Bauxite, Bentonite, Beryllium, Bismuth, Cadmium, Chromium, Cobalt, Coking Coal, Copper, Diatomite, Feldspar, Fluorspar, Gallium, Germanium, Gold, Graphite, Gypsum, Indium, Iron, Kaolin, Lead, Lignite, Lithium, Magnesite, Manganese, Mercury, Molybdenum, Nat. Gas, Nickel, Oil shales, Palladium, Perlite, Petroleum, Phosphates, Platinum, Potash, Rhenium, Salt, Selenium, Silver, Steam Coal, Sulfur, Talc, Tantalum, Tellurium, Tin, Titanium, Tungsten, Uranium, Vanadium, Zinc

increasingly reliant on mineral resources such as lithium, cobalt, and copper (World Bank 2017).

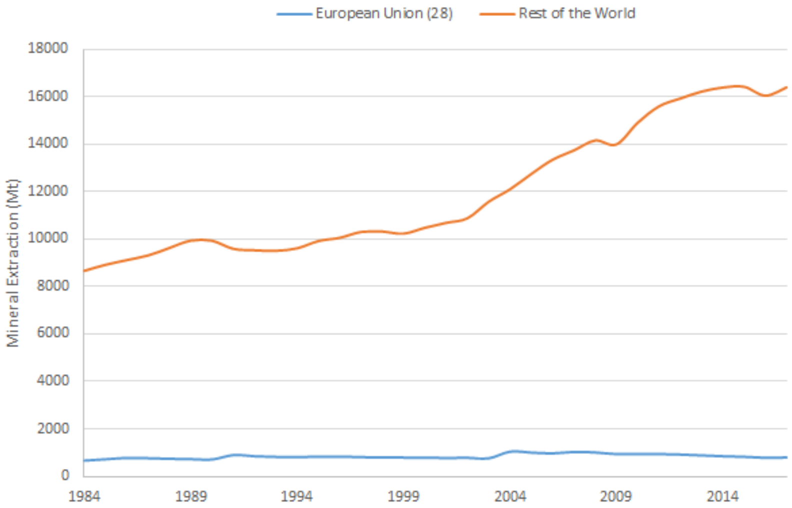

Figure 12 - Global and EU28 extraction time series between 1984 and 2017 *(Reichl, Schatz et Zsak 2019)*

Most materials extracted (Figure 13) (87%) in Europe are energy related, followed by industrial materials (6%), followed by salt (5%), and then metallic materials (2%). While the EU is mostly self-sufficient in terms of industrial materials (see appendix II), it relies heavily on importations for metallic materials (University of Leoben 2004) (Schüler, et al. 2017).

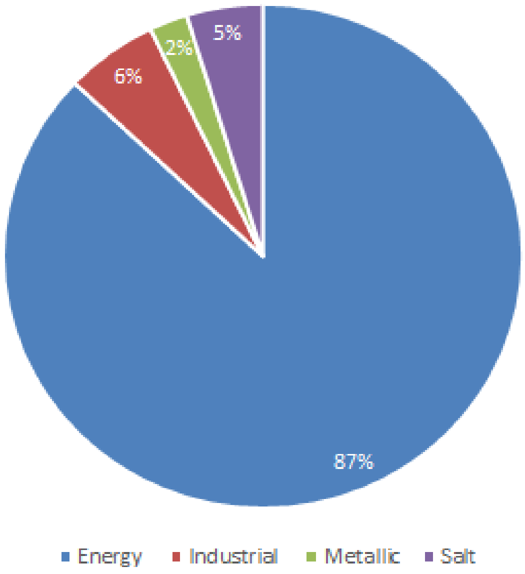

Figure 13 - EU28 cumulated extraction (1984 - 2017) segregated by mineral types + salt *(Reichl, Schatz et Zsak 2019)*

1.1.5.1.2 Mineral criticality

The Joint Research Centre (JRC) regularly updates the critical material list for the EU both in terms of economic importance and supply risk (JRC reports). Most of these materials are important for the industrial sectors and some particularly important for the decarbonisation pathways modelled in EUCalc and shown on the online platform. Because there are technological levers relying on resources, the mineral module considers only the resource that seem consequential for a particular pathway. Table 1 below shows the list of all minerals that have an importance on technologies critical for decarbonisation associated with energy technology, transport technology, digital technology, etc. For some of them, the granularity from the inputs is not enough to provide credible outputs, whilst others the lack of data constrains the modelling. The module models those that present sufficient data and sufficient input granularity (coloured green in Table 1).

Table 1 – Critical material table presenting both a supply risk and an economic importance, as well as the results from granularity and data scoping (Y: Yes; N: No) *(European Commission: Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs 2017) (European Commission: Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs 2017)*. In green, the modelled materials and in orange the materials lacking having one or two N's in the right column

Material	***Criticality***	***Supply Risk***	***Economic Importance***	***Sufficient Data***	***Sufficient Granularity***
Cobalt	Critical	Y	Y	Y	Y
Gallium	Critical	Y	Y	N	N
Indium	Critical	Y	Y	N	Y
Graphite	Critical	Y	Y	Y	Y
Platinum	Critical	Y	Y	N	N
Phosphate	Critical	Y	Y	Y	Y
Dysprosium	Critical	Y	Y	N	N
Neodymium	Critical	Y	Y	N	N
Aluminium	Non-critical	N	Y	Y	Y
Copper	Non-critical	Y	N	Y	Y
Steel	Non-critical	Y	N	Y	Y
Gold	Non-critical	N	N	N	N
Lead	Non-critical	Y	N	Y	Y
Lithium	Non-critical	Y	N	Y	Y
Manganese	Non-critical	Y	N	Y	Y
Nickel	Non-critical	Y	N	Y	Y
Potash	Non-critical	Y	N	Y	Y
Silver	Non-critical	Y	N	N	N
Tellurium	Non-critical	Y	N	N	N

1.1.5.2 Mineral availability

Observers fear that current trends in mineral usage could lead to severe resource depletion and geopolitical issues within the century. The apprehension concerns developing nations and developed countries, which both rely on mineral resources to sustain their development and transitions (BRGM 2015) (Coulomb, et al. 2015).

The most extracted resources worldwide are industrial minerals, which are comprised among others of sand, gravel, clay and in general crushed rocks. They account for 48% (43.8 billion tons) in 2017 (International Resource Panel 2019) of all extracted resources. These serve primarily for the construction sector. Among these, sand is the resource for which scarcity leads to environmental and geopolitical issues (Torres, et al. 2017).

There has also been a surge in ore extraction from 2.6 billion tons in 1970 to 9.1 billion tons in 2017 (International Resource Panel 2019). European activity sectors (drawn from EUCalc) involved in the recent digital and energy transitions are metallic mineral intensive. For instance, batteries in smartphones, laptop, electric vehicles require lithium.

Table 2 below provides a mineral overview including sectorial importance, scarcity threat, and geographical concentration.

Table 2 – Overview of critical metallic minerals based on the McKinsey Global Institute methodology *(Dobbs, et al. 2011)*

MINERAL	RESERVES[17] (MT)	YEARS LEFT[18]	RESOURCE[19] (MT)	MAIN EXTRACTING COUNTRIES (REICHL, SCHATZ ET ZSAK 2019)	SECTORIAL IMPORTANCE
IRON	85,000	54	230,000	Australia 32% China 24% Brazil 16%	*Transport* *Technology* *Industry* *Energy*
COPPER	700	36	3,500	Chile 30% Peru 9% China 9%	*Transport* *Technology* *Industry* *Energy*
BAUXITE	28,000	96	75,000	Australia 27% China 21% Brazil 12%	*Transport* *Technology* *Industry* *Energy*
NICKEL	79	37	130	Philippines 22% Russia 12% Canada 11%	*Industry* *Technology* *Transport*
COBALT	7.1	50	25	Congo D.R. 60% China 7% Canada 5%	*Technology* *Transport*
LITHIUM	13.5	300	40	Australia 37% Chile 34% Argentina 16%	*Transport* *Technology* *Industry*
LEAD	89	18	2,000	China 47% Australia 13% USA 7%	*Transport*
MANGANESE	570	32	Unknown	China 29% South Africa 20% Australia 14%	*Industry*

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[17] In 2015 (US Geological Survey 2019)

[18] Extraction in 2015 (Reichl, Schatz et Zsak 2019) over Reserves (US Geological Survey 2019)

[19] In 2015 (US Geological Survey 2019)

POTASH	3,500	100	250,000	Canada 30% Russia 17% Belarus 15%	*Agriculture*
PHOSPHATE	223	309	300,000	China 44% United States 13% Morocco 13%	*Agriculture*

The method used in

Table 2 to calculate the years left for resources comess from the McKinsey Global Institute report on the resource revolution (Dobbs, et al. 2011). Lithium and Cobalt were added because they are present in batteries for consumer electronics and electric vehicles.

Two important messages can be drawn from the above table. Firstly, if the world demand remains the same as the one in 2015, reserves for some minerals are going to be depleted as early as 2035. Reserve depletion will lead to price increase for commodities, which inherently leads to increase in prices for the consumer. This will render more difficult economic development and sustainable transitions. Lithium appears to be the only mineral for which reserves do not pose an immediate threat. Secondly, none of the EU-28 countries is the main extractor of any minerals present in table 1. In order to satisfy demand, in 2015, 189 Mt of metallic minerals were extracted in Europe, while 248 Mt were imported (Eurostats 2019). It suffices to say that Europe’s demand in metallic minerals is satisfied through importation. One is left to wonder whether geopolitical tensions could lead to demands not being met. Metallic minerals supply therefore faces a dual threat: scarcity – linked to price volatility – and dependence to certain countries. The mineral module can solely model the scarcity aspect.

EUCalc basics

The modelling framework enables one to explore a wide range of (un)sustainable futures given potential shifts in behavior, 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).

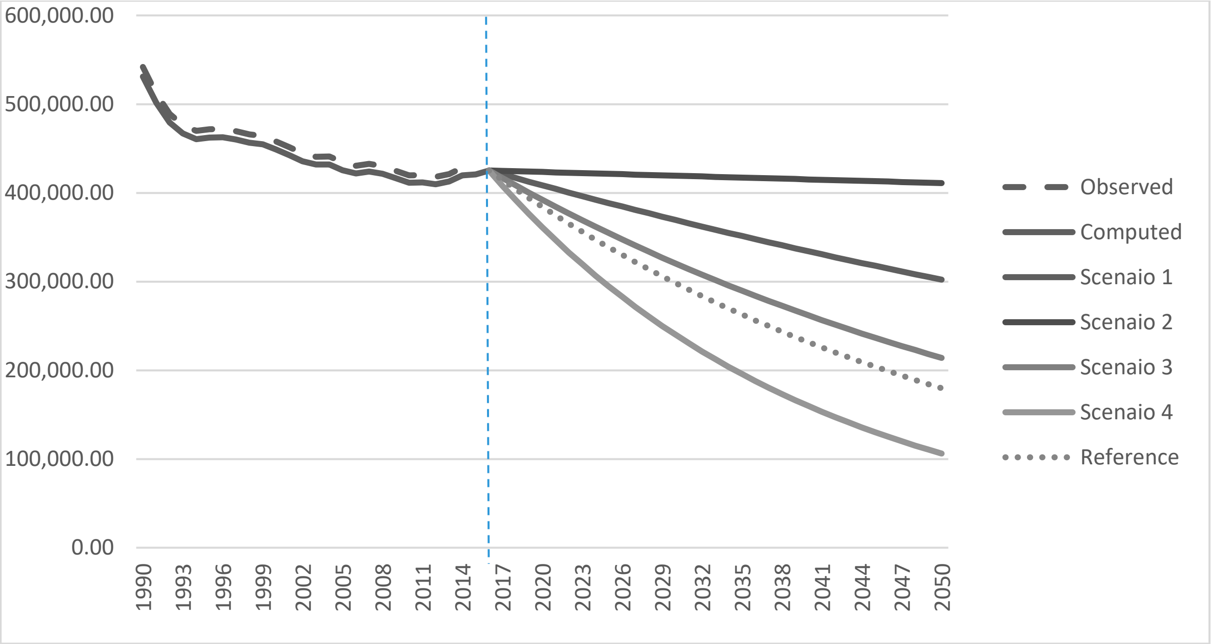

Figure 14 – Overall model logic (illustration graph, made by the authors)

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 behavioral, 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 pathways 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 14)[20].

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

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:

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.

[redacted] Objective of the document

The objective of the present document is to present the rationales and scientific background behind the input data of the agriculture; land-use, land-use change and forestry; biodiversity; water; and mineral modules of EUCalc[21]. The inputs and database cover all EU28 member states plus Switzerland and aims at describing historical trends from 1990 to 2015. As 2015 is currently the reference year used for the European Calculator, we projected data from 2015 until 2050.

The module inputs include specific data associated with the 'lever and ambition levels' (Section 2), the 'fixed assumptions' (i.e., data that depends on either or both country and years, Section 3), and 'the constants & parameters' (i.e. fixed parameter that are not changing whatever the country or year, Section 4). Finally, Section 5 presents the database that have been used to feed the EUCalc framework regarding the resources modules, namely agriculture; land-use, land-use change and forestry; biodiversity; water; and mineral modules.

2 Lever and ambition levels

Levers and ambition levels are at the forefront of the Calculator, they enable any user to explore a wide range of scenarios and their sustainability impacts. The following section presents the data and scientific background behind each of these levers and ambition levels. It is worth mentioning that contrary to agriculture, lulucf, and biodiversity modules, water and mineral modules do not include levers but compute the sustainability impacts of each pathway, in terms of water and mineral use & depletion.

[redacted] Agriculture

2.1.1 Self-sufficiency & food net-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.,

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[21] In the spirit of the calculators before us, we make available the current data inputs. These can be accessed via the link and password provided below. The naming of each input file and well as the metadata provided follow the EUCalculator standards detailed in the project's Data Management, Deliverable 11.2, accessible via this link. *http://www.european-calculator.eu/wp-content/uploads/2017/07/del-11.2-data-managment-plan-v7.pdf*
Direct link for data (password: agr_euc_09): *https://cloud.pik-potsdam.de/index.php/s/cv7gafpbGQdG1nJ*

[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*

2014), and in a wider extent, sustainability impacts leakage risk (e.g. uneven working conditions, land-use and land-use change).

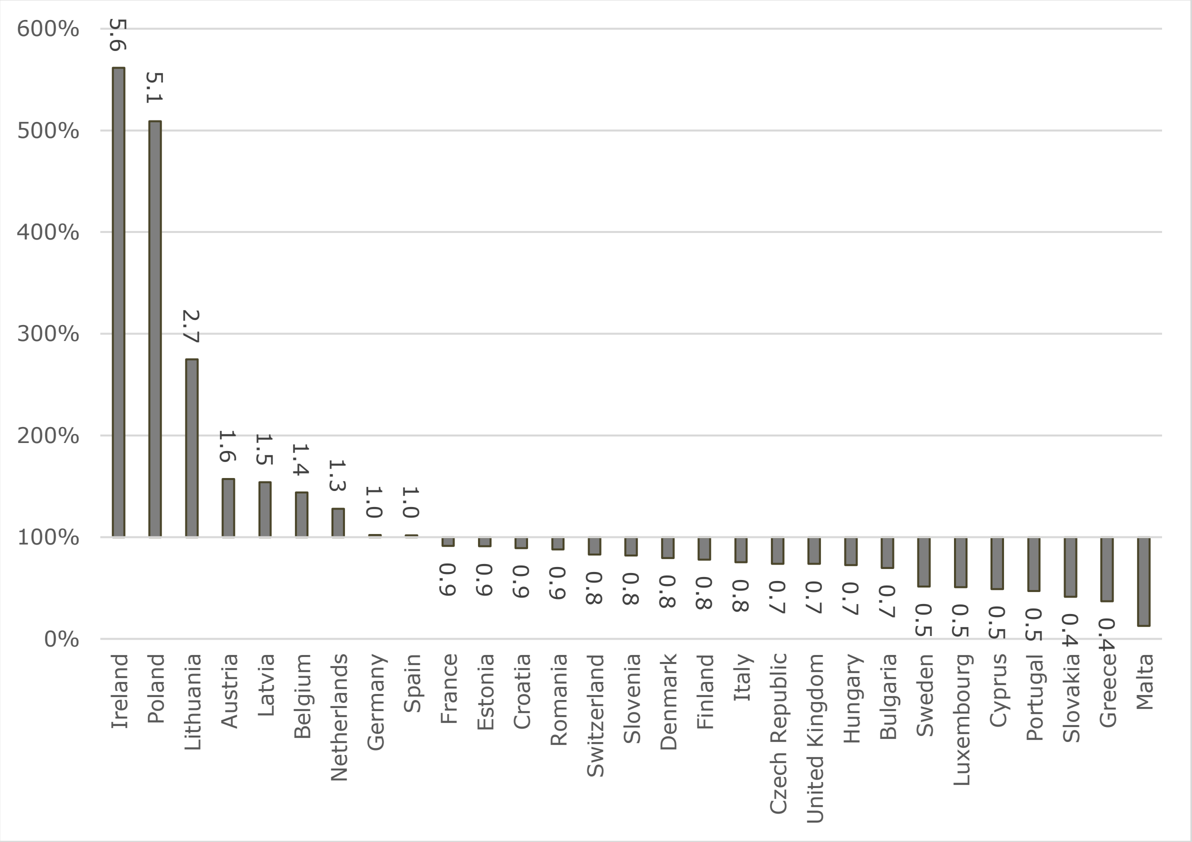

Figure 15 – Self-sufficiency for cattle meat in the EU28+1(2013)[23]

The EU's self-sufficiency level for crop-based food is approximately 81%, and 103% for livestock-based food (Strapasson et al., 2016). Nevertheless, the European Member States present highly heterogeneous self-sufficiency ratio, and thus embedded GHG emissions through food goods, as illustrated by the Figure 15.

Ireland is exporting 5.6 times more cattle meat than it is consuming. Based on the most recent emission factors estimated by the FAO[24], the meat production in 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

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[23] 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*

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

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 emissions.

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 percentage (%). The levers enable to set the imports, exports and domestic production for each food group, expressed in kcal. Given the import level, the lever also enables to track and assess 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[25] (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.

Lever setting – Observed data

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[25] Specific deliverables, namely D4.2 and 4.3, are covering the stakeholder workshops regarding the present document features

Current situation: As mentioned previously, the EU's self-sufficiency level for the livestock-based food is slightly positive (Figure 16). The production of the major crop types and crop-based goods is much more heterogeneous (Figure 17).

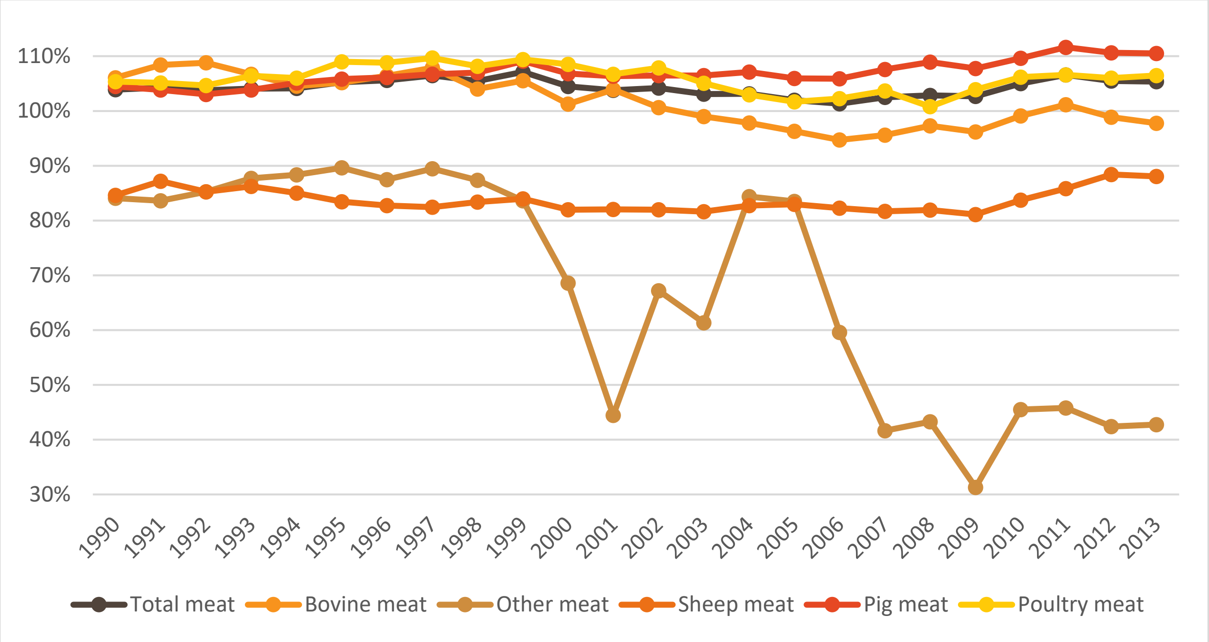

Figure 16 – Self-sufficiency for meat in the EU28[26]

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[27]. 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.

As shown by Figure 17, 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

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[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

[27] 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

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.

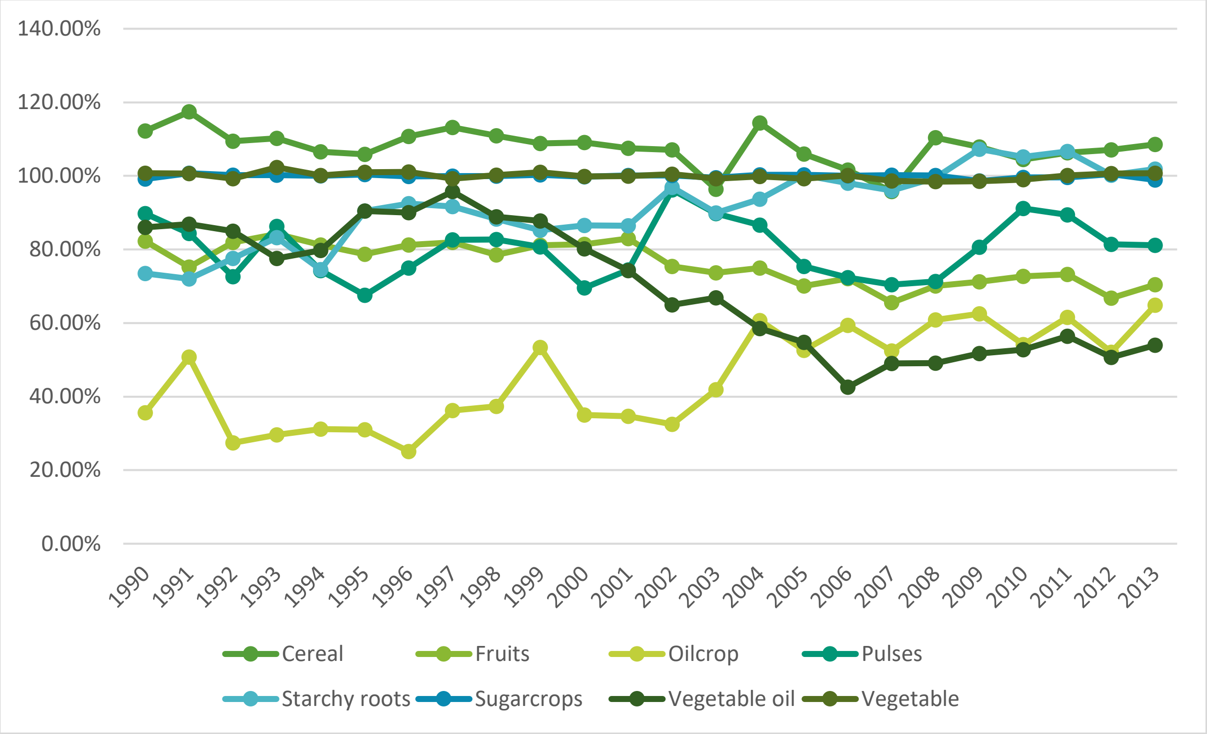

Figure 17 – Self-sufficiency for major crop-based food group in the EU28[28]

Lever setting – Ambition levels

<u>Scenarios for 2050:</u> 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 4).

Table 4 – 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%

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[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

Given this approach, Figure 18 and Figure 19 illustrate 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 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).

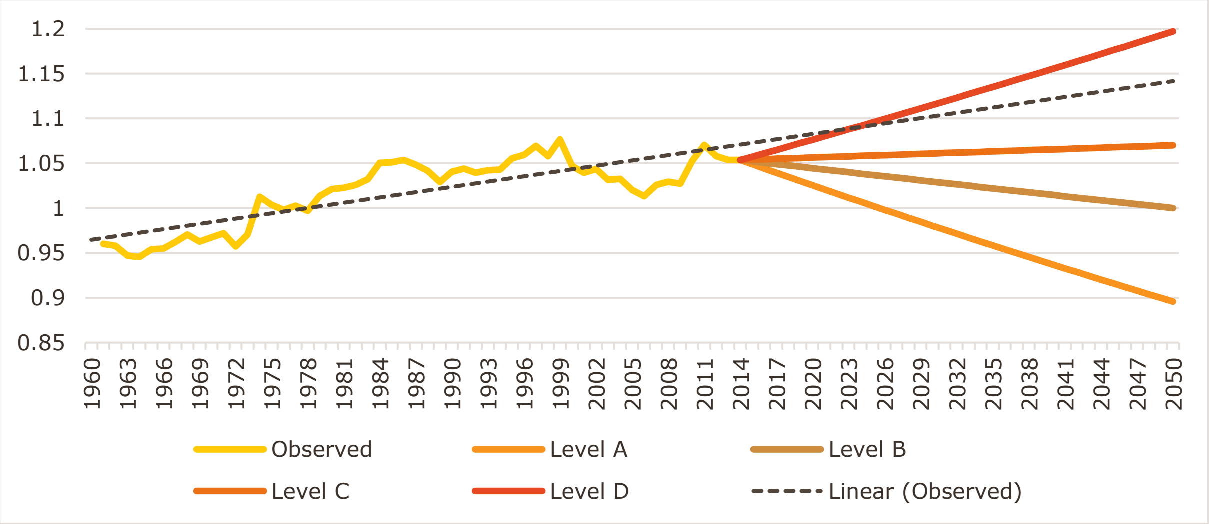

Figure 18 – Self-sufficiency for meat in the EU28 by 2050[29]

The same rationales can be applied to crops (Figure 19). 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.

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[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

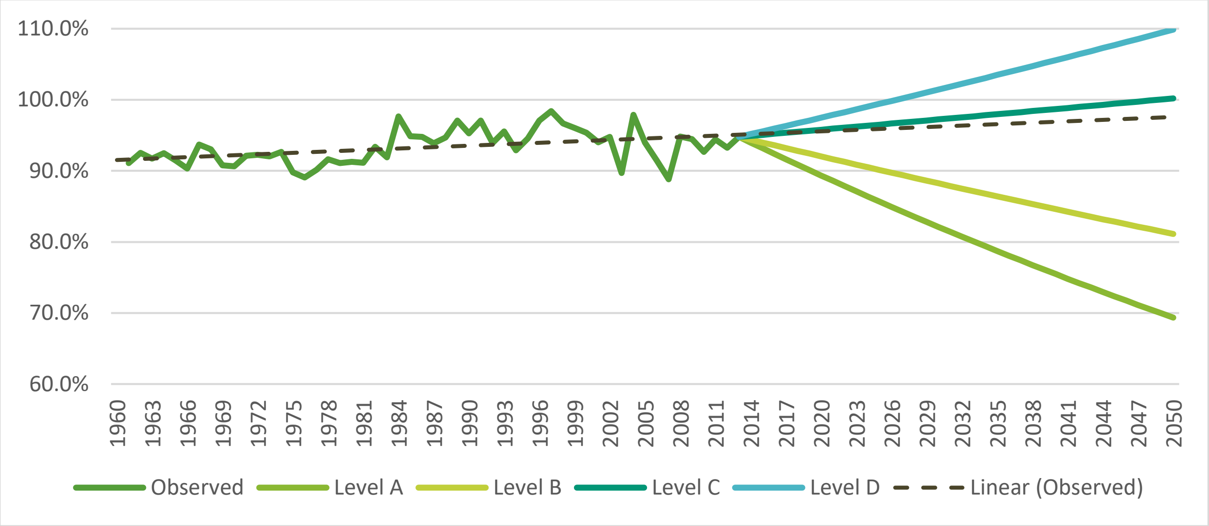

Figure 19 – Self-sufficiency for crop-based food in the EU28 by 2050[30]

Lever setting – Disaggregation method

As shown by the Figure 20, 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 Figure 18 and Figure 19, but without setting any convergence between the countries to keep considering the heterogeneous agricultural context of each member states.

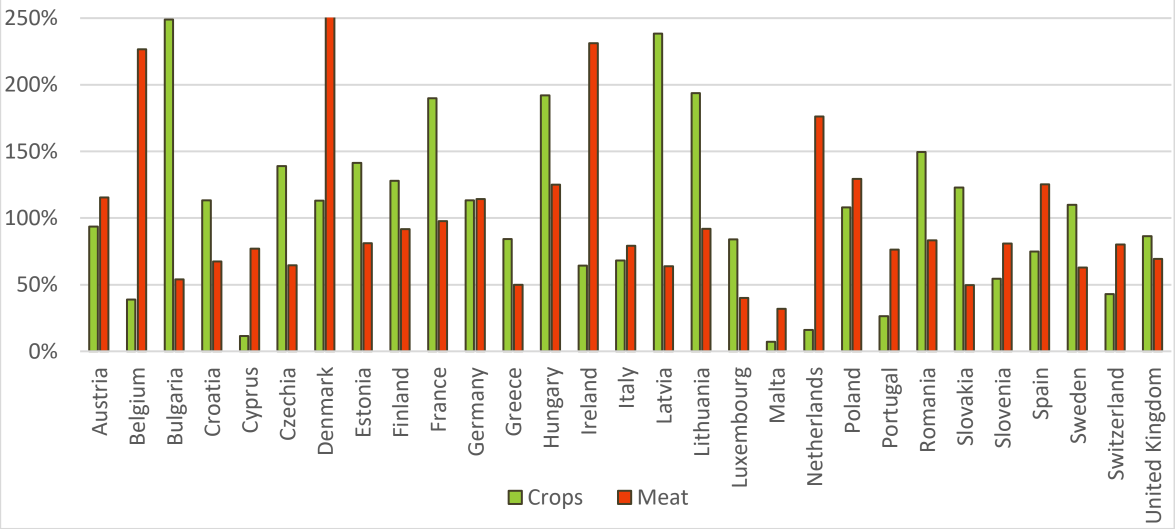

Figure 20 – Food self-sufficiency ratio among EU member states + Switzerland in 2013[31]

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[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

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

2.1.2 Climate-smart crop production systems

Lever rationales

As shown by Figure 21, 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).

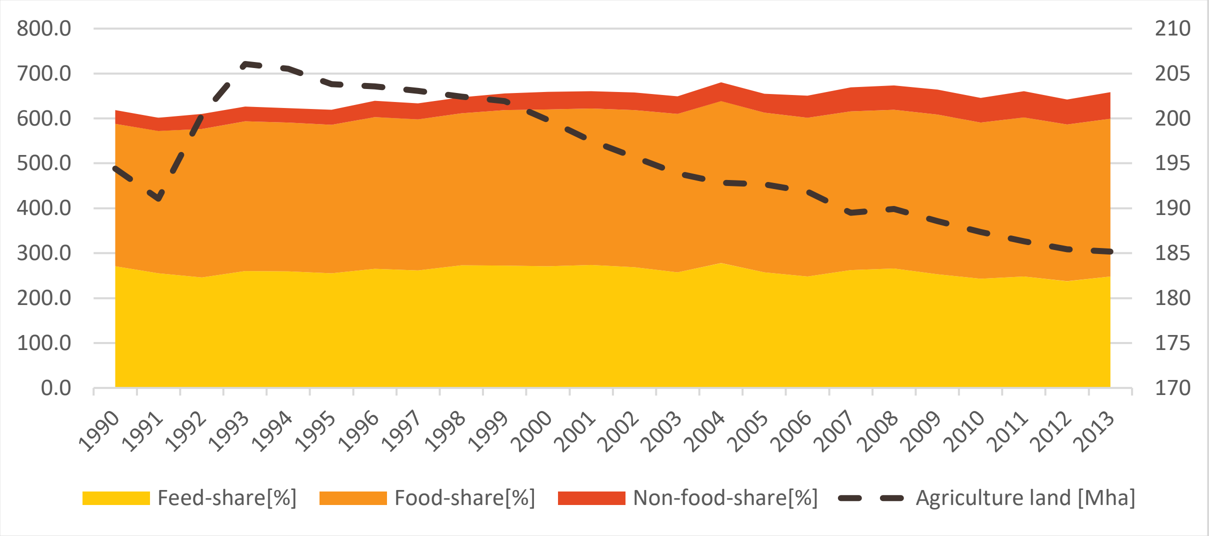

Figure 21 – Agriculture commodity consumption by use (%, left axis) and total agriculture land use (Mha, right axis)[32]

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*

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

[32] 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

> *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.

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 5 – 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) – *included in the yiels -*	%

Table 5 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.

Lever setting – Observed data

Agriculture land represents 39% of the Europe land cover[33], 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 22), the context in each member state (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.

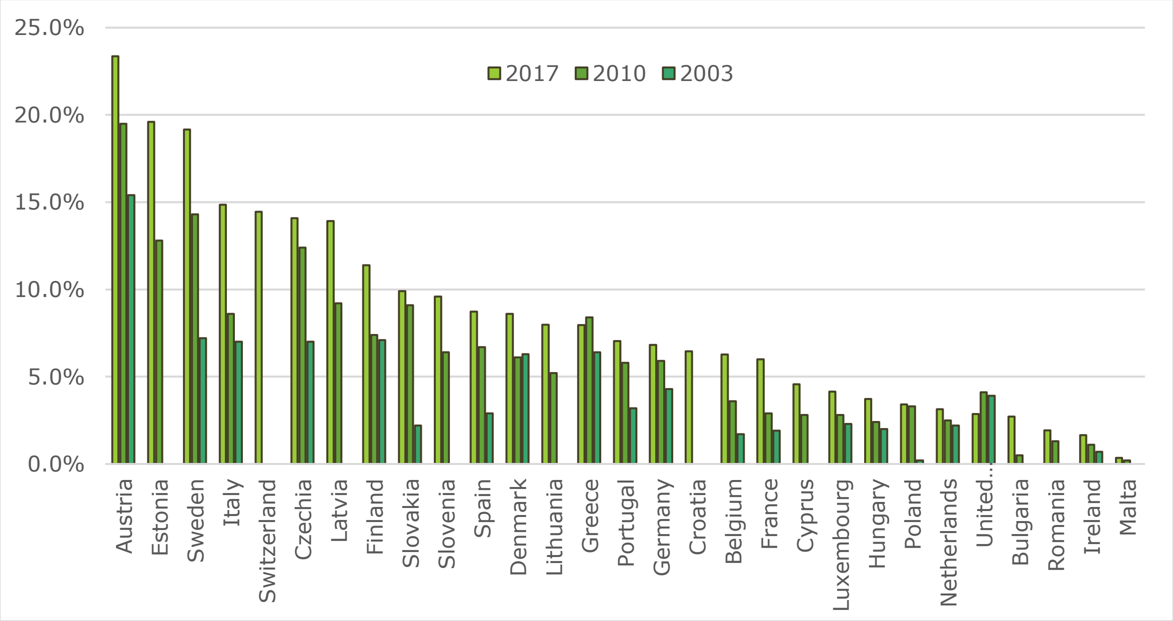

Figure 22 – Share of land under organic farming practices in the EU 28+1 since 2003[34]

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[33] 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

[34] EUROSTAT: land-cover (dataset: org_cropar), Direct link: https://ec.europa.eu/eurostat/data/database

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 heterogeneous. 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[35]. The practice enables using less inputs while using best ecosystem natural services. Depending 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:

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).

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[35] FAO definition, Conservation agriculture; Direct link: http://www.fao.org/conservation-agriculture/en/

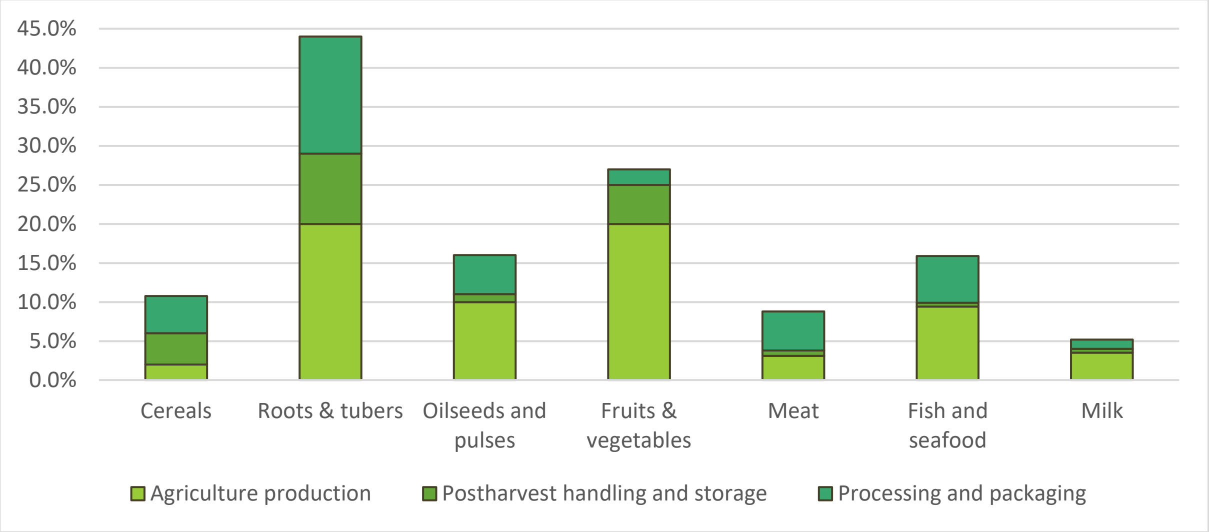

Figure 23 – Food losses by production stages in Europe (Gustafsson et al., 2013)

Crop yields: the crop yields at the EU level have almost been increasing continuously since 1990, a 40% increase in 25 years (Figure 24, 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.

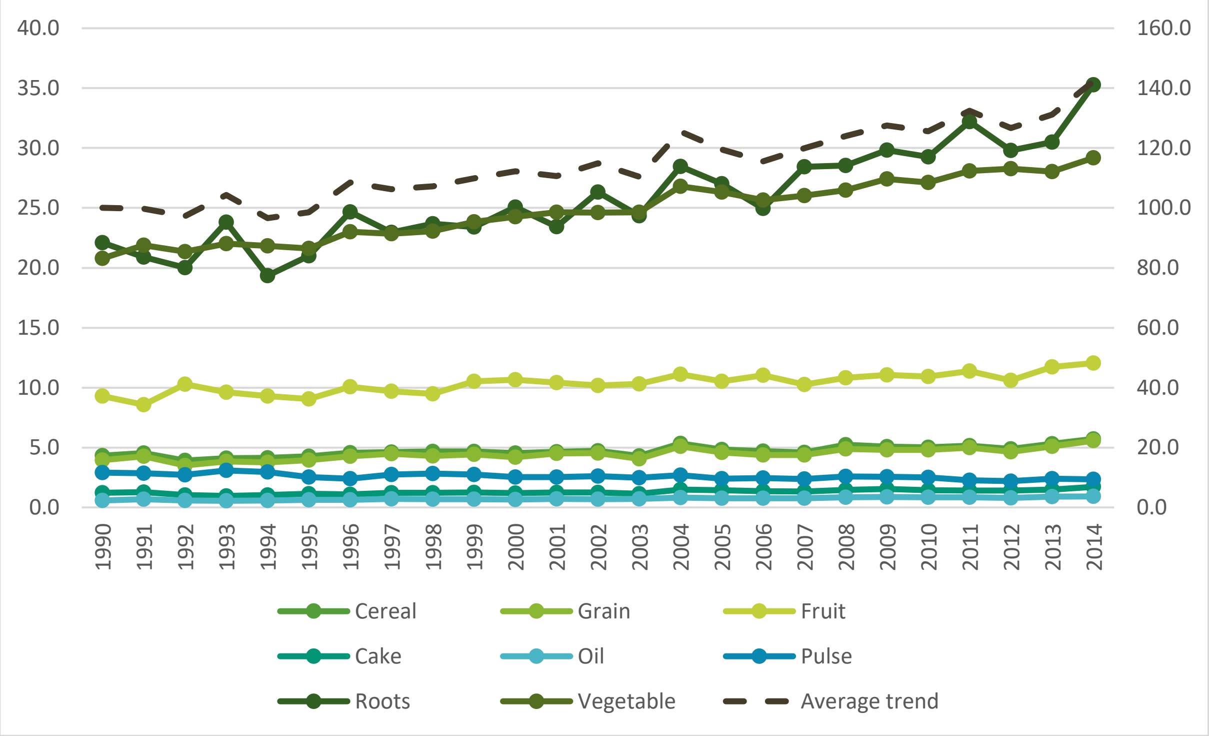

Figure 24 – Average crop yield in the EU28 since 1990[36]

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[36] Food and Agriculture Organization (FAO), FAOSTAT, Crops;

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 25).

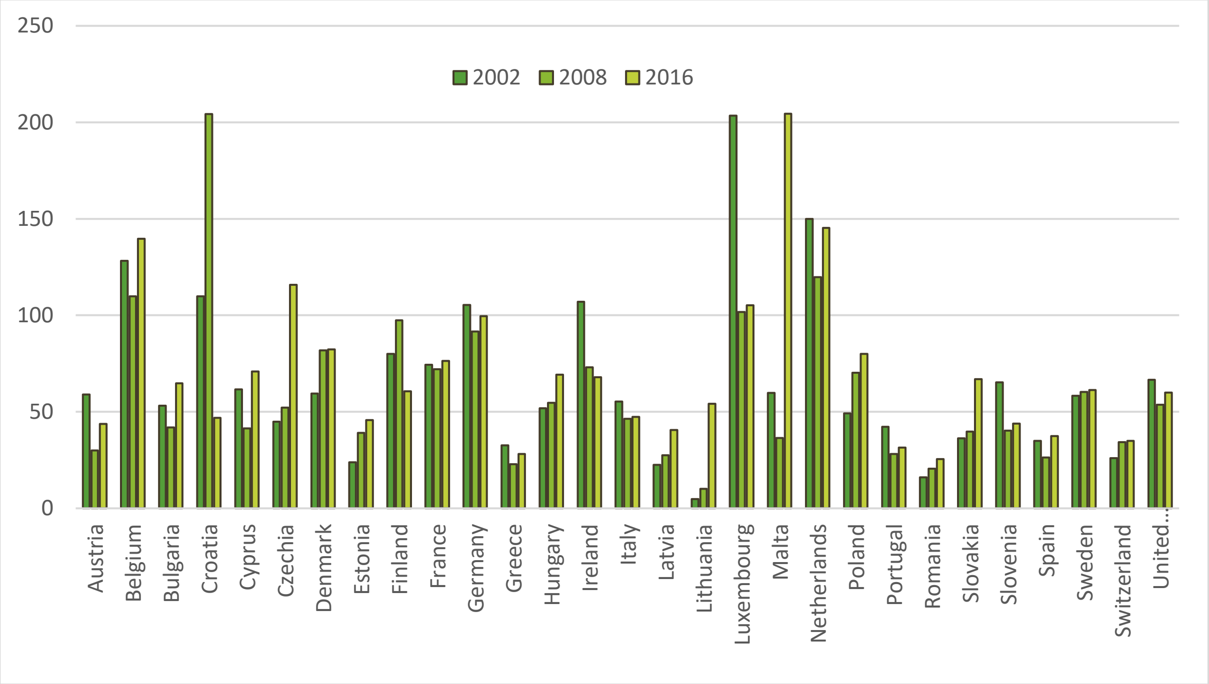

Figure 25 – Synthetic fertilizer use in the EU28+1 in kg/ha[37]

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 26).

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

[37] Food and Agriculture Organization (FAO), FAOSTAT, Fertilizers by nutriment;

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

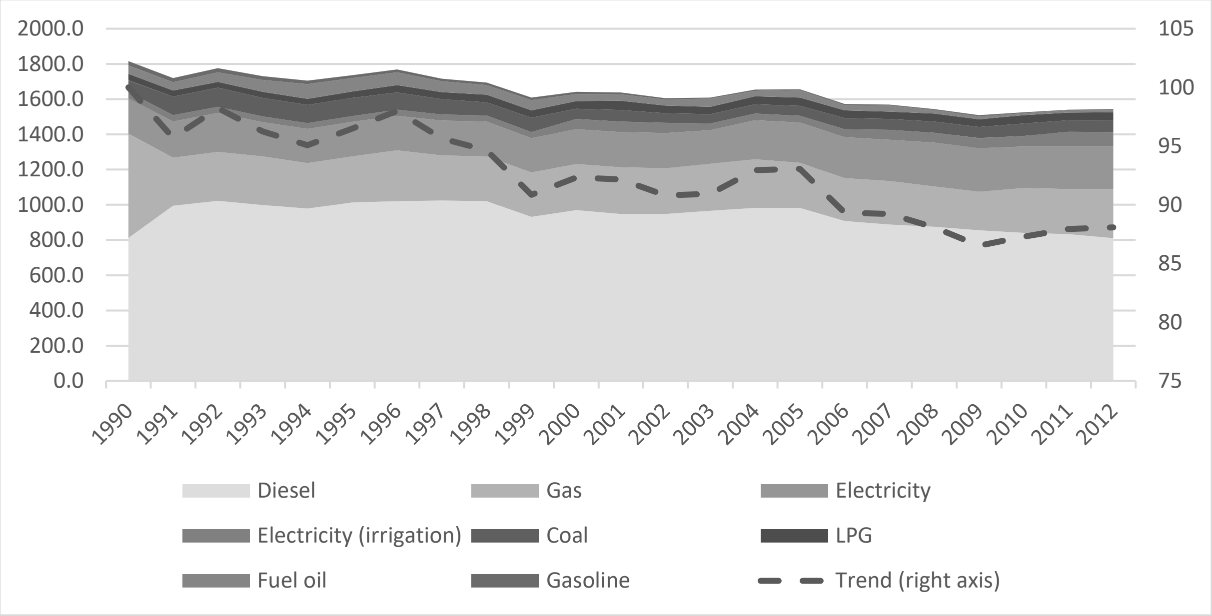

Figure 26 – Average energy consumption by type in kWh/ha in the EU28, since 1990[38]

Residues for soil quality: Table 6 presents the current use of the residues in each EU member state, based on Searle and Malins (2015). Data from Table 6 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) estimate 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.

Table 6 – 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%

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[38] Food and Agriculture Organization (FAO), FAOSTAT, Energy-use;

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

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 7 – 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 7), 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 maximizing the use of ecological processes in the functioning of agroecosystems. 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.

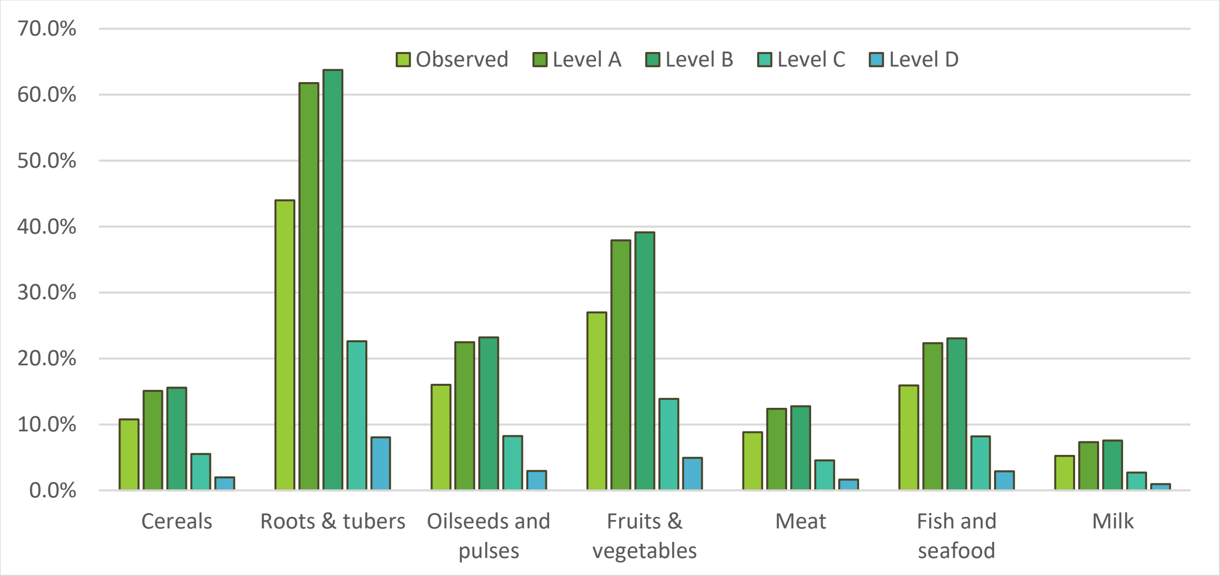

Figure 27 – Estimated food wastes & losses by production stages in Europe by 2050 (Gustafsson et al., 2013)

As shown by Figure 27, 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 28 presents the example of the maize yield according to the 4 scenarios.

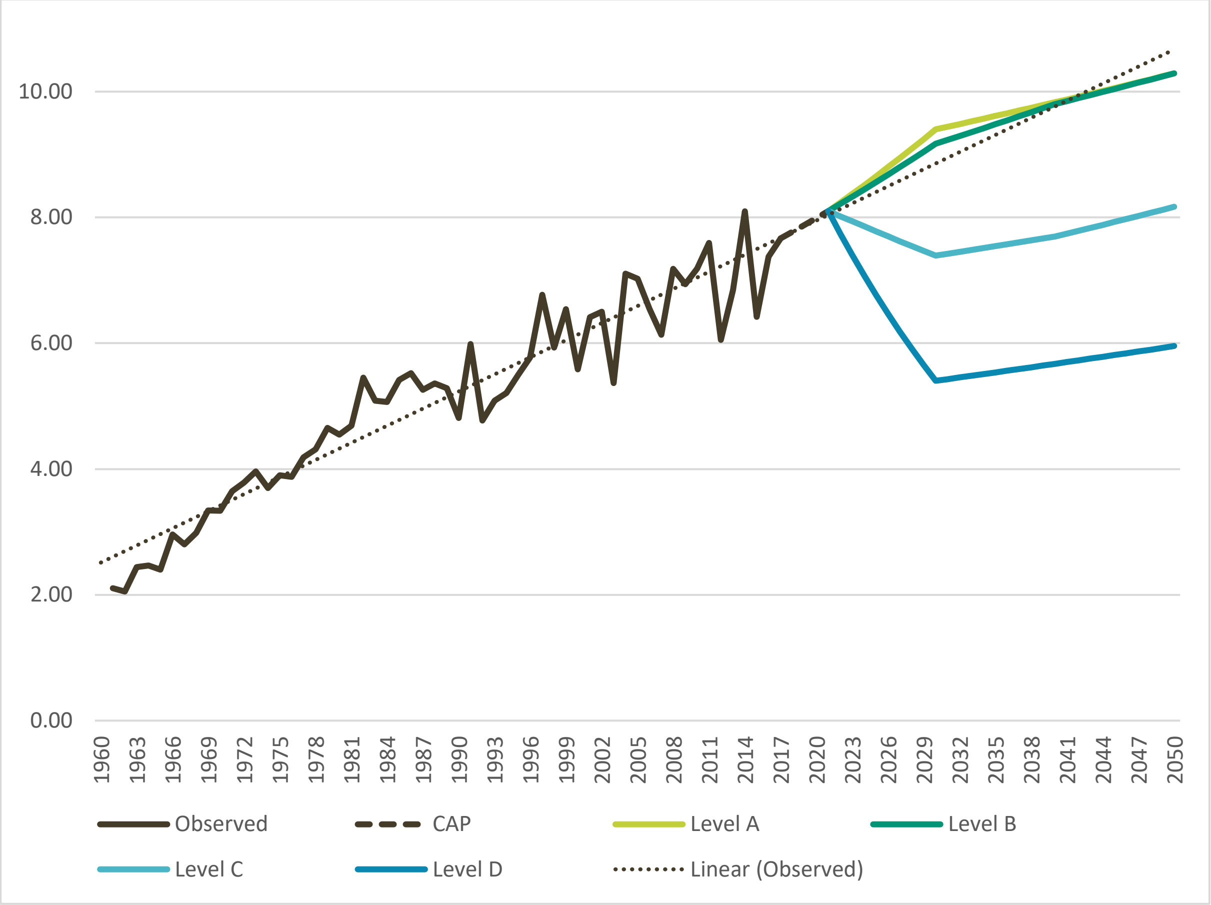

Figure 28 – Average estimated maize yield evolution in Europe by 2050 per scenario

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 29 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).

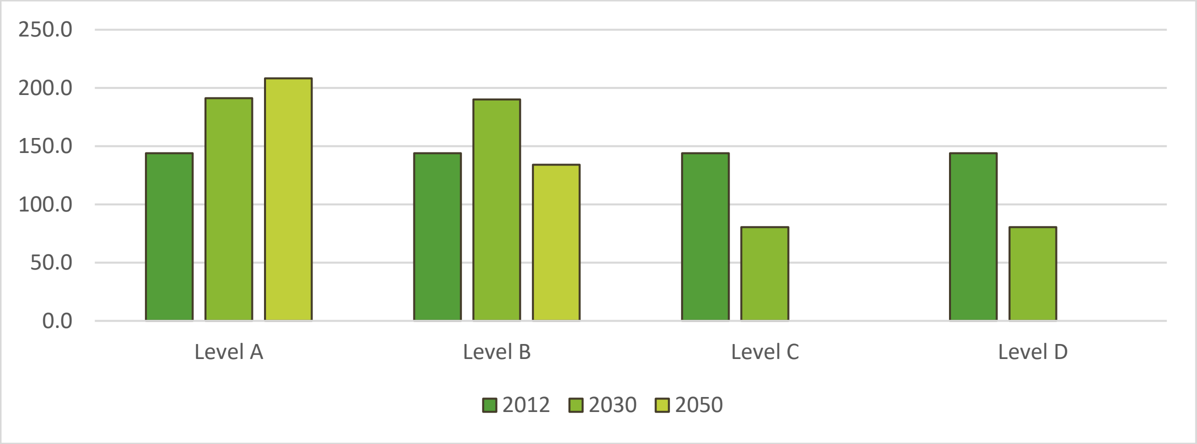

Figure 29 – Estimated of the average fertilizer-use evolution in Europe by 2050

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

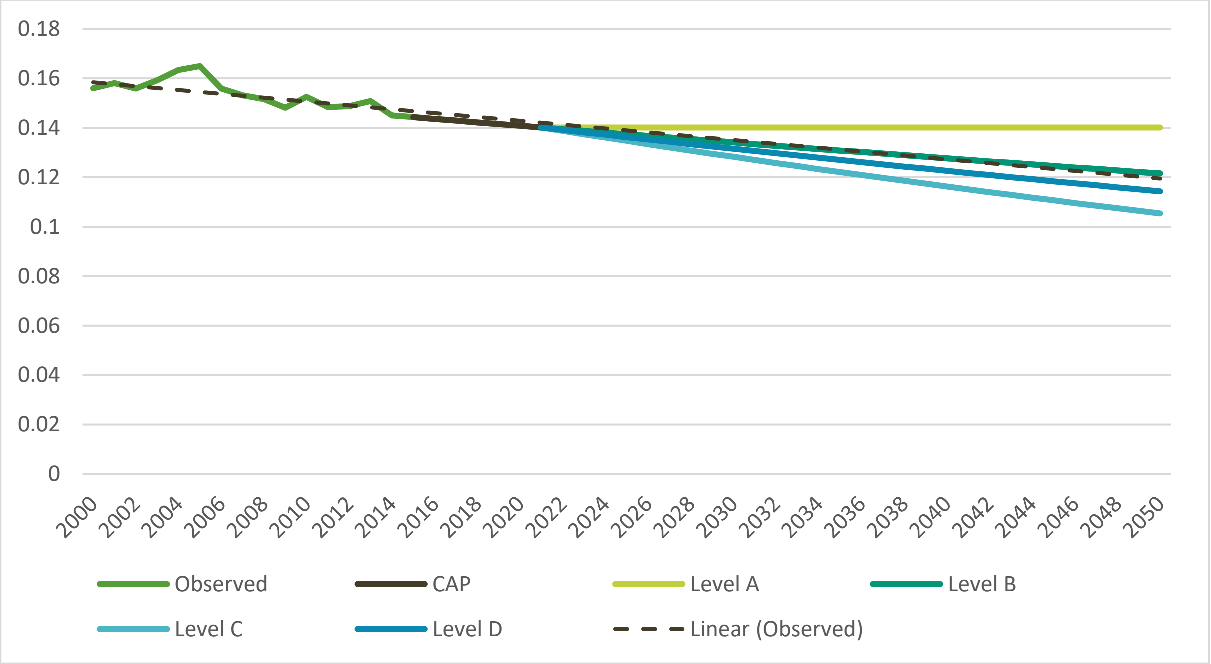

Figure 30 – Estimated energy-use per ha by 2050[39]

Energy-use: Figure 30 presents the energy-use associated with the deployment of the different scenarios. Main assumptions are based on FAO pathways by 2050 (FAO,

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[39] FAO crop

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 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 launch 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 31. Given the lack of data at the Country level, the presented rates are applied against the reference year data for each country (2010).

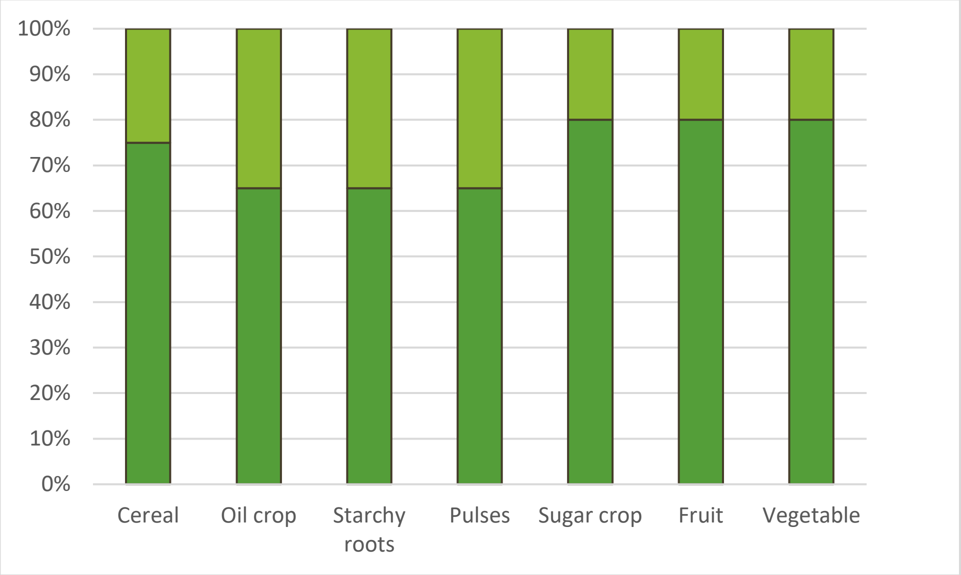

Figure 31 – Estimated yield decrease compared with 2010 for agroecology in Europe (Poux and Aubert, 2018)

2.1.3 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 32), 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.

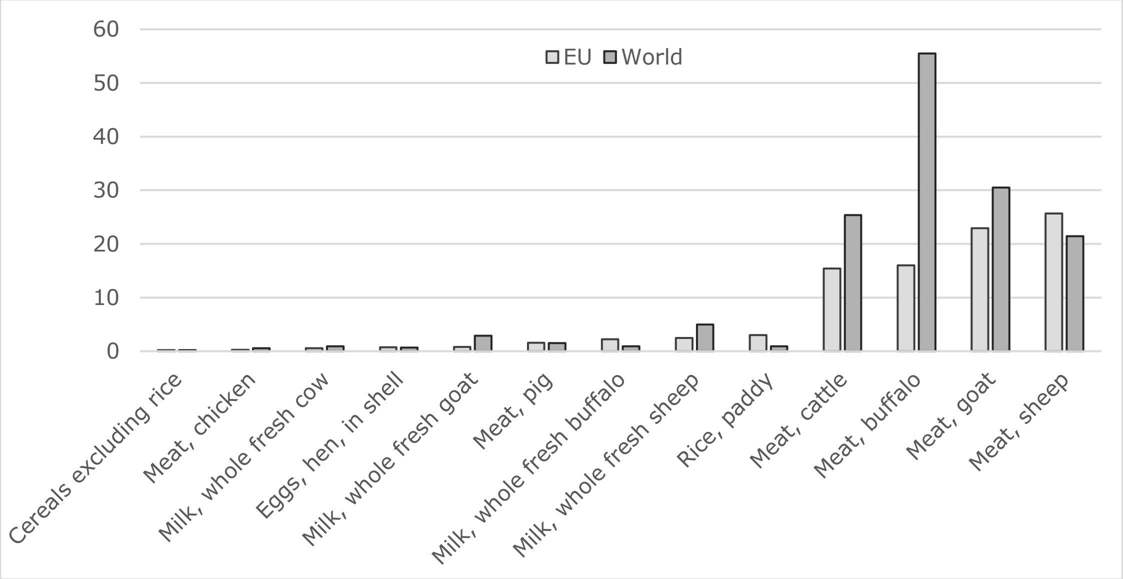

Figure 32 – Emission factor by food group (2013)[40]

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

#	Sub-lever…	… in brief	Unit
1	Losses	Sets the share of losses towards the agri-food production system including agriculture	%

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[40] Food and Agriculture Organization (FAO), emissions intensities;

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

	(meat)	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 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 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).'*[41]

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[41] Eurostat glossary, livestock unit definition;

Direct link: https://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary:Livestock_unit_(LSU)

Thanks to the LSU, livestock can be expressed in a common unit which enables aggregating different animal types. Table 9 presents the lsu factors that are used in the model:

Table 9 – 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 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 results and only focused 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[42].

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

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[42] Food and Agriculture Organization (FAO), enteric fermentation;

Direct link: *http://www.fao.org/faostat/en/#data/GE* extensive to intensive approach, and explicitly suggest distinguishing cropping and livestock system.

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[43]."*

As shown by Figure 33, despite an increasing trend, the share of livestock organic farming is still representing a slight share of livestock production.

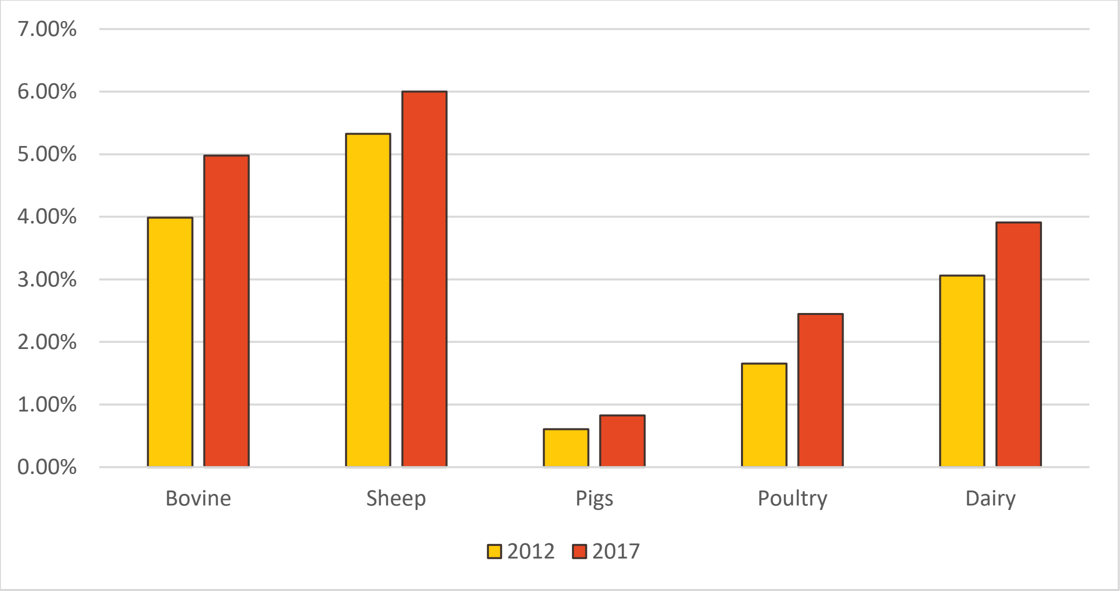

Figure 33 – Organic share of the livestock population in the EU28+1[44]

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,

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[43] 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*

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

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:

<u>Food wastes & losses (meat):</u> the extent of wood waste at the different production stages for the livestock-based commodity are aggregated though the meat, fish and milk groups. Table 10 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):

Table 10 – Animal based products wastes & losses %

Food Group	**Agriculture production**	**Postharvest handling and storage**	**Processing and packaging**
Meat	3.1%	0.7%	5.0%
Animal based products	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.

<u>Livestock yields:</u> the trend for livestock yields during the last decades is mainly positive (Figure 34) for all livestock types, mainly thanks to genetics (e.g. breeding) and feed (e.g. concentrates) (Poux and Aubert, 2018).

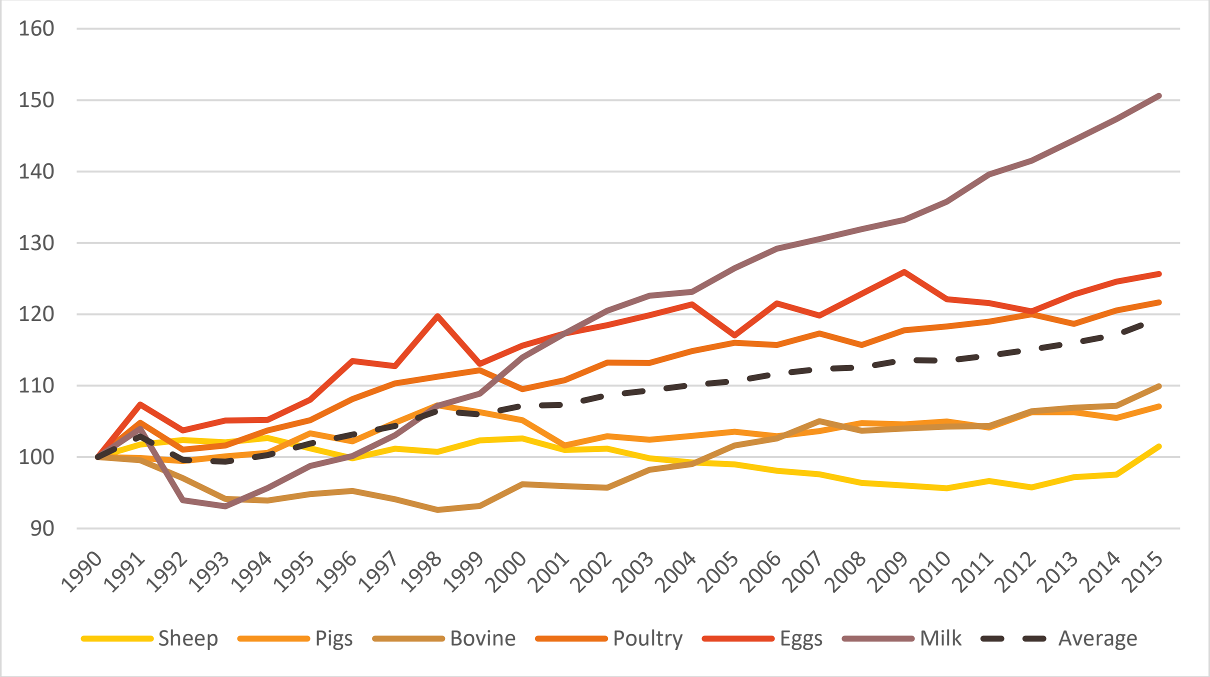

Figure 34 – Livestock yield evolution in the EU28+1[45]

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 35, 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%.

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[45] Food and Agriculture Organization (FAO), Livestock primary;

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

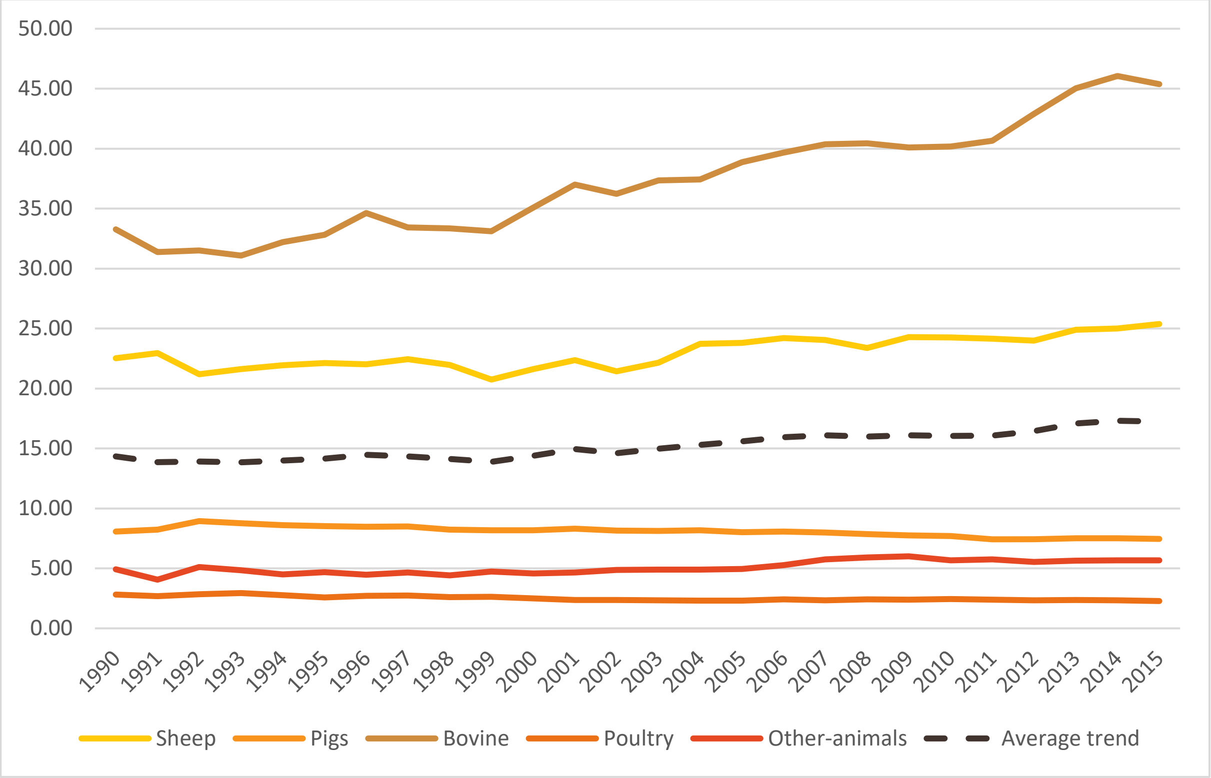

Figure 35 – Livestock average slaughter age in EU28+1 since 1990 (months/animal type)[46]

<u>Manure management:</u> the split of manure management practice depends on the livestock type, and the agricultural practices within the country. As shown by Figure 36, although the manure production decreased with the livestock population, the manure management practices mix remains roughly constant.

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[46] Food and Agriculture Organization (FAO), Livestock primary;

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

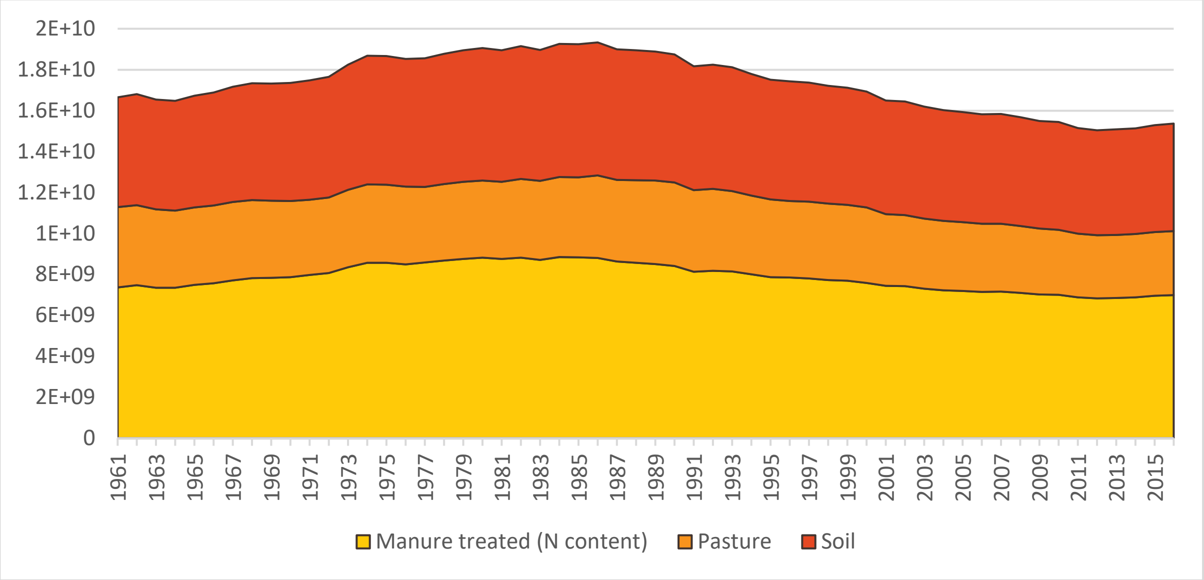

Figure 36 – Manure management practices in the EU28 since 1961 (kgN)

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 11 enteric fermentation emission factors per livestock type used by FAOSTAT.

Table 11 – Enteric fermentation emission per livestock type[47]

Livestock type	kgCH₄/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

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[47] Food and Agriculture Organization (FAO), enteric fermentation;

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

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 37).

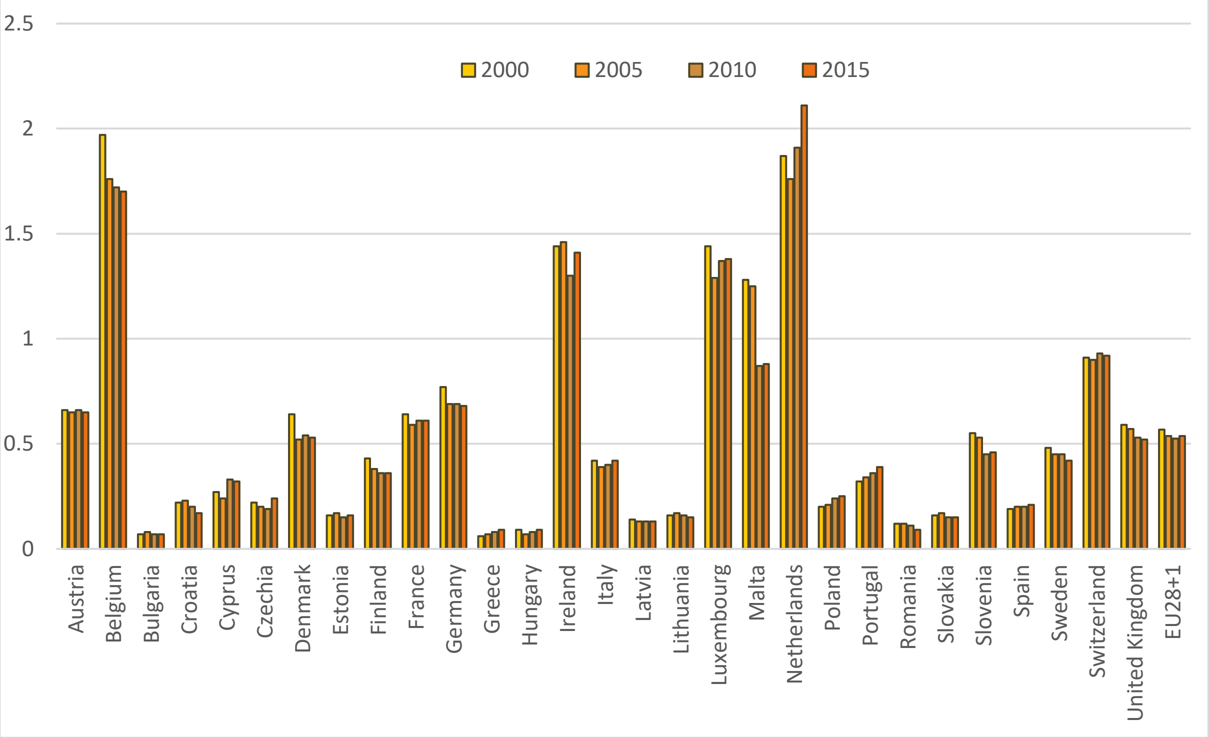

Figure 37 – Cattle density in the EU28+1[48]

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

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[48] Food and Agriculture Organization (FAO), Livestock patterns;

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

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 12).

Table 12 – 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%
Animal based products	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 38). Such as crop yields which are affected by the change of production systems, the agriculture module assumes a linear trend 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 European level, but while considering the heterogeneity between the countries.

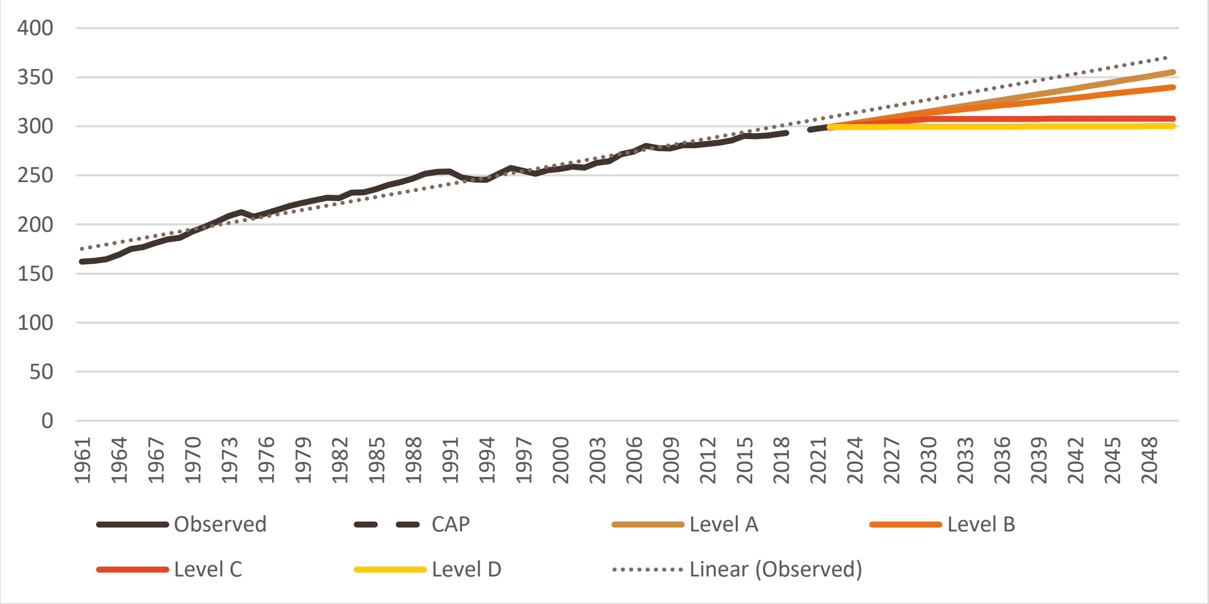

Figure 38 – Non-dairy cattle yields in the EU[49] (FAO, 2018; Poux and Aubert, 2018)

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[49] Food and Agriculture Organization (FAO), Livestock primary;

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[50]. For extensive approaches, we will apply the current gap between the average slaughter age of each livestock type, between intensive and extensive approach.

Table 13 – European average annual slaughter rate, 2015-2050 (in %)

Animal	**Observed[51]**	**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.

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*

[51] Food and Agriculture Organization (FAO), Livestock primary;

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

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 levels 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).

Grazing intensity is set depending on the ambition level setting as presented by Table 14. 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 14 – 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.

2.1.4 Alternative protein sources (livestock)

Lever rationales

In the EU, the livestock is fed using approximatively 480 Mt of feedstuffs (FEFAC, 2016)[52]. In other words, more than half of the available crop, more than 60% of the cereals and 70% of oil crops are currently consumed by 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).

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

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

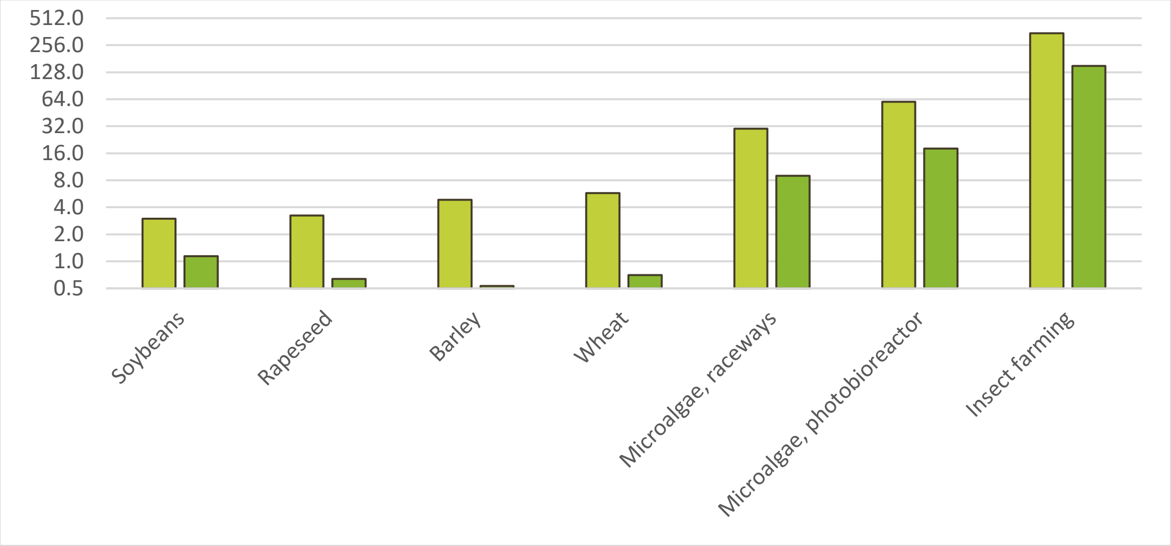

Figure 39 – Typical yields and protein yields of crops, microalgae and insects[53] *(t/ha, logarithm scale) , (Baudry et al., 2018a; Dossey et al., 2016)*

It is worth mentioning that both microalgae biorefinery and insect farming must valorize 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:

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[53] Food and Agriculture Organization (FAO), FAOSTAT, Crops;

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

Table 15 – 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 from agricultural production systems levers. Table 16 presents the sub-levers included in the 'alternative protein sources for livestock' lever:

Table 16 – 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 oil crop-based 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 domestic-production 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 flow), it was finally acknowledged that it should be a stand-alone lever.

Lever setting – Observed data

Figure 40 presents the current feed consumption per type, excluding grazing, for each member states and Switzerland.

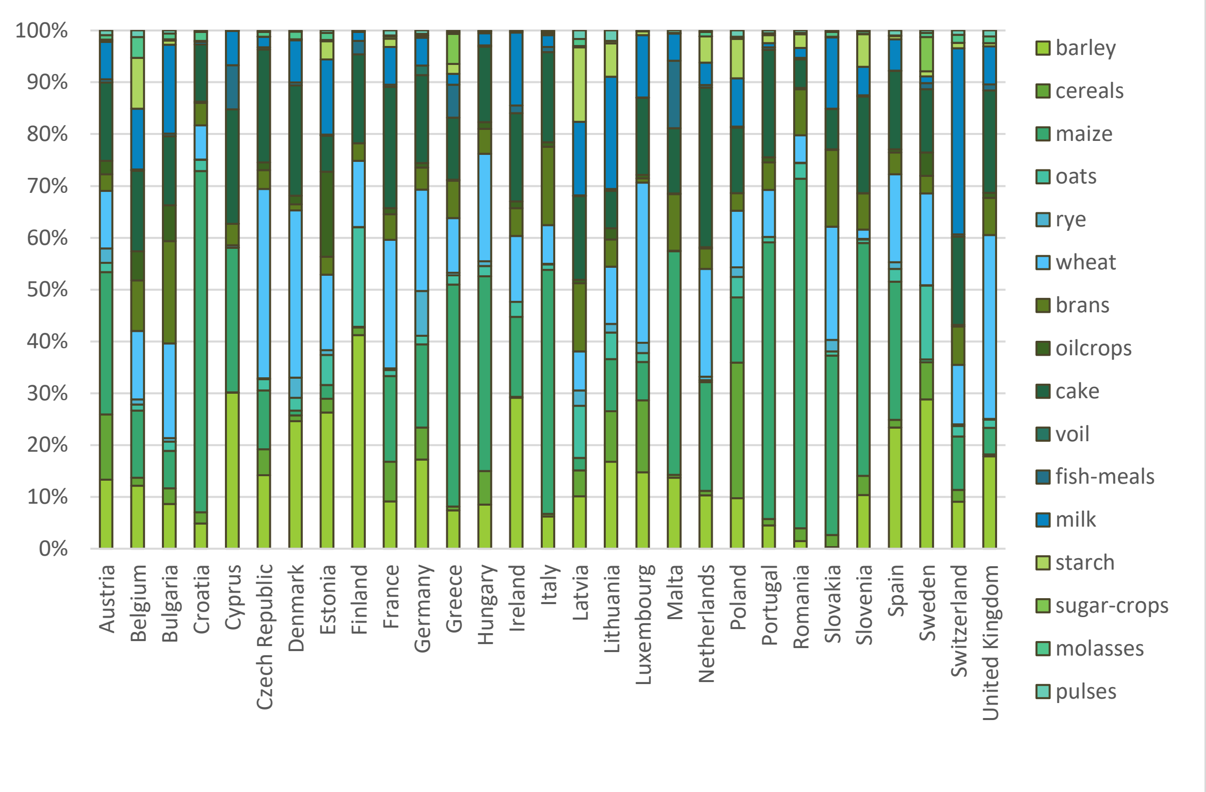

Figure 40 – Feed consumption by type and by country in the EU28+1 (2015)[54]

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

<u>Insect-based meals:</u> 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).

<u>Algae-based meals:</u> 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

<u>Insect-based meals:</u> 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.

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

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

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 17 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 17 – 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.

Lever setting – Disaggregation method

Given the lack of a country specific database, the data presented in Table 17 is applied homogeneously across the European countries, following the approach detailed for food wastes and losses.

2.1.5 Bioenergy capacity

Lever rationales

The European Union renewable production represented 226.5 Mtoe by 2017, with an average increase of 5.1% per year since 2007. Following this trend, the production capacity would double every 14 years. Renewable energy represents 17.5% of the overall energy consumption[55].

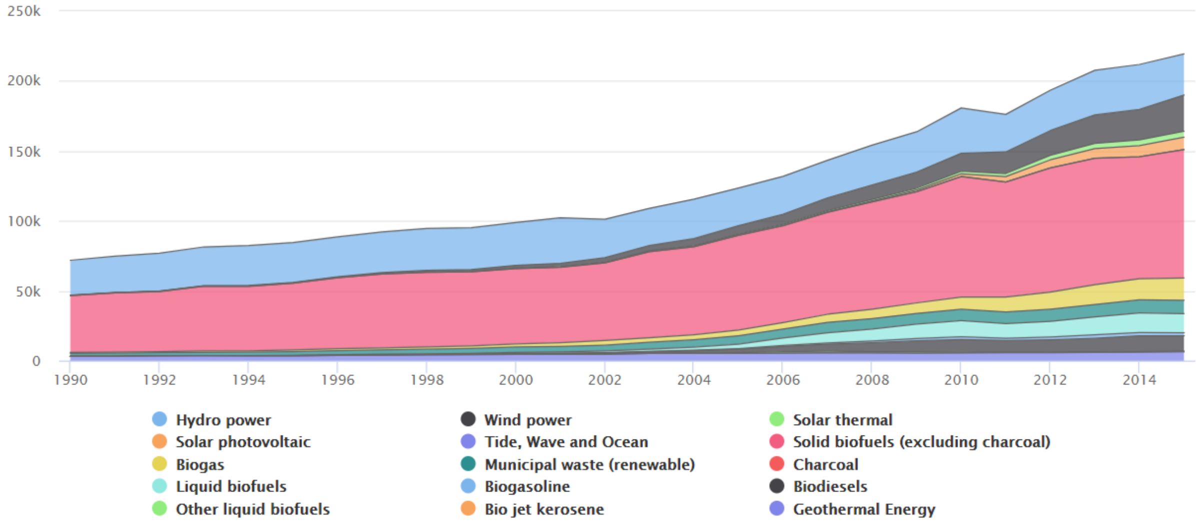

Figure 41 – Renewable energy consumption in the EU28+1 (expressed in ktoe)

As presented in Figure 38, bioenergy represents the main renewable energy carrier with 62% of the European production. The bioenergy 2015 breakdown includes 75% for solid bioenergy, used for power and heating, 13% for biogas and finally 12% for liquid biofuels used as diesel and gasoline in the transport sector.

Beyond the consumption and production volumes, bioenergy is critical in terms of sustainability issues through multiple aspects, including the biomass feedstock sustainability (see the next section: biomass-use hierarchy) in terms of GHG emissions, use-competition, and food security. Although controversial, bioenergy is critical regarding net-zero pathways through LULUCF but also BECCS (bioenergy with CO_2 capture and storage). The latter potentially enables to remove CO_2 from the atmosphere, hence allowing CO_2 offsetting, or mitigation, of otherwise sectors hard to decarbonize such as transportation (Fajardy and Dowell, 2017).

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[55] EUROSTAT: Supply, transformation and consumption of renewable energies - annual data (dataset: nrg_107a), Direct link: https://ec.europa.eu/eurostat/data/database

Lever description

The present lever enables to set the solid, gaseous and liquid bioenergy production capacity in EU28+1 by 2050. Table 28 presents in brief the parameters and variables that are driven by the bioenergy capacity lever.

Table 18 – Sub-lever list included in the biomass hierarchy lever

#	**Sub-lever…**	**… in brief**	**Unit**
1	Solid biofuel-based electricity	Sets the production capacity of solid biofuel-based electricity, including both CHP and only power generation	GW
2	Biogas	Sets the production capacity of biogas, and the biogas technology mix including digestor, landfill, sewage, other-biogases, thermal-biogases, renewable municipal-wastes	GW, %
3	Liquid biofuels	Sets the production capacity of liquid biofuel, including biogasoline, biodiesel, biojetfuel and other biofuels	ktoe
4	Efficiency	Sets the efficiency per technology type while distinguishing existing and new-capacities heterogeneous efficiency	%
5	Load factors	Sets the load factors per technology type while distinguishing existing and new-capacities heterogeneous load-factors	%

Solid biofuel-based electricity includes power and heat production units fuelled by primary solid biofuels which refer to charcoal, fuelwood, wood residues and by-products, black liquor, bagasse, animal waste, other vegetal materials and residuals and renewable fraction of industrial waste, according to Eurostat definition[56].

Biogas includes biomass-based gas produced through digestor, landfill, sewage, other-biogases, thermal-biogases, renewable municipal-wastes, according to Eurostat definition.

Liquid biofuels include the production capacity for biogasoline, biodiesel, biojetfuel and other biofuels expressed in ktoe. Depending on the biomass availability (biomass-use hierarchy lever), biofuel capacities will be driven towards different technology conversion pathways including esterification, HVO (Hydrotreated Vegetable Oils), BtL (Biomass to Liquid) for biodiesels; fermentation and enzymatic pathways for biogasoline; HVO and BtL for bio jet kerosene.

Efficiency & load factors: Efficiency refers to the energy output on energy input ratio and sets the biomass demand per energy output. The load factors refer to the ratio between the actual electricity production and the nominal production capacity given a fixed period, usually the year (8760 hours).

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[56] Eurostat, Glossary: Biofuels; Direct link: https://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary:Biofuels

Lever setting – Observed data

<u>Biogas production capacity</u>: Between 2011 and 2016, the biogas production rose from 752 GWh to 17,264 GWh. The agriculture module only considers the biogas produced through digesters, which is the main pathway used in Europe. The following Figure present the technology and mix for biogas in the EU28+1 in 2017.

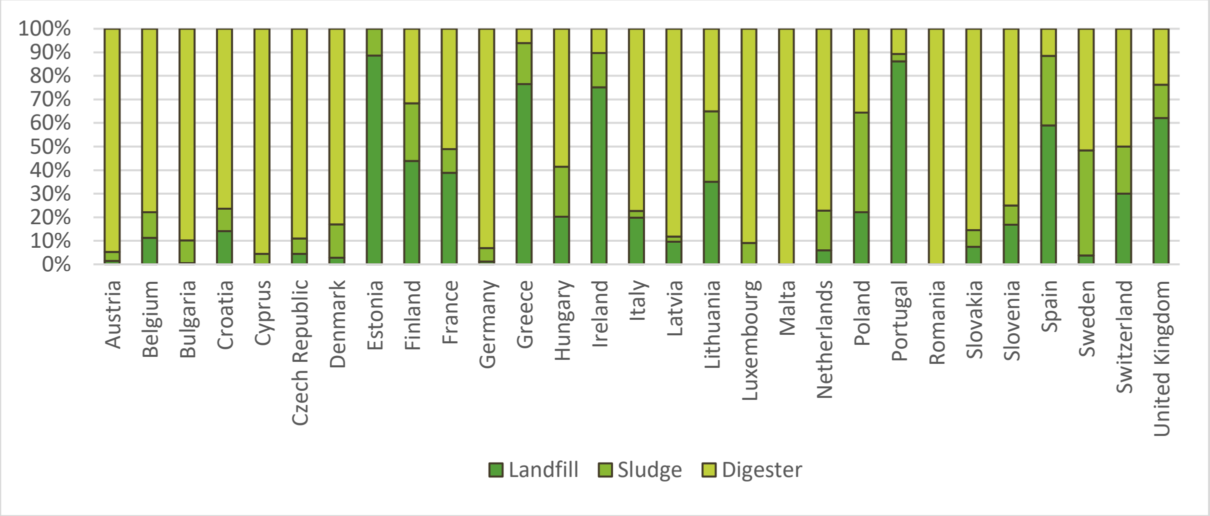

Figure 42 – Biogas technology mix in the EU28+1(2017)[57]

<u>Liquid biofuel production capacity</u>: 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.

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[57] EUROSTAT: Primary production - all products - annual data (dataset: nrg_109a),

Direct link: *https://ec.europa.eu/eurostat/data/database*

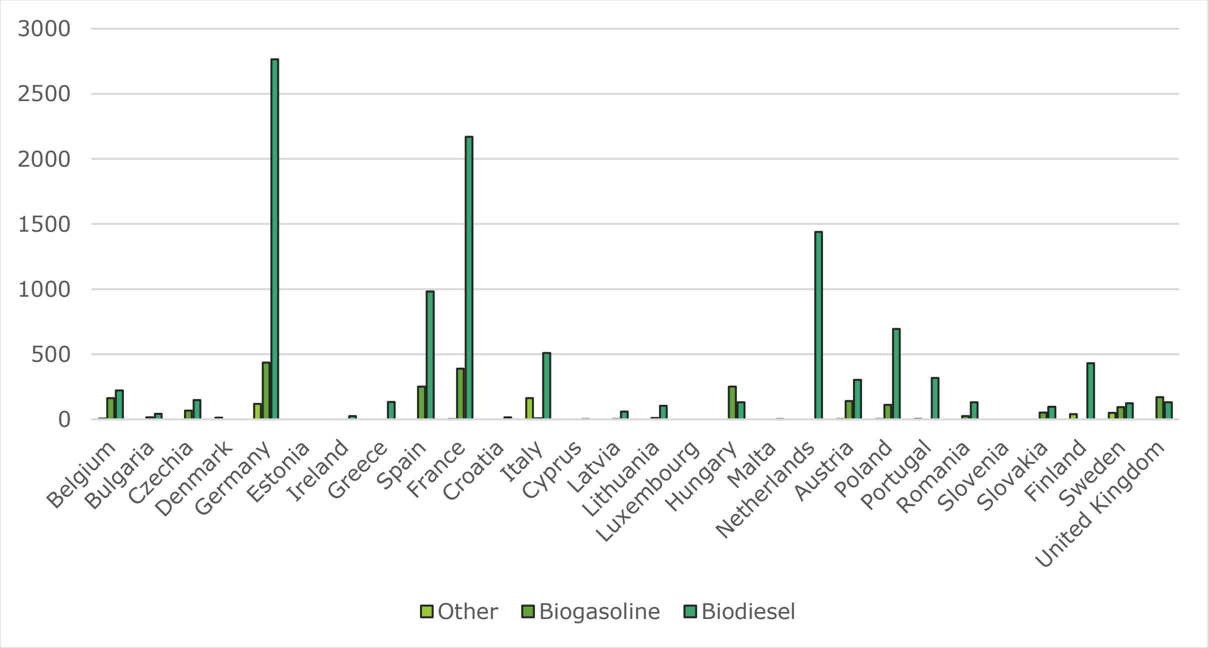

Figure 43 – Liquid biofuel production in the EU28(2015)[58]

<u>Solid biofuel production capacity</u>: Biomass-based electricity capacity represents 17.5GW in 2015, with Sweden, United Kingdom, Finland and Germany representing more than the half of the European total capacities.

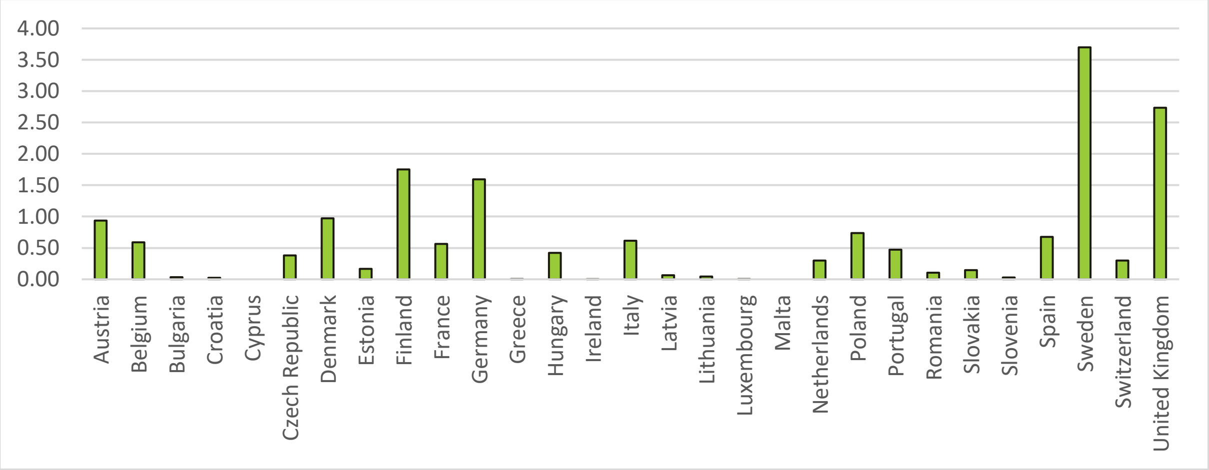

Figure 44 – Solid biofuel production in the EU28(GW)

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[58] EUROSTAT: Primary production - all products - annual data (dataset: nrg_109a),

Direct link: https://ec.europa.eu/eurostat/data/database

Efficiency and load-factors were computed using Eurostat data and IEA factors (production, capacities, CHP shares).

Table 19 - Efficiency for biogas and biomass-based electricity and heating (2015)

Country	Biogas (%)	Biomass (%)
Austria	0.313	0.308
Belgium	0.319	0.312
Bulgaria	0.300	0.300
Croatia	0.300	0.300
Cyprus	0.330	0.320
Czech Republic	0.301	0.301
Denmark	0.300	0.300
Estonia	0.308	0.306
Finland	0.303	0.302
France	0.311	0.308
Germany	0.311	0.307
Greece	0.300	0.300
Hungary	0.318	0.312
Ireland	0.329	0.319
Italy	0.314	0.309
Latvia	0.300	0.300
Lithuania	0.300	0.300
Luxembourg	0.325	0.317
Malta	0.330	0.320
Netherlands	0.309	0.306
Poland	0.317	0.311
Portugal	0.317	0.312
Romania	0.300	0.300
Slovakia	0.300	0.300
Slovenia	0.300	0.300
Spain	0.321	0.314
Sweden	0.300	0.300
Switzerland	0.330	0.320
United Kingdom	0.327	0.318

Lever setting – Ambition levels

Solid biofuel-based electricity: the lever setting considers the pathways provided by as the lower ambition level, while the most ambitious level is based on (Capros et al., 2013) and (Scholz, 2012). Efficiency & load-factors for biomass and biogas units are based on (De Vita et al., 2018).

Table 20 – solid-biofuel based electricity capacities by 2050

Country	2015	Level 1	Level 2	Level 3	Level 4
Austria	0.940	2.470	2.947	3.423	3.900

Belgium	0.590	0.760	0.770	0.785	0.800
Bulgaria	0.030	0.480	0.985	1.743	2.500
Croatia	0.030	0.170	0.278	0.439	0.600
Cyprus	0.000	0.000	0.008	0.019	0.030
Czech Republic	0.380	1.420	1.490	1.595	1.700
Denmark	0.970	1.420	1.515	1.658	1.800
Estonia	0.170	0.420	0.440	0.470	0.500
Finland	1.750	2.120	2.815	3.858	4.900
France	0.570	1.650	2.038	2.619	3.200
Germany	1.590	3.000	4.475	6.688	8.900
Greece	0.002	0.010	0.308	0.754	1.200
Hungary	0.420	0.470	1.203	2.301	3.400
Ireland	0.010	0.020	0.290	0.695	1.100
Italy	0.620	0.780	1.310	2.105	2.900
Latvia	0.070	0.180	0.310	0.505	0.700
Lithuania	0.050	0.110	0.233	0.416	0.600
Luxembourg	0.000	0.010	0.033	0.066	0.100
Malta	0.000	0.000	0.000	0.000	0.000
Netherlands	0.300	0.880	0.985	1.143	1.300
Poland	0.740	1.410	2.133	3.216	4.300
Portugal	0.470	0.510	0.608	0.754	0.900
Romania	0.100	0.330	0.823	1.561	2.300
Slovakia	0.150	0.280	0.560	0.980	1.400
Slovenia	0.030	0.100	0.175	0.288	0.400
Spain	0.680	1.230	1.848	2.774	3.700
Sweden	3.700	4.000	4.050	4.125	4.200
Switzerland	0.300	0.900	1.100	1.400	1.700
United Kingdom	2.740	13.600	13.875	14.288	14.700

Biogas: the extent of the biogas deployment is based on (Kampman et al., 2016) and (Scarlat et al., 2018).

Table 21 - Biogas deployment table

Country	2015	Level 1	Level 2	Level 3	Level 4
Austria	0.19	0.33	0.517	0.703	0.89
Belgium	0.18	0.31	1.350	2.910	4.47
Bulgaria	0.02	0.03	0.170	0.380	0.59
Croatia	0.03	0.05	0.198	0.419	0.64
Cyprus	0.01	0.02	0.030	0.045	0.06

Czech Republic	0.37	0.63	0.643	0.661	0.68
Denmark	0.1	0.18	1.138	2.574	4.01
Estonia	0.01	0.02	0.045	0.083	0.12
Finland	0.00008	0.00014	0.001	0.001	0.0019
France	0.34	0.58	3.843	8.736	13.63
Germany	5.64	9.59	9.768	10.034	10.3
Greece	0.05	0.08	0.133	0.211	0.29
Hungary	0.07	0.12	0.508	1.089	1.67
Ireland	0.05	0.09	1.368	3.284	5.2
Italy	1.34	2.27	2.848	3.714	4.58
Latvia	0.06	0.1	0.128	0.169	0.21
Lithuania	0.02	0.04	0.153	0.321	0.49
Luxembourg	0.01	0.02	0.033	0.051	0.07
Malta	0	0.01	0.010	0.010	0.01
Netherlands	0.24	0.41	1.495	3.123	4.75
Poland	*0.22*	*0.37*	*1.795*	*3.933*	*6.07*
Portugal	0.07	0.11	0.628	1.404	2.18
Romania	0.01	0.02	1.825	4.533	7.24
Slovakia	0.09	0.15	0.360	0.675	0.99
Slovenia	0.03	0.05	0.085	0.138	0.19
Spain	0.22	0.38	1.583	3.386	5.19
Sweden	0	0	0.008	0.019	0.03
Switzerland	0.07	0.13	0.208	0.324	0.44
UK	1.63	2.77	3.223	3.901	4.58

Efficiency: Each countries' power plant stock includes electricity and combined heat and power (CHP) plants, with different efficiency values (Da Vita, 2018; IEA, 2010b).

Table 22 – Efficiency for biogas and biomass-based electricity and heating (2050)

Country	Biogas (%)	Biomass (%)
Austria	0.365	0.367
Belgium	0.353	0.350
Bulgaria	0.390	0.400
Croatia	0.390	0.400
Cyprus	0.330	0.320
Czech Republic	0.387	0.396
Denmark	0.390	0.400
Estonia	0.373	0.378
Finland	0.383	0.391

France	0.367	0.370
Germany	0.368	0.370
Greece	0.390	0.400
Hungary	0.354	0.352
Ireland	0.333	0.324
Italy	0.362	0.362
Latvia	0.390	0.400
Lithuania	0.390	0.400
Luxembourg	0.340	0.334
Malta	0.330	0.320
Netherlands	0.372	0.376
Poland	0.357	0.356
Portugal	0.355	0.354
Romania	0.390	0.400
Slovakia	0.390	0.400
Slovenia	0.390	0.400
Spain	0.347	0.343
Sweden	0.390	0.400
Switzerland	0.330	0.320
United Kingdom	0.335	0.327

Liquid biofuels: The lever setting for liquid biofuels capacity follows ranges between 23.5 Mtoe - European reference scenario (Capros et al., 2013) and 147 Mtoe and (Baker et al., 2017).

Lever setting – Disaggregation method

The setting is common to all the countries.

2.1.6 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 23 – 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 valorization 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 24 – 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 25 – 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

Bioenergy technology mix, feedstock buffer: 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

Industrial byproducts: 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.

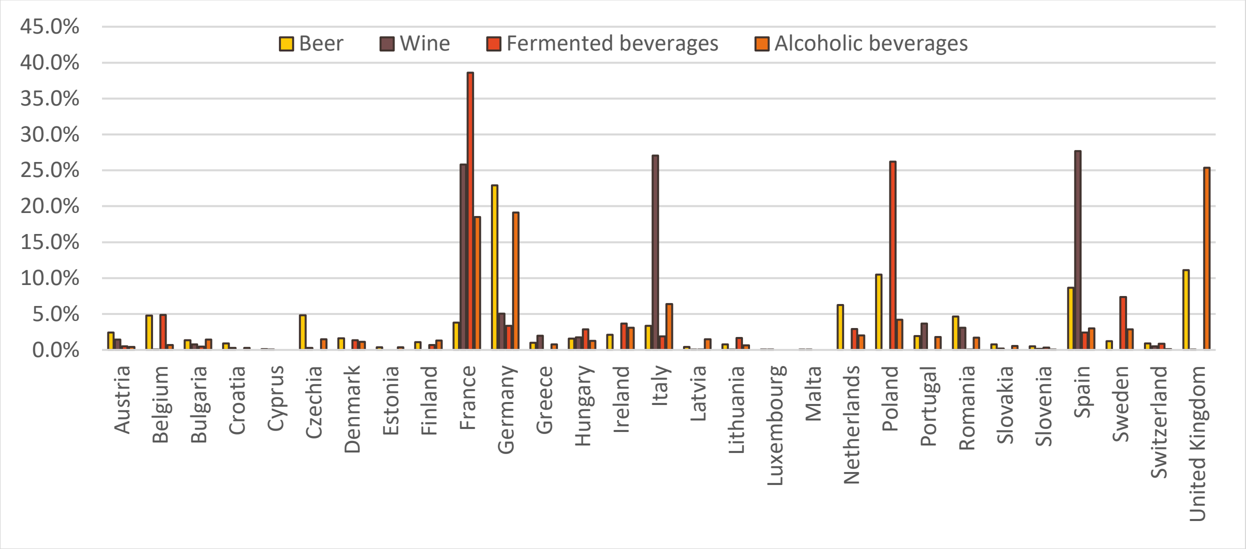

Figure 45 – Share of beer and wine production in the EU28+1[59]

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 26 – 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

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[59] FAOSTAT, Commodity Balances - Crops Primary Equivalent

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

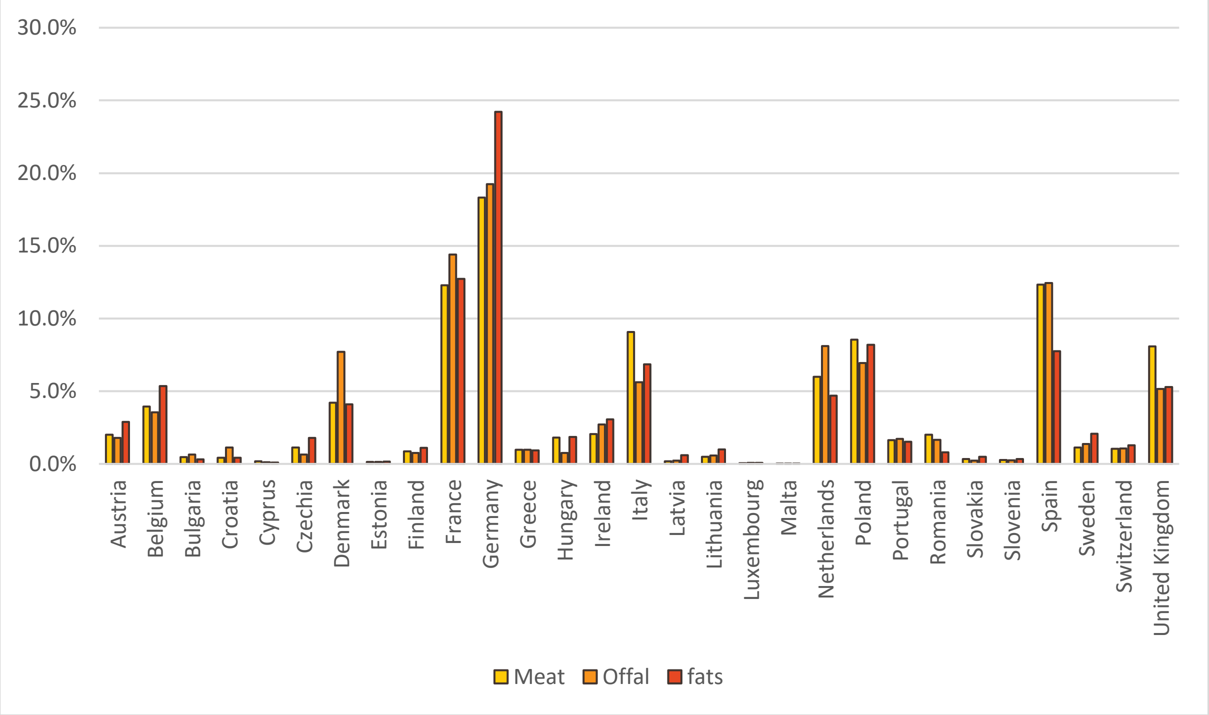

Figure 46 – Share of meat, offal and fats production in the EU28+1[60]

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.

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

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

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

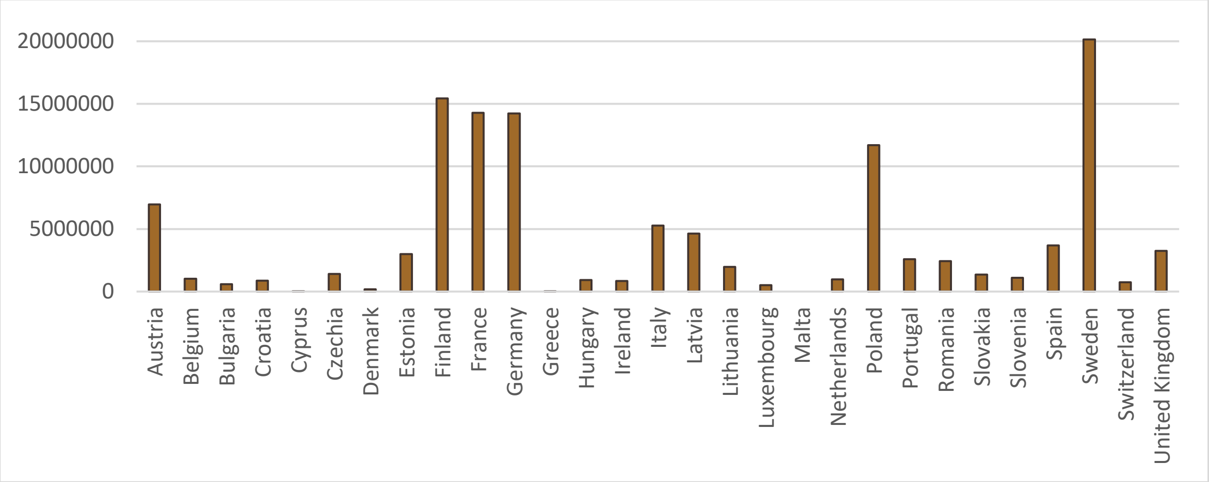

Figure 47 – Wood processing byproducts in the EU28+1(2017)[61]

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 27 – 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%

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[61] FAOSTAT, Forestry production & trade

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

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%

Feedstock mix: The following Figures present the feedstock mix for biogas, liquid bioenergy and solid bioenergy.

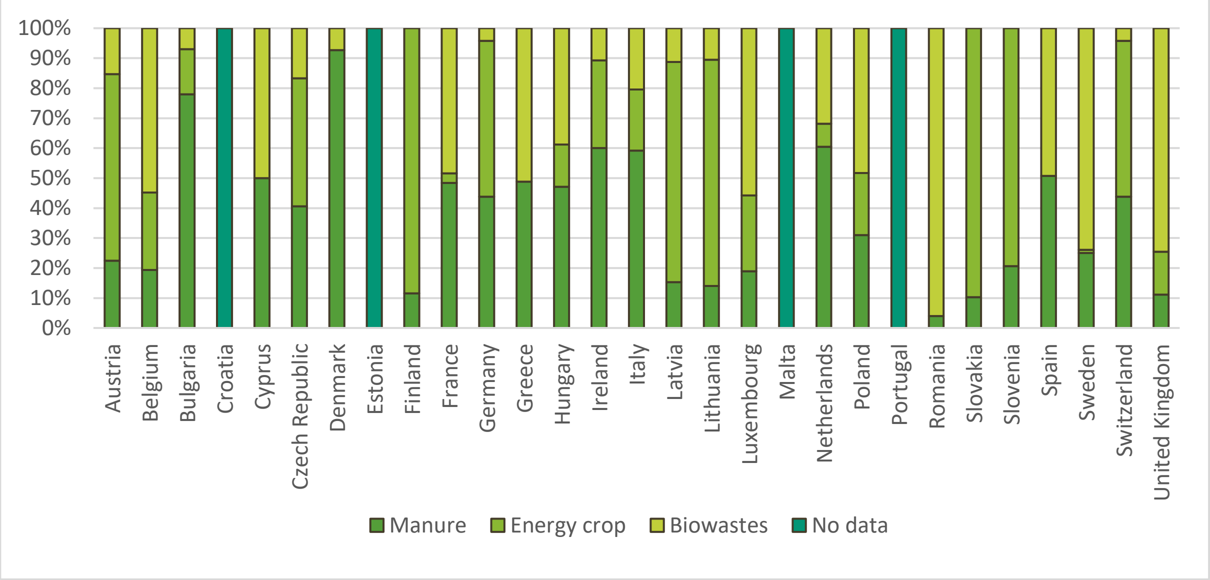

Figure 48 – biogas feedstock mixes in the EU28+1(2015)

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. 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.

In terms of liquid biofuels, most of the production currently relies on food crop for both biodiesel and ethanol:

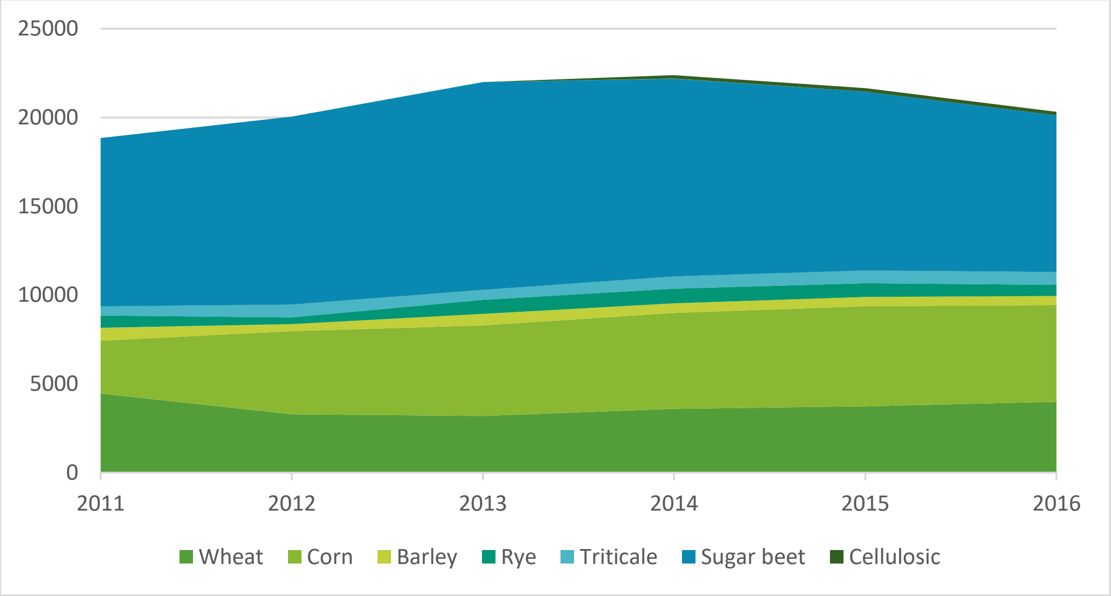

Figure 49 – Ethanol production in the EU28 (Flach et al., 2017)

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.

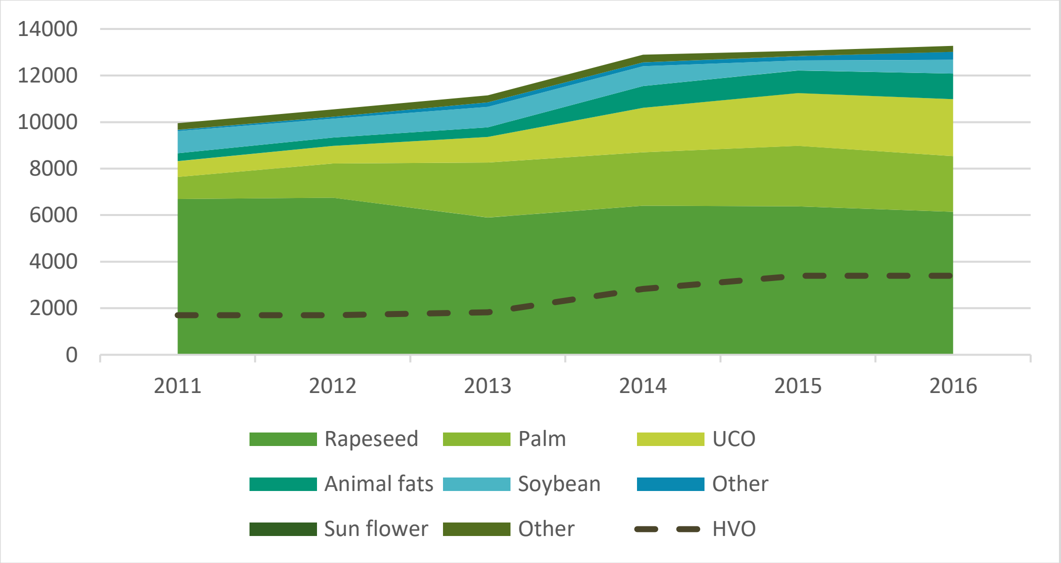

Figure 50 – Biodiesel production in the EU28 (Flach et al., 2017)

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).

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.

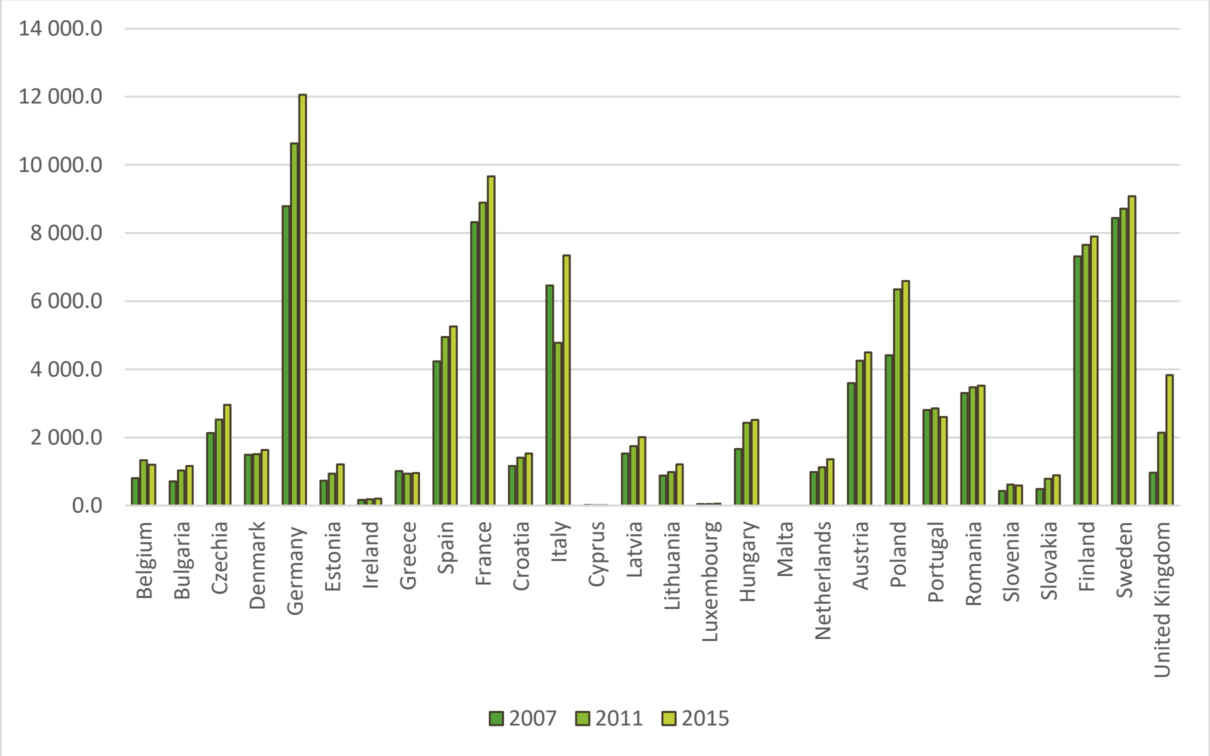

Figure 51 – Solid bioenergy production in the EU28[62]

In 2015, the solid biofuel feedstock breakdown consisted in 78% fuel wood and byproducts, in 13% in black liquor, 7%of vegetal material and residues, and 2% of other organic components.

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

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[62] EUROSTAT: Primary production - all products - annual data (dataset: nrg_109a),

Direct link: https://ec.europa.eu/eurostat/data/database 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.

Table 28 – 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 29 – 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.

[redacted] Land-use, land-use change & forestry (lulucf)

2.2.1 Land-management

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.

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[63]. 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.

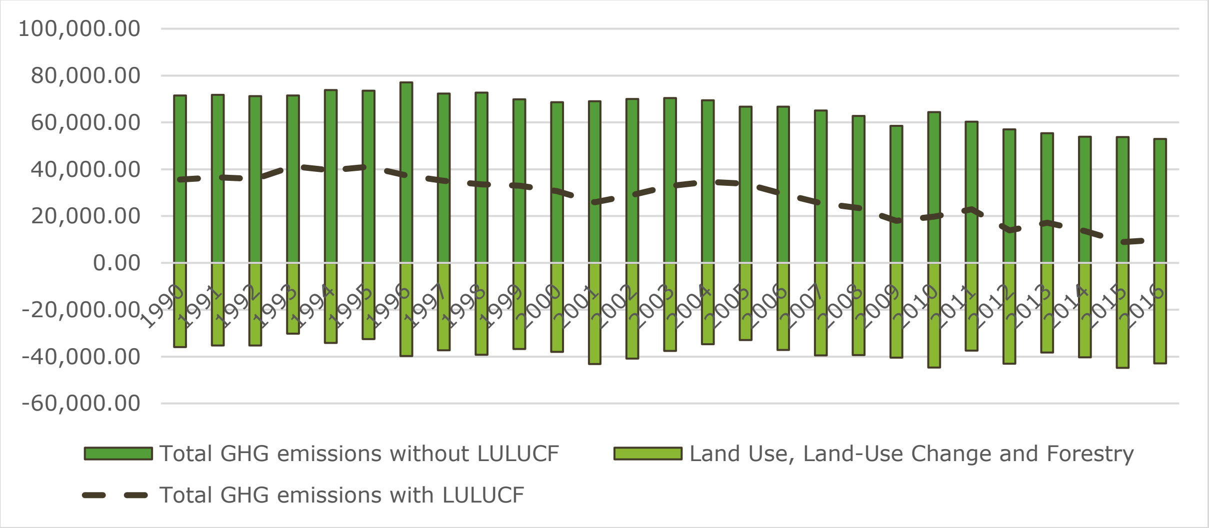

Figure 52 – Sweden GHG inventory and LULUCF balance[64]

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

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[63] 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*

[64] 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*

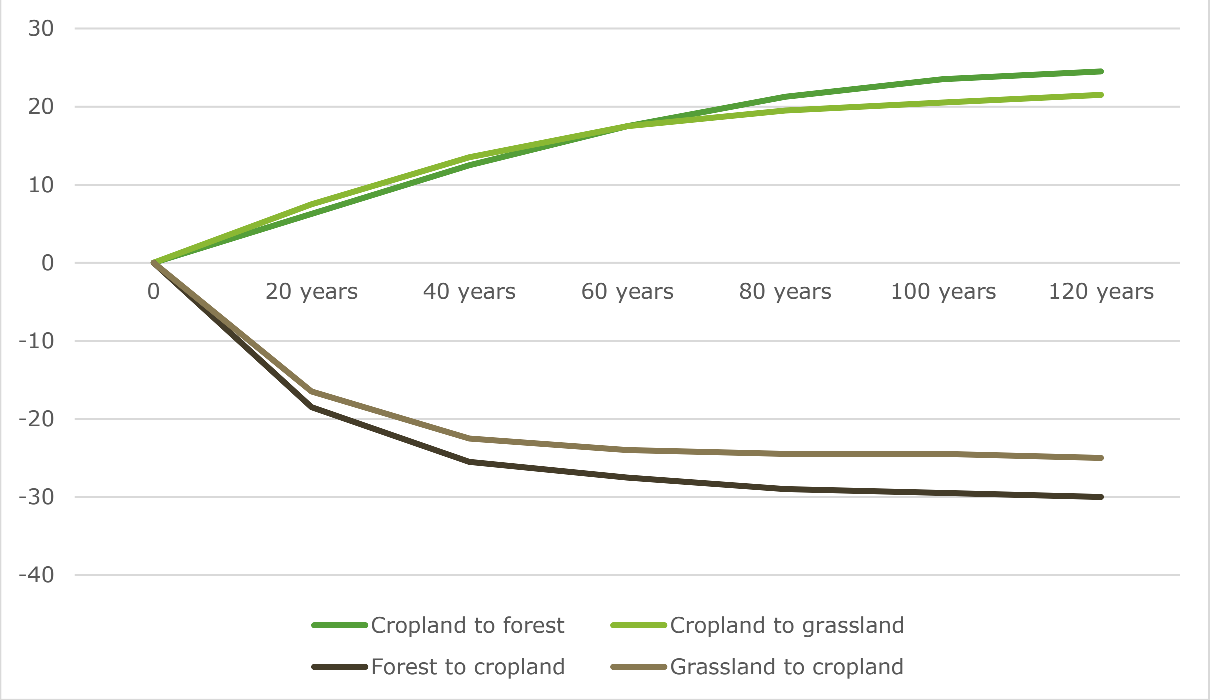

Figure 53 –Illustrative land-use change and its associated carbon-dynamics[65]

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 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.

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[65] 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

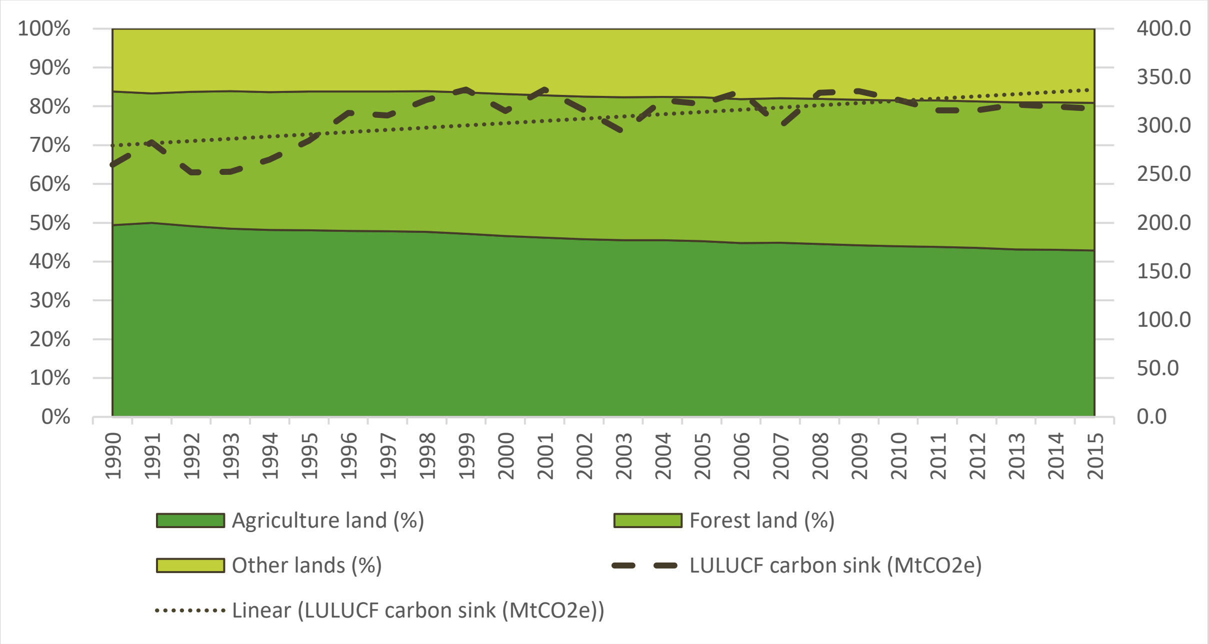

Figure 54 –Evolution of the LULUCF in the EU since 1990[66]

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:

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[66] 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 30 – Sub-lever list included in the land-management lever

#	Sub-lever…	… in brief	Unit
1	Land-use allocation	Sets the land allocation to spare lands between forest, grassland and unmanaged lands	%
2	Land-use change	Sets the pathways for land use change for settlements, wetland and other lands	ha, %

Land-use allocation: 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[67].
- Grassland dedicated to biodiversity and ecosystems preservation such as water and soil quality issues.
- 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).

Land-use change dynamics: the dynamics of the settlements, wetlands and other lands is set through the land management lever.

Emission factors: land emission factors are based on UNFCCC inventories and are specific for each country, year, carbon pool, and land-use change dynamics (e.g. grassland converted to forest).

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

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[67] 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

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?
- ✓ 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

Land-use allocation: Figure 51 presents the dynamics of settlements, cropland, grassland, and forests in Europe over the years.

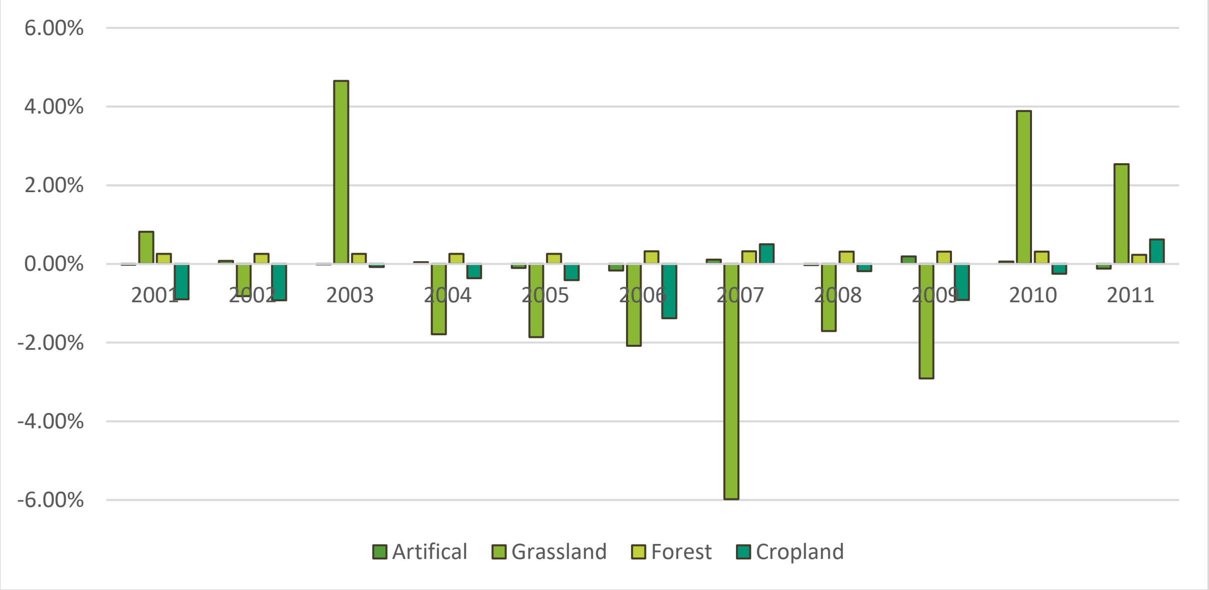

Figure 55 –Land-use change in the European Union between 2000-2011 (%)[68]

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, non-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.

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[68] Food and Agriculture Organization (FAO), FAOSTAT, Land-Use, European Union (total);

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

Land-use change dynamics is critical to capture and track the carbon dynamics associated with lulucf. The former versions of the Calculators uses net land-use changes to compute the carbon sdynamics, which highly limits the consistency of the carbon stock dynamics assessement. The European Caluclator uses the more detailled data base available at the EU members level which are the UNFCCC inventoiries as illustrated by Table 31:

Table 31 – Land-use matrix for the EU28 (2017)[69]

TO: / FROM:	Forest land (managed)	Forest land (unmanaged)	Cropland	Grassland (managed)	Grassland (unmanaged)	Wetlands (managed)	Wetlands (unmanaged)	Settlements	Other land	unmanaged land	Initial area
Forest land (managed)	163080.5	#	19.6	31.1	#	3.6	3.4	61.5	4.3	#	163203.97
Forest land (unmanaged)	#	2943.7	0.0	0.0	#	#	#	0.1	0.1	#	2943.85
Cropland	517.2	#	126017.6	722.7	#	2.7	8.8	302.6	20.0	#	127591.71
Grassland (managed)	306.1	4.0	471.1	85611.6	#	77.6	32.0	184.4	53.9	#	86740.61
Grassland (unmanaged)	#	#	0.1	#	471.1	0.1	#	0.0	0.0	#	471.37
Wetlands (managed)	6.3	#	1.4	11.4	#	7054.7	6.3	23.0	4.0	#	7107.20
Wetlands (unmanaged)	1.9	#	4.2	3.1	#	#	17158.8	27.8	0.8	#	17196.59
Settlements	9.6	#	82.8	57.2	#	3.2	0.8	29248.3	62.0	#	29463.98
Other land	19.3	#	274.0	25.3	#	0.6	1.5	37.2	12603.7	#	12961.59
Total unmanaged land	#	#	#	#	#	#	#	#	#	322.3	322.35
Final area	163941.04	2947.73	126870.77	86462.35	471.10	7142.58	17211.59	29884.89	12748.81	322.35	448003.22
Net change	737.07	3.88	-720	-278	-0.3	35.39	15.00	421	-212	0.00	0.00

#no data

In the EUCalc model, the land management lever sets the land dynamics for wetlands, settlements, other lands and unmanaged lands (purple, Table 45). Given the demand for agriculture commodities and indirectly agriculture lands, the model computes the other dynamics (blue) given the lever setting (agriculture practices for cropland-grassland rotation (in red, Table 45), and the previously mentioned land allocation sub-lever to allocate land-use to land speared).

Lever setting – Ambition levels

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[69] UNFCCC inventory 2017 (2019), European-Union (Convention), Table 4.1;

Direct link: https://unfccc.int/documents/194946

<u>Land-use allocation:</u> 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 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 56 –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.
>
> <u>Level 2</u> assumes that priority is given to the deployment of grassland free of economic activity that is turned towards biodiversity and ecosystems conservation. Two third of the lands are allocated to grassland, 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.

<u>Land-use change dynamics</u>: The land management lever sets trajectories for settlements, wetlands and other lands as well as the land-use change matrix for these land uses. For example, when demand for settleements increases, it sets the breakdown given historical trends in terms of forest being deforested, grassland being converted, and so on for the level 2.

Cropland-grassland-forest dynamics are set depening on the agriculture land dynamics, agriculture practices and agriculture commodity demand. Intensive practices are intensive in temporary grassland and cropland-grassland swap whereas agroecology moves the system towards permanent grassland and optimize agriculture land carbon pools. Settlaments and other lands demands are following the histrorical trends for level 2, while level 1 consider a greater need for lands (e.g. bad settlement expansion management), following the European historical worst trends. The higher levers follow a common pathway but while following the best practices.

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.

2.2.2 Climate-smart forestry

Lever rationales

According to the UNFCCC inventory[70], forests enabled capturing 419 $MtCO_2e$ in 2016 in the EU 28+1, which represents almost 8% of the GHG emissions (Figure 57).

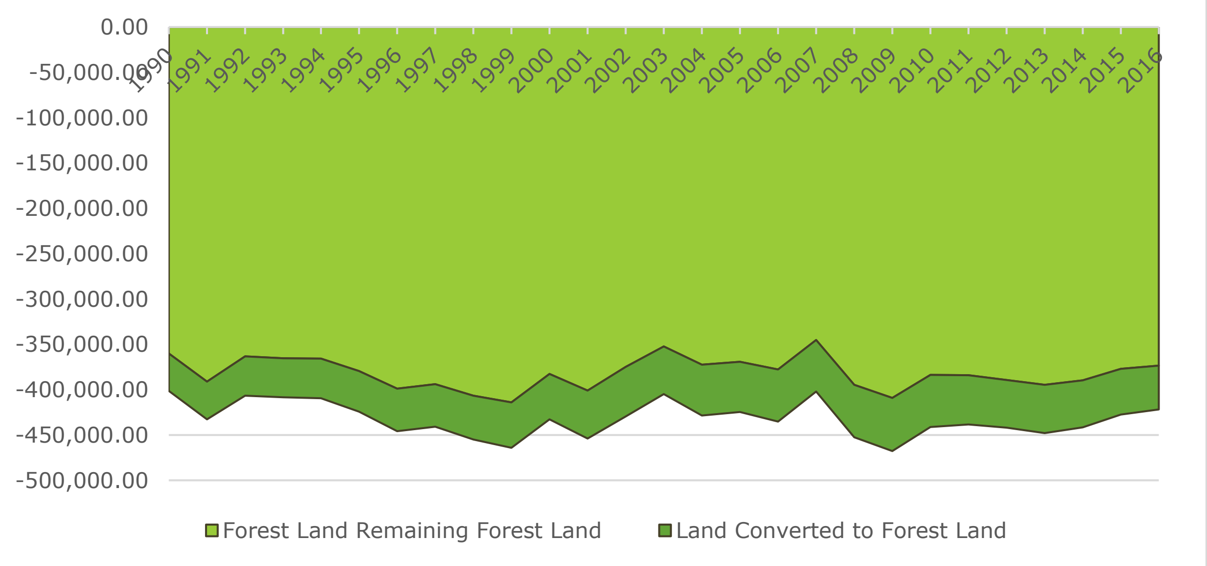

Figure 57 – GHG emissions stored by Forests in the EU since 1990 (%)

According to the European forest institute (EFI), 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

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[70] 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 ;

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 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.

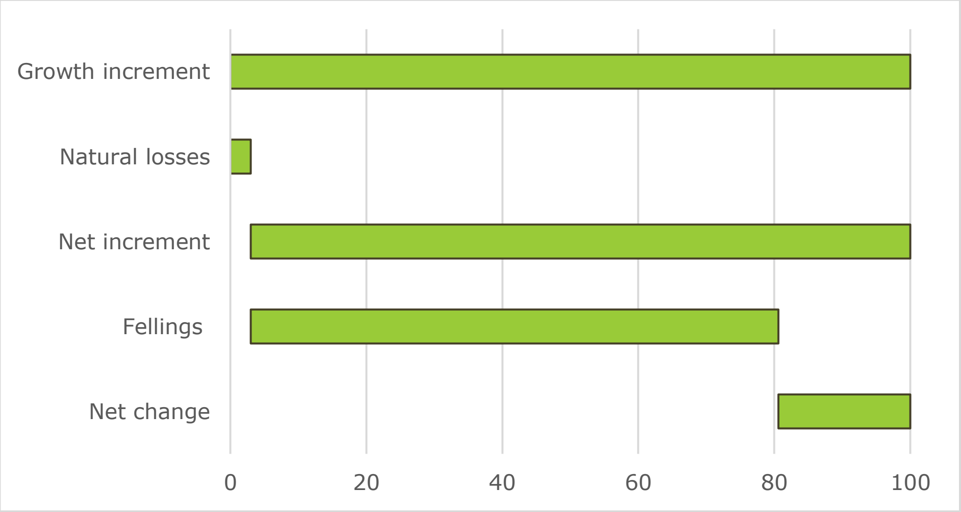

Figure 58 – Illustration of the forest system (EFI & FAO, 2015)

Through the deployment of Climate Smart Forestry (CSF) management practices (Nabuurs et al., 2017), the imbalance of the dynamic forest system (Figure 58) 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 understood 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*".

Table 32 presents the forest management practices driven by the climate smart forestry lever. The latter have been identified based on Nabuurs et al. (2017).

Table 32 – 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) and Schelhaas et al. (2007), the forest carbon pool could provide an additional sequestration benefits of approximately 170 Mt CO_2/year by 2050:

Full grown coppice: 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.

Enhanced productivity: 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. This is in line with the biodiversity lever that enables one to freeze forest areas for biodiversity conservation up to a level that complies with the Aichi targets.

Harvested wood products: 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 (Baudry et al., 2019).

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 resilience (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 are driven by the biodiversity lever as 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.

Lever setting – Observed data

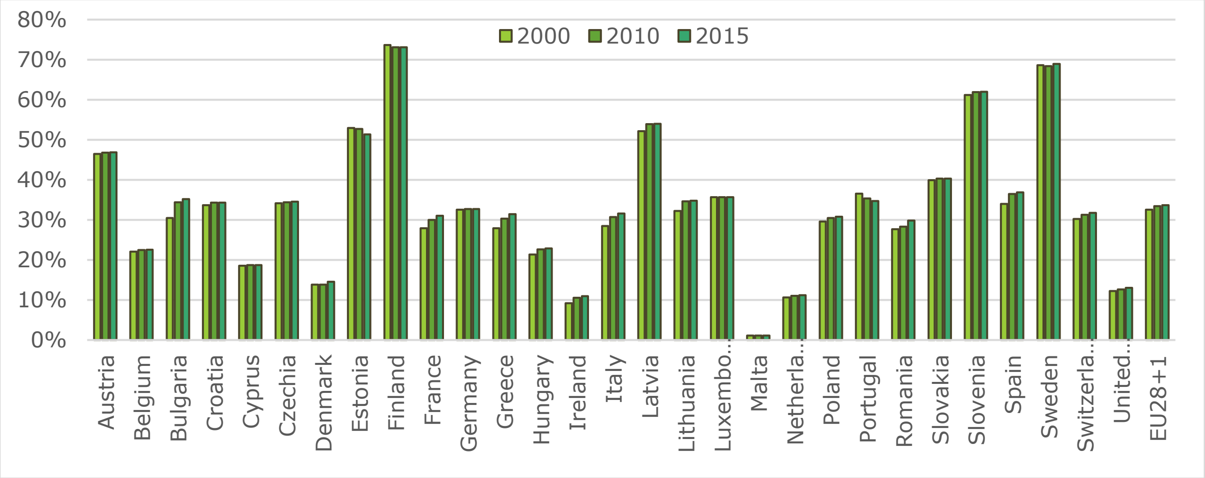

Figure 59 – GHG emissions stored by Forests in the EU since 2000 (%)[71]

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 59, 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 60 presents the observed data for the EU28+1 in 2010 regarding the share of forest area generated through coppice sprouting.

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[71] 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 ;

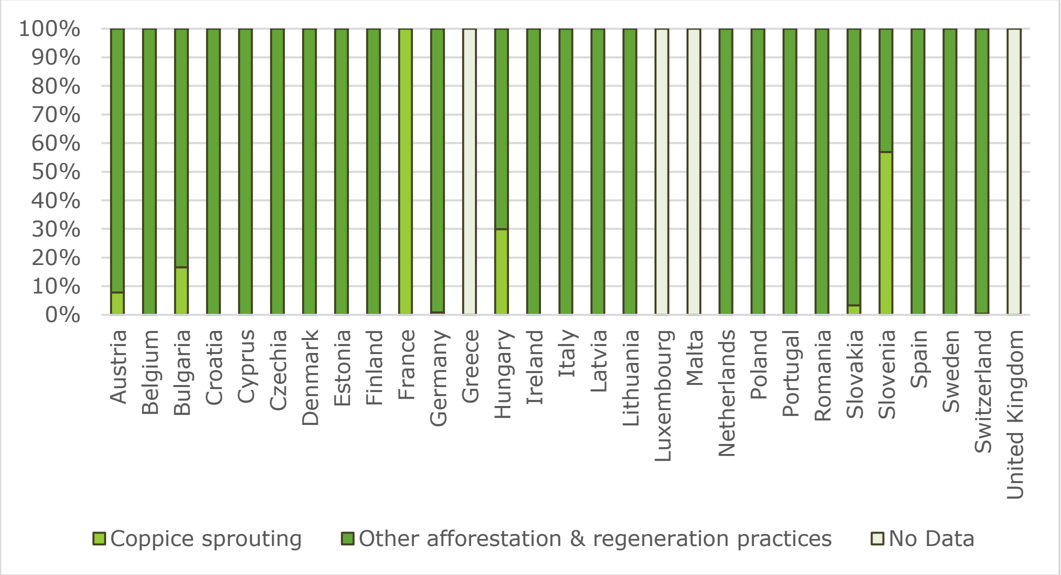

Figure 60 – Share of forest area by regeneration types in Europe, 2010 (EFI & FAO, 2015)

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).

<u>Enhanced productivity:</u> 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 61 presents the mean growing stock density by country in the EU28+1 in 2015.

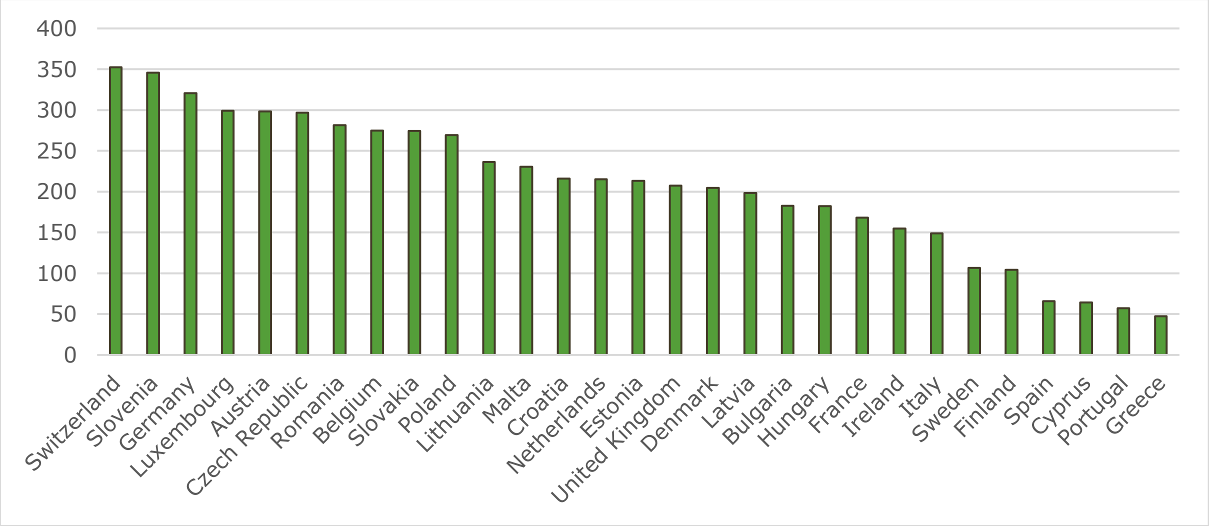

Figure 61 – Mean growing stock density by country in the EU28+1, 2015[72]

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[72] European Environment Agency, Forest: growing stock, increment and fellings, 2015;

Harvest rate: At the EU28+1 level, the annual feelings rate is about 70%[73], which is the recommended level 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 59).

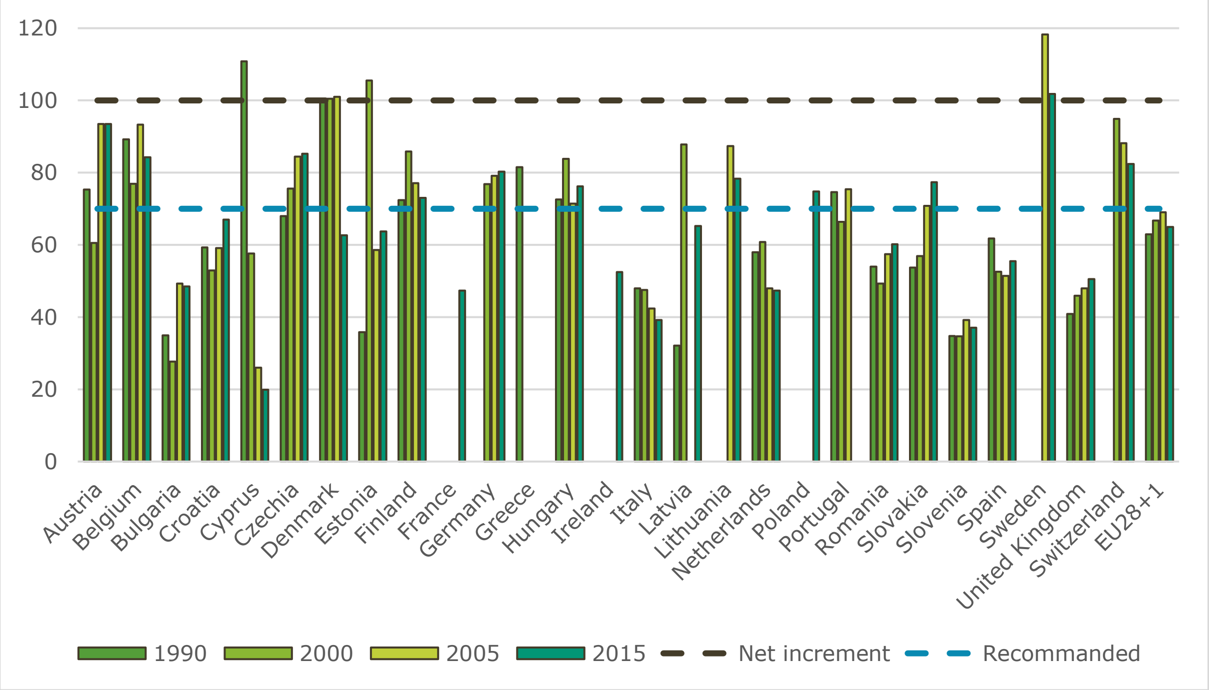

Figure 62 – Annual fellings in the EU28+1 since 1990 (EFI & FAO, 2015)

Production from the forestry sector: 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 63).

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[73] 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

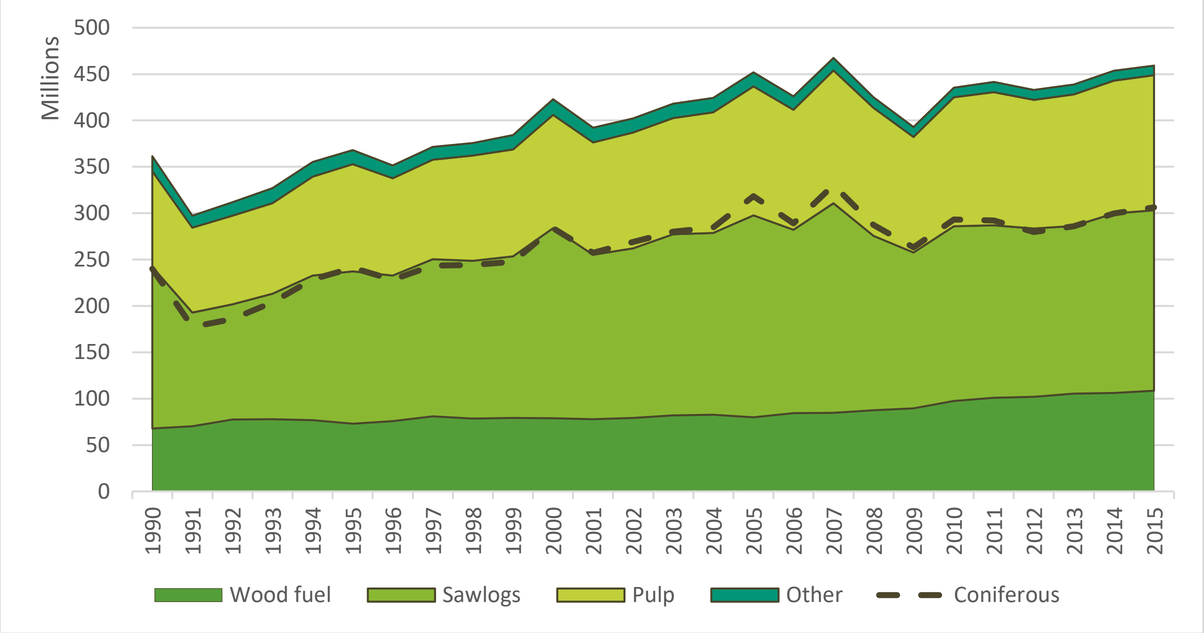

Figure 63 – Wood production in EU since 1990 (Mm3)[74]

<u>Reduced natural disturbances:</u> Damaged forest areas are widely heterogeneous across the European countries (Figure 64).

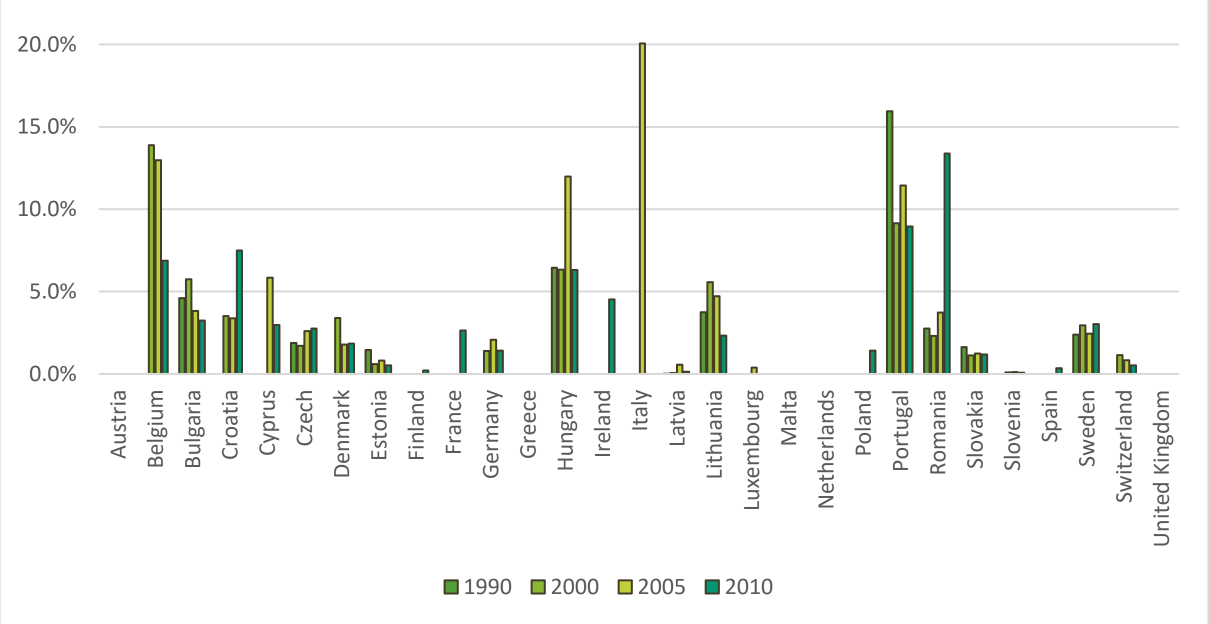

Figure 64 – Damaged forest areas in the EU28+1

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[74] FAOSTAT, Forestry Production and Trade

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

Beyond the extent of damaged areas, the causes are also heterogeneous, 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 33 – 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 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 considers 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 considers that CSF deployment occurs in all forest, whatever their ownership, which assumes very incentive forest management programs and that all European forest will be covered by sustainable forestry management plans.

Coppice surplus (m^3/ha): Figure 65 presents the yearly biomass increment surplus according to the ambition level, and thus to the deployment of coppice sprouting in European forest.

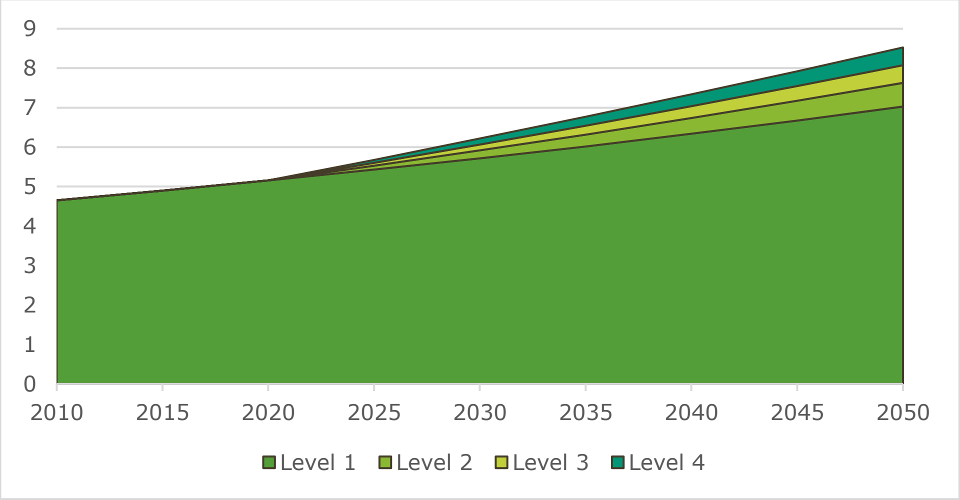

Figure 65 – Gross increment through coppice sprouting deployment (m3/ha)

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 66 presents the yearly biomass increment surplus that stem from the deployment of enhanced productivity management practices in European forest.

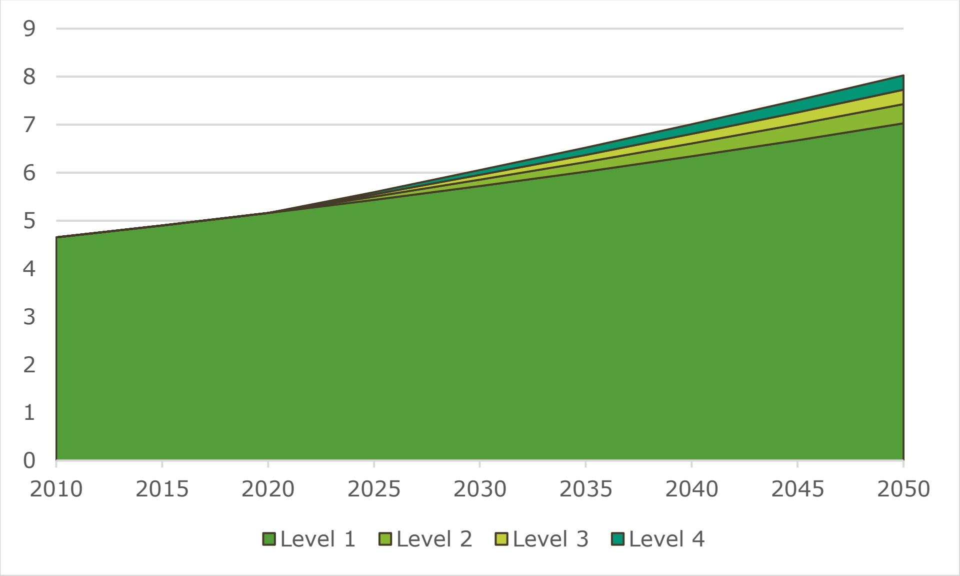

Figure 66 – Gross increment through improved management practices (m3/ha)

Following the same patterns, enhanced productivity management practices enables the European forest to yield up to 1 m^3/ha extra biomass on areas under CSF practices Nabuurs et al. (2017).

Natural disturbances (m^3/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 67). It is worth mentioning that direct interlinkages between the climate module and forestry module remains to be set in that matter.

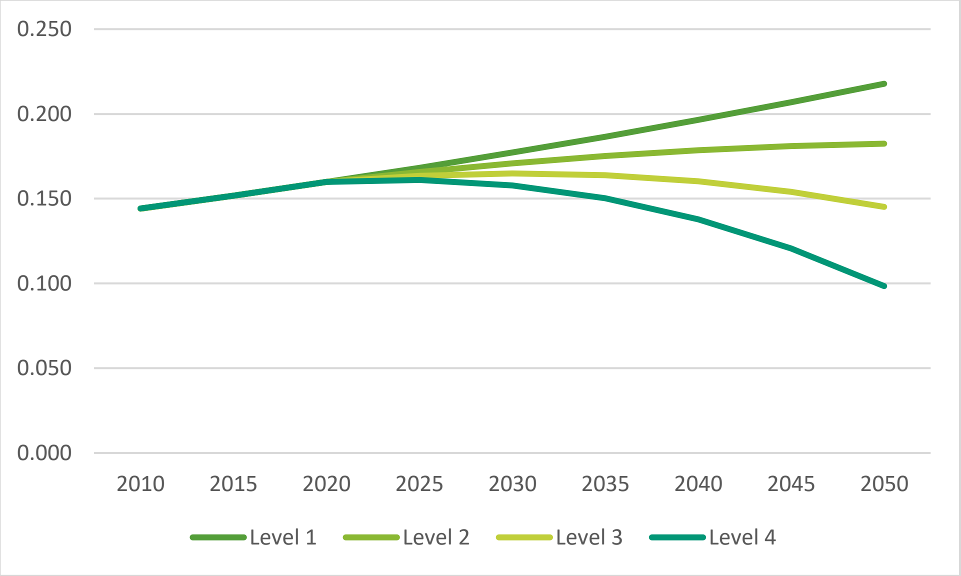

Figure 67 – Natural losses assumption through improved management practices (m3/ha)

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 33, 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.

[redacted] Biodiversity

2.3.1 Protected area size

Lever description

The `protected area size` lever enables the modelling framework to quantify the emissions that might reasonably be expected to be tied to the conservation of biodiversity through habitat maintenance and restoration (primarily as carbon sink). It assumes biodiversity refugia for plants with 2°C of warming and eventually takes into account how loss of plant species richness could lead to the development of carbon sources through climate-mediated habitat conversion. The lever is expressed as the percentage of a country protected for biodiversity and classified as being a natural habitat. These percentages are then converted to emissions. While the component of each lever relating to human pressure is not factored directly into the emission calculations, the reduction/elimination of such pressures would be required in order to reach the mitigation benefits expressed for this sector in EUCalc.

Lever setting – Observed data

As previously mentioned, the total extent of protected areas in the EU28 and Switzerland reached about 25% in 2015 (UNEP-WCMC and IUCN, 2019). Protected areas are increasing over the years for all of the European countries (Figure 68). However, the extent of protected areas is highly heterogeneous and ranges from 10% to 53% in 2015 (Figure 69).

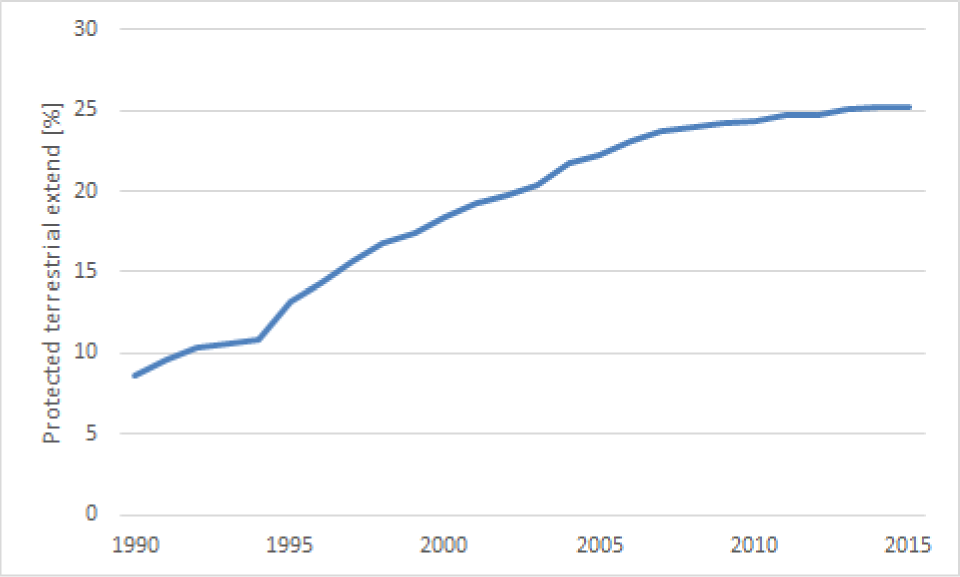

Figure 68 – Total protected terrestrial extend in EU28+Switzerland (numbers based on WDPA; UNEP-WCMC and IUCN, 2019)

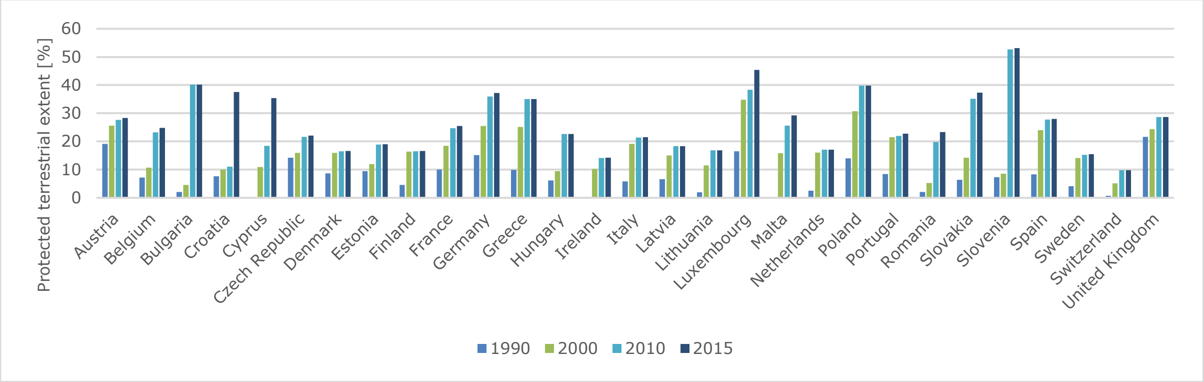

Figure 69 – Protected terrestrial extend in EU28+Switzerland per country (numbers based on WDPA; UNEP-WCMC and IUCN, 2019)

Lever setting – Ambition levels

The policies that drive the lever are those set by the Convention on Biological Diversity (CBD) as representing the member states (and which the EU is a part of). Protected areas could follow either EU wide programs such as Natura 2000, SSIs, and lands set aside by the Birds and Habitats Directive or those of individual countries (state forests and parks) and even of civil society (private reserves, refuges such as those protected by Land Trusts, etc.)

Table 34 - Ambitions levels for protected area

Level	Definition
1	Each country meets their CBD Aichi 2020 target 11 by 2020, with the definition of protected being restricted to those areas primarily focused on biodiversity conservation in areas with natural habitat. Human pressures on these protected areas reduced. For example, some National Parks contain settlements, and allow uses not entirely consistent with biodiversity conservation (the amount of non- 'natural' habitats in current protected areas can exceed 10% of the area). This means that for 2020, and continuing to 2050/2100, the biodiversity protection threshold is set at 17% of natural habitats using the European Space Agency Climate Change Initiative Land Cover Database (ESA-CCI) for 2015 for land cover definition. Maintain existing protected areas in good status and well managed. Reduce the level of human pressure on existing protected areas, which is substantial in many parts of the EU (see Figure 6).
2	Each country meets their Aichi targets in areas classified both as natural and also as a climate refugia for biodiversity (plants) at 2°C. This means that some countries will require substantially more protected areas than 17%, including restoration of habitats. Reduce human pressures on protected areas by 50%. Values for climate refugia based on data from Warren et al. (2018 a,b).
3	Each country meets the proposed 2030 targets (Plan for Nature) for countries protecting 30% of their land surface for biodiversity. As the goal of the target is biodiversity conservation, then this is further modified by the 30% of areas identified as in being in natural condition (including pastures) in 2015, and plant refugia under 2°C warming (where possible). In many EU countries this will

	require restoration of some percentage of agricultural habitat. This will potentially reduce crop yields but will increase negative emissions. This potentially increases the likelihood of leakage in cases where the rest of the world does not follow the EU in mitigation efforts
4	Highest biodiversity protection ambition following the guidelines of half for nature and the ambitious proposed potential CBD 2050 targets. In this level, 50% of each country is set aside for nature, drawing first from natural habitats, then looking at level of restoration necessary in agricultural habitats (helping meet CBD Aichi target 15). Priority for restoration given to plant refugia at 2°C. Human pressure on existing protected areas reduced by 75%. This may lead to 'leakage' in the food and timber production sectors by requiring greater imports of food or timber to offset lands lost within the EU for these sectors. Many countries will not have 50% of their land identified as potential plant refugia at 2°C, and this is the reason it is identified only as a possible goal for prioritization of restoration.

Lever setting - Disaggregation method

The absolute protected area extend is predefined by the lever and the same for each country (e.g. 17% of a country's area by 2020). However, the rate of extension is adjusted to each country's existing protected area, which results in some countries having to put more effort into extending their protected area network than others.

2.3.2 Land prioritization

The extension of protected areas creates a demand on available land and thus directly competes against the demand from agriculture and timber production. Creating new or extending existing protected areas therefore is not only a question of selecting areas which support high levels of biodiversity under changing climatic conditions but also a prioritization exercise. Some individuals might be willing to risk food security for greater biodiversity protection although other natural habitats would also provide a biodiversity benefit.

Lever description

Initially, all priorities for meeting protected area goals come from the restoration of agricultural lands which are currently located within protected area boundaries. Once all these areas are restored, the `protected area size` lever enables the modelling framework to consider two different strategies of prioritization:

Level A: Priority is given to the protection of natural areas not currently part of the World Database on Protected Areas (WDPA). In many cases, these would likely be forested areas and this would mean these areas would no longer be available for intensive forestry, but potentially could be used for sustainable forestry with a biodiversity priority.

Level B: Priority is given to the restoration of land currently used for food production. These areas would no longer be available for food production.

It is not possible to determine in advance which of these lever settings provide the higher benefit in terms of emission reductions (or source sink). There are emission ramifications in the choice, e.g. selecting setting B would lead to creation of more sinks but might require agriculture intensification elsewhere thus offsetting emission gains.

Lever setting

The lever does not have any direct data associated. It is merely a logical flag and determines the order of land allocation within the modelling framework.

[redacted] Water and minerals

2.4.1 Water

This section presents the different levers suggestions explored during the workshop on resource use lead by Imperial College in London (see Deliverable 4.3). However, none of these levers were implemented since:

- no carbon trade-off could be foreseen through these levers.
- some levers were tackling water quality rather than quantity, which is out of scope for the current version of the module.
- some historical data justifying ambition levels were either insufficient or missing.

Table 35 summarizes the proposed levers for water management, and which could be implemented in the future.

Table 35 – List of possible levers for water management the water module

		Levers	**Short description**
Water Management	1.	Water use efficiency [%]	This lever sets the percentage of current water loss avoided. It will impact the total water demand
	2.	Sustainable water abstraction [%]	This lever sets the percentage of water sustainably abstracted. It will impact the total water demand.

	3.	Water framework Directive (WFD) ambitions [%]	This lever sets the percentage of water bodies (rivers, groundwater) achieving good status defined by the WFD.
	4.	Sea water desalination [Mm3]	This lever sets the amount of seawater in Mm3 that is desalinated to meet water demand in EU. It will impact the quantity in Mm3 of readily available water resources.
	5.	Wastewater treatment and reuse [%]	This lever sets the percentage of wastewater treated and reused in EU. It will impact the quantity in Mm3 of readily available water resources.

2.4.2 Minerals

All levers come from the industry module. The content document for the *Industry* module introduces all levers in the mineral module. The following levers have been introduced as inputs: product import (trade), material efficiency, technology development (use of secondary materials), and finally material switch, which represent the substitution potential.

Nevertheless, the industry module solely models steel, aluminium, and copper and their associated levers. Because of the lack of literature on the subject, very few scenarios have projected the substitution and efficiency aspect of the following minerals: lithium, lead, graphite, manganese, and nickel. They are therefore introduced as fixed assumption.

The JRC report on cobalt (P., et al. 2018) provides ambition levels (Table 36) for 2030 for the levers mentioned above.

Table 36 – Cobalt lever settings, 1 being business as usual and 4 being very ambition for 2050. The regression is linear

Lever	*1990*	*2015*	*2050*			
			1	2	3	4
Material Switch Cobalt to other	0	0	-15%	-25%	-35%	-50%
Technology Development Cobalt	0	0	5%	10%	15%	20%

3 Fixed assumptions

Fixed assumptions refer to data that are either country or year dependent, compared to constants that are not country or year dependent, and lever inputs that are both country and year dependent. Fixed assumption can be found in the database files, such as the other inputs.

[redacted] Agriculture

The agriculture module includes fixed assumptions regarding the emission factors and ratio for crops, livestock, and biomass.

3.1.1 Emission factors

Crop related emissions factors are based on FAOSTAT database and Searle and Malins (2016):

- N_2O and CH_4 emissions induced by the residues being burnt, expressed in tCH_4/t of residues, and tN_20/t of residues;
- N_2O emissions induced by the soil residues, expressed in tN_20/t of residues;
- Residues yields per crop type, expressed in kcal/kcal;
- Rice emission factors expressed in tCH_4/ha of rice cultivated area;
- Fertilizer emissions expressed in tN_2O/tN.

Livestock emission factors are also based on FAOSTAT:

- Manure management associated emissions per livestock type, expressed in tCH_4/lsu and tN2O/tN;
- Manure applied in the soil per livestock type, expressed tN2O/tN;
- Manure left in pasture per livestock type, expressed tN2O/tN;

3.1.2 Livestock manure

Livestock manure production is based on FAOSTAT:

- Manure production per livestock type, expressed in kgN/lsu;

[redacted] Land-use, land-use change & forestry (lulucf)

Land-use from 1990 to 2105 is based on FAOSTAT, including the cropland, grassland, forest land, agriculture land, wetlands, settlements and other lands, expressed in ha. The data is partly used as fixed-assumption and for calibration purposes.

[redacted] Biodiversity

The biodiversity module does not contain any fixed assumptions.

[redacted] Water

Table 37 provides an in-depth description of the fixed assumptions used in the Water module.

Table 37 - Description of fixed assumptions used in the water module

Dataset	**Description**	**Main sources**	**Data quality check**	**Hypotheses & computation**
Livestock water requirements [m3/lsu/year]	Water required by livestock unit over a year for the following animal groups: Sheep, poultry, hens, pigs, bovines, dairies, other animals.	Animal water footprints in m3/animal/yr for all animals: [Mekonnen & Hoekstra, 2012]; Value for rabbits in m3/animal/yr used in category «other animals» [Tschudin et al., 2011] Conversion factors from animal unit to LSU unit: [Eurostat]	Good quality data from reliable, coherent and credible sources However, the values are worldwide average.	Livestock water requirements in m3/lsu/year are computed by: 1) converting water footprints for animal sub-categories in m3/animal/year into LSU by using conversion factors in lsu/animal as follows: *animal_WF[m3/LSU/year]= animal_WF[m3/animal/year] / conv_factor[LSU/animal]* 2) multiplying these values with animal sub-category shares within one group *(animal water footprint[m3/LSU/year] * Livestock population share[%])* 3) Summing up all shares of sub-category water footprints within each animal group to get water footprint for 1 lsu in each animal group.
cooling technologies share by energy vector [%]	Shares of cooling system for thermoelectric generation technologies by country for different energy vectors (nuclear, oil, gas, biomass). The cooling systems considered include once-through cooling, wet recirculating cooling and dry cooling	Shares of cooling technologies by country: [Davies et al., 2013]	Good quality data from reliable, coherent and credible sources	As shares are only available for the regions of Western Europe and Eastern Europe, these values were allocated to EU28+1 countries according to the definition of these regions: - Western Europe includes Belgium, Denmark, Germany, Ireland, Greece, Spain, France, Italy, Cyprus, Luxembourg, Malta, Netherlands, Austria, Portugal, Finland, Sweden, UK and Switzerland - Eastern Europe includes Bulgaria, Czech Republic, Estonia, Croatia, Latvia, Lithuania, Hungary, Poland, Romania, Slovenia and Slovakia

Household water leakage factor [%]	Current estimates of the efficiency from the public water supply network.	-Current estimates for each EU28 country have been provided by JRC -Value for Switzerland: [Saladin, 2002]	Good quality data from reliable, coherent and credible sources	All values for EU28 are provided by JRC. Value for Switzerland is extracted from a report by SKAT Foundation
Irrigation efficiency [%]	Current estimates of irrigation efficiencies	-Current estimates for each EU28 country have been provided by JRC	Good quality data from reliable, coherent and credible sources	All values for EU28 are provided by JRC. Value for Switzerland is approximated to the average irrigation efficiency in EU28.

Minerals

The fixed assumptions in the model are with respect to amount of scrap – recycled materials – in product production, that is, what percentage a scrap mineral is represented within a product. These components are directly linked to the collection capacity of materials as well as the recycling capacity. Waste management not being part of the EUCalc model, assumptions had to be made about scrap in the future. When available, the data from the rest of the world (RoW) and Europe were divided. Otherwise they were put as similar EU28+1 and the rest of the world. In terms of forecast, if predictions were provided, they were added to the model but not extrapolated. For instance, there was a prediction of 9% scrap lithium by 2025, therefore the number was carried until 2050. Ultimately, these fixed assumptions serve to calculate how much minerals needs to be extracted to satisfy demand.

Table 38 - Fixed assumptions concerning primary and secondary percentage in a product, ultimately giving indications onto the demand for extraction.

Variable	*Scrap Amount*	*1990*	*2015*	*2050*	*Historical Data*	*Forecast Data*
EU Steel_BOF	25%	65%	67%	*TechDev*	(World Steel Association 2019)	*Industry* (Accenture Strategy 2017) (Xylia, et al. 2016)
EU Steel_EAF	90%	35%	33%			
RoW Steel_BOF	25%	64%	76%	60%		
RoW Steel_EAF	90%	36%	27%	40%		
EU Aluminium_primary	0%	62%	61%	TechDev	(International Aluminium Institute 2019)	(Backman 2008) (Global CCS Institute
EU Aluminium_secondary	100%	38%	39%			

RoW Aluminium_primary	0%	71%	67%	69%	(European Aluminium Association 2014) (Scharf-Bergmann 2013)	2010) (Modaresi and Müller 2012)
RoW Aluminium_secondary	100%	29%	33%	31%		
EU Copper_primary	0%	64%	53%	TechDev	(International Copper Study Group 2019) (Elshkaki, et al. 2016)	(International Copper Study Group 2019) (Elshkaki, et al. 2016)
EU Copper_secondary	100%	36%	47%			
RoW Copper_primary	0%	72%	64%	64%		
RoW Copper_secondary	100%	28%	36%	36%		
EU Lithium_primary	0%	100%	100%	91%	(Pagliaro and Meneguzzo 2019)	
EU Lithium_secondary	100%	0%	0%	9%		
RoW Lithium_primary	0%	100%	100%	91%		
RoW Lithium_secondary	100%	0%	0%	9%		
EU Cobalt_primary	0%	0%	0%	*TechDev*	(P., et al. 2018)	
EU Cobalt_secondary	100%	0%	0%	*TechDev*[75]		
RoW Cobalt_primary	0%	0%	0%	20%		
RoW Cobalt_secondary	100%	0%	0%	20%		
EU Manganese_primary	0%	0%	98.4%	97.8%	(Hagelstein 2009)	
EU Manganese_secondary	100%	0%	1.6%	2.2%		
RoW Manganese_primary	0%	0%	98.4%	97.8%		
RoW Manganese_secondary	100%	0%	1.6%	2.2%		
EU Graphite_natural	0%	67%	67%	67%	(MineralInfo 2016)	
EU Graphite_synthetic	100%	33%	33%	33%		
RoW Graphite_primary	0%	67%	67%	67%		
RoW Graphite_secondary	100%	33%	33%	33%		
EU Nickel_primary	0%	97.2%	97.2%	97.2%	(Cusano, et al. 2018)	
EU Nickel_secondary	100%	2.8%	2.8%	2.8%		
RoW Nickel_primary	0%	97.2%	97.2%	97.2%		
RoW Nickel_secondary	100%	2.8%	2.8%	2.8%		
EU Lead_primary	0%	75%	40%	20%		

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[75] Technology development lever developed in the industry module passed as input to the mineral module

EU Lead_secondary	100%	25%	60%	80%	(International Lead Association n.d.)
RoW Lead_primary	0%	75%	50%	40%	
RoW Lead_secondary	100%	25%	50%	60%	

4 Constants and parameters

[redacted] Agriculture

4.1.1 Livestock yields: offal & animal fats

The offal and animal fats yield per livestock type expressed in kcal per LSU[76], i.e. livestock unit, enables to compute the by-production of both offal and animal fats depending on the slaughtered livestock evolution. The data is based on the FAOSTAT database[77].

Table 39 – Livestock yields: offal & animal fats

Variable	Fats (kcal/lsu)	Offals (kcal/lsu)
Bovine	1129333,33	280000,00
Sheep	389664,00	117936,00
Pig	332705,73	46825,32
Poultry	198434,52	55059,52

4.1.2 Livestock energy conversion efficiency

The livestock energy efficiency consists of the percentage of energy inputs (kcal) as feed effectively converted to animal final product (kcal), such as meat, eggs or milk (Alexander et al., 2016).

Table 40 – Livestock energy conversion efficiency

Livestock type	Efficiency
Non-dairy cattle	3,80%
Sheep	6,30%
Pig	8,50%
Poultry	19,60%
Other animals	4,40%
Hens-poultry	25%
Dairy-cattle	24%

4.1.3 Alternative protein sources yield

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

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[76] Eurostat glossary, livestock unit definition;

Direct link: https://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary:Livestock_unit_(LSU)

[77] Food and Agriculture Organization (FAO), Livestock primary;

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

Table 41 – 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	/

4.1.4 Beverage yields

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 42. 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.

Table 42 – 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	-

[redacted] Land-use, land-use change & forestry (lulucf)

There are no constants and parameters in the lulucf modules, only fixed assumptions and lever inputs.

[redacted] Biodiversity

The biodiversity module does not contain any constant or static parameters.

[redacted] Water

This section presents the list of constants used in the water module:

- Water requirements for crops (Mekonnen & Hoekstra, 2011)
- Water requirements for material production (various sources, see Table 43)
- Energy consumption water factors (Davies et al., 2013 ; Fricko et al., 2016)
- Energy withdrawal water factors (Davies et al., 2013 ; Fricko et al., 2016)
- Households consumptive use: 20% (Bisselink et al., 2018)
- Industry consumptive use: 15% (Bisselink et al., 2018)
- Irrigation conveyance losses: 20% (Bisselink et al., 2018)
- Irrigation margin factor: 20% (Bisselink et al., 2018)
- Livestock drinking use: 2% (Bisselink et al., 2018)
- Livestock consumptive use: 15% (Bisselink et al., 2018)

Table 43 provides a detailed description of the aforementioned constants and parameters

Table 43 - Description of constants and parameters used in the Water module

Dataset	**Description**	**Main sources**	**Data quality check**	**Hypotheses & computation**
water requirements for crops [m3/kcal]	Average water footprint in m3/kcal from freshwater resources consumed by the following crop types: fruits, sugarcrops, vegetables, cereals, oilcrops, pulses, starches. Used to calculate water demand by crops in m3 from crop production in kcal	-Global average water footprint from freshwater resources in m3/ton over the period 1996-2005: [Mekonnen & Hoekstra, 2011] -Caloric value of crops in kcal/kg: [Mekonnen & Hoekstra, 2011]	Thorough data from reliable, coherent and credible sources However, the values are global average	-Computed based on global average blue water footprint of crop and caloric value of crop as follows: *Global_avg_WF_crop / (caloric_value_crop * 1000)*
Material water requirements [m3/ton]	Average water footprint from freshwater resources for industrial processing cooling during the production of the following materials:	-values for steel, cement, glass and lime: [Gerbens-Leenes et al., 2018] -values for paper (pulp & recycled): [Van Oel, P. R., &	Data from various sources ranging from scientific publications to industrial white papers. Water requirements values were not	As data was not found for some production materials considered in the EU Calculator, we completed the total industrial water demand by using calibration data to fill the gap.

	Steel, cement, glass, lime, paper (pulp & recycled), aluminium (primary & secondary), ammonia, other chemicals.	Hoekstra, A. Y., 2010] -values for aluminium (primary & secondary): [European Aluminium, 2018] -values for Ammonia: [Unger et al., 2013] -values for plastic chemicals: [Li et al., 2010]	found for some material productions, namely: wood & wood products, food & beverage & tobacco, machinery equipment, copper, textiles.	
Energy cooling withdrawal water factors [m3/GWh]	Water that is temporarily or permanently removed from water resources to generate 1 GWh of electricity (for cooling and maintenance). These factors are presented by energy vector (coal, oil, nuclear, gas, solar, wind, hydroelectric, marine, geothermal) and by cooling technology (once-through cooling, wet recirculating cooling and dry cooling)	[Davies et al., 2013 ; Fricko et al., 2016]	Thorough data from reliable, coherent and credible sources	
Energy cooling consumption water factors [m3/GWh]	Water that is permanently removed from water resources to generate 1 GWh of electricity (for cooling and maintenance). These factors	[Davies et al., 2013 ; Fricko et al., 2016]	Thorough data from reliable, coherent and credible sources	

	are presented by energy vector (coal, oil, nuclear, gas, solar, wind, hydroelectric, marine, geothermal) and by cooling technology (once-through cooling, wet recirculating cooling and dry cooling)			
Irrigation conveyance losses [%]	Share of the water that is lost during conveyance from extraction point to delivery point.	[Bisselink et al., 2018]	Data from reliable and credible source	
Irrigation margin factor [%]	Share of water that has to be added to the irrigation water volume in order to prevent soil salinity	[Bisselink et al., 2018]	Data from reliable and credible source	
Livestock drinking use [%]	Share of water provided to livestock that is dedicated to drinking purposes.	[Mekonnen & Hoekstra, 2012]	Data from reliable and credible source	
Livestock consumptive water use [%]	Share of water withdrawn from freshwater sources for livestock that is removed from the immediate water environment	[Bisselink et al., 2018]	Data from reliable and credible source	
Households consumptive water use [%]	Share of water withdrawn from freshwater sources for households that is removed from	[Bisselink et al., 2018]	Data from reliable and credible source	

	the immediate water environment			
Industry consumptive water use [%]	Share of water withdrawn from freshwater sources for industry that is removed from the immediate water environment	[Bisselink et al., 2018]	Data from reliable and credible source	

[redacted] Minerals

4.5.1 Reserves in 2015

4.5.1.1 Mineral reserves

This section presents the list of mineral <u>reserve</u> amount used in the mineral module (US Geological Survey 2019):

Table 44 - Mineral reserves

Mineral	***Amount [Mt]***
Bauxite (Aluminium)	280,00
Copper	700
Cobalt	7.2
Graphite	110
Iron (Steel)	87,000
Lead	87
Lithium	13.5
Manganese	570
Nickel	81
Phosphate	6,378[78]
Potash	3,500

4.5.1.2 Fossil Fuel reserves

This section presents the list of fossil fuel <u>reserve</u> amount used in the mineral module

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[78] Phosphate rock is 67000 Mt converted to phosphate element **Invalid source specified.**

Table 45 - Fossil fuel reserves

Fuel	**BP Statistics (British Petroleum 2019)**	**IEA**	**Other Sources**
Oil	1,684 billion barrels	1492 billion barrels (International Energy Agency 2016)	1,492.88 million barrels (Organization of the Petroleum Exporting Countries 2016)
Gas	189 Tm^3	199,954 Gm^3 (International Energy Agency 2016)	201,139.9 Gm^3 (Organization of the Petroleum Exporting Countries 2016)
Coal	1,054,782 Mt	984,624 Mt (International Energy Agency 2016)	984,624 Mt (World Energy Council 2016)

4.5.2 Mineral decomposition

A summary of mineral decomposition is given in the Table 46 below.

4.5.2.1 Mineral decomposition table

Table 46 - Metal decomposition in kg per unit (unit indicated in the variable column)

Variable	**Aluminium**	**Copper**	**Cobalt**	**Graphite**	**Steel**	**Lithium**	**Manganese**	**Nickel**	**Lead**	**Reference**
LDV_ICE[num]	92	26	0	0	968	0	0	0	8.7	(World Steel Association 2019) (European Aluminium Association 2013) (Linde and Reddy 2002) (Jamasmie 12)
LDV_EV[num]	148	118	16.8	33.2	1,320	7.2	11.4	16.8	0	(European Aluminium Association 2013) (Michaux 2019) (Jamasmie 12)
LDV_PHEV[num]	118	81	3.36	6.64	1,237	1.44	2.28	3.36	0	(European Aluminium Association 2013) (Michaux 2019) (Jamasmie 12)
LDV_FCV[num]	135	74	0	0	995	0	0	2	0	(Burnham 2012)
HDVL_ICE[num]	136	28	0	0	1,197	0	0	0	13.6	(Burnham 2012) (Linde and Reddy 2002) (IHS Consulting 2014)
HDVL_EV[num]	372	336	126	249	2,076	54	85.5	126	0	(Michaux 2019) (Burnham 2012)
HDVL_PHEV[num]	199	141	25.2	49.8	1,838	10.8	17.1	25.2	0	(Michaux 2019) (Burnham 2012)

HDVL_FCV[num]	195	102	0	0	1,529	0	0	2.4	0	(Burnham 2012)
HDVM_ICE[num]	468	98	0	0	4,799	0	0	0	16	(Linde and Reddy 2002) (Burnham 2012) (Appendix: Truck Types and Classes 2011)
HDVM_EV[num]	1,064	899	273	539.8	7,129	117	185.25	273	0	(Burnham 2012) (Appendix: Truck Types and Classes 2011)
HDVM_PHEV[num]	640	432	54.6	107.9	6,311	23.4	37	54.6	0	(Burnham 2012) (Appendix: Truck Types and Classes 2011)
HDVM_FCV[num]	668	350	0	0	5,251	0	0	8.4	0	(Burnham 2012) (Appendix: Truck Types and Classes 2011)
HDVH_ICE[num]	1,080	98	0	0	11,073	0	0	0	27	(Burnham 2012) (Appendix: Truck Types and Classes 2011) (Linde and Reddy 2002) (IHS Consulting 2014)
HDVH_EV[num]	1,756	899	420	830	16,452	180	285	420	0	(Burnham 2012) (Appendix: Truck Types and Classes 2011)
HDVH_PHEV[num]	1,420	432	84	166	14,565	36	57	84	0	(Burnham 2012) (Appendix: Truck Types and Classes 2011)
HDVH_FCV[num]	1,542	351	0	0	12,117	0	0	19.3	0	(Burnham 2012) (Appendix: Truck Types and Classes 2011)
2W_ICE[num]	8	1.9	0	0	84.9	0	0	0	1.8	(Burnham 2012) (Appendix: Truck Types and Classes 2011) (Linde and Reddy 2002)
2W_EV[num]	14.7	18.8	2.1	4.15	123	0.9	1.425	2.1	0	(Burnham 2012) (Appendix: Truck Types and Classes 2011) (Passarini, et al. 2018)
2W_PHEV[num]	10.6	15	0.42	0.83	111.3	0.18	0.285	0.42	0	(Burnham 2012) (Appendix: Truck Types and Classes 2011)
2W_FCV[num]	13.2	14	0	0	89.3	0	0	0.32	0	(Burnham 2012) (Appendix: Truck Types and Classes 2011)
Bus_ICE[num]	680	190	0	0	7,154	0	0	0	27	(Burnham 2012) (Appendix: Truck Types and Classes

										2011) (Linde and Reddy 2002)
Bus_EV[num]	1,043	809	273	539.8	9,757	117	185.25	273	0	(Burnham 2012) (Appendix: Truck Types and Classes 2011)
Bus_PHEV[num]	868	590	54.6	107.9	9,146	23.4	37	54.6	0	(Burnham 2012) (Appendix: Truck Types and Classes 2011)
Bus_FCV[num]	999	548	0	0	7,352	0	0	12	0	(Burnham 2012) (Appendix: Truck Types and Classes 2011)
Trains[num][79]	5,000	1000	0	0	6,000	0	0	0	0	(Djukanoc 2017) (Copper Development Association 2019) (Parkin 1991)
Tramways[num]	5,000	500	0	0	6,000	0	0	0	0	(Djukanoc 2017) (Copper Development Association 2019) (Parkin 1991)
Planes[num]	320,000	8,000	0	0	40,000	0	0	0	0	(Sullivan, Lewis and Keoleian 2018) (Willima Rowland 2016) (Copper Development Association n.d.)
Ships[num]	150,000	900,000	0	0	9,900,000	0	0	0	1,200,000	(Sullivan, Lewis and Keoleian 2018) (Hess, et al. 201)
Road[km]	0	1	0	0	82,191	0	0	0	0	(USGS 2006) (Schipper, et al. 2018)
Rail[km]	0	0	0	0	50,000	0	0	0	0	(Schipper, et al. 2018) (Krishnan 2017)
Trolley-cable[km]	0	10,000	0	0	80	0	0	0	0	(Copper Development Association 2019)
Pipe[km][80]	0	0	0	0	10,000	0	0	0	0	(Zeng, Han and Zhang 2016) (Wermac 2019)
Reno_Resi[m2]	0.03	0	0	0	40	0	0	0	0	(Mahamid 2016) (Delft University of Technology 2004) (Schipper, et al. 2018)

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[79] Amount per carriage as the inputs come as number of carriages

[80] 4mm diameter

Reno_Non_Resi[m2]	1.1	0	0	0	65	0	0	0	0	(Delft University of Technology 2004) (Schipper, et al. 2018) (Guggemos and Horvath 2005)
New_Resi[m2]	0.03	2	0	0	40	0	0	0	0	(Mahamid 2016) (Delft University of Technology 2004) (Schipper, et al. 2018)
New_Non_Resi[m2]	1.1	2	0	0	65	0	0	0	0	(Schipper, et al. 2018) (Delft University of Technology 2004) (Guggemos and Horvath 2005)
Washing Machine [num]	4	1.78	0.0032	0	35	0	0	0	0	(World Steel Association 2010) (Kim, et al. 2014) (Reuter, et al. 2013)
Dryer[num]	4	1.78	0.0019	0	46.3	0	0	0	0	(World Steel Association 2010) (Kim, et al. 2014)
Freezer[num]	4	1.78	0	0	33	0	0	0	0	(World Steel Association 2010) (Kim, et al. 2014)
Dishwasher[num]	4	1.78	0.002	0	13.5	0	0	0	0	(World Steel Association 2010) (Kim, et al. 2014)
Fridge[num]	4	1.78	0	0	35	0	0	0	0	(World Steel Association 2010) (Kim, et al. 2014)
Phones[num]	0.03	0.015	0.0023	0.0046	0.0254	0.001	0.0016	0.0023	0	(Reuter, et al. 2013) (ECOINFO 2014)
TV[num]	1.4	1.6	0	0	3.56	0	0	0	0	(Reuter, et al. 2013)
Computers[num]	0.7	0.346	0.042	0.083	1.02	0.018	0.0285	0.042	0.315	(Reuter, et al. 2013) (ECOINFO 2014)
PV-CSI[MW]	20,596	7,530	0	0	55,900	0	0	0	0	(Sullivan, Clark and Wang 2010) (Bödeker, Bauer and Pehnt 2010)
PV-thinfilm[MW]	44,992	7,530	0	0	55,900	0	0	0	0	(Sullivan, Clark and Wang 2010) (Bödeker, Bauer and Pehnt 2010)
Wind-Onshore [MW]	4,180	4,760	0	0	11,900	0	0	0	0	(Sullivan, Clark and Wang 2010) (Andersen 2015) (Broehl and Gauntlett 2018)

Wind-Offshore[MW]	4,180	10,540	0	0	11,900	0	0	377	0	(Sullivan, Clark and Wang 2010) (Andersen 2015) (Broehl and Gauntlett 2018)
Hydro [MW]	52	1,502	0	0	50,000	0	0	0	0	(Sullivan, Clark and Wang 2010)
CSP[MW]	96,000	3,000	0	0	8,000	0	0	1200	0	(Sullivan, Clark and Wang 2010)
Battery[MWh]	560	680	420	830	0	180	285	420	0	(Michaux 2019)
Marine[MW]	0	1,500	0	0	900,000	0	0	0	0	(Uihlein 2016)
Oil[MW]	120	400	0	0	50,000	0	0	0	0	(Sullivan, Clark and Wang 2010) (Kannan, et al. 2004)
Coal[MW]	419	450	0	0	50,721	0	0	0	0	(Sullivan, Clark and Wang 2010) (Spath and Mann 2000)
Gas[MW]	204	10	0	0	31,375	0	0	0	0	(Sullivan, Clark and Wang 2010) (Spath and Mann 2000)
Geothermal[MW]	45,200	907	0	0	1,200,000	0	0	0	0	(Sullivan, Clark and Wang 2010)
Nuclear[MW]	40	650	0	0	30,000	0	0	0	0	(Sullivan, Clark and Wang 2010)
Electricity Demand [GWh]	0	0.2	0	0	0	0	0	0	0	(Schipper, et al. 2018)
Steel[t]	0	0	0	2.2	1	0	10	3.4	0	(MineralInfo 2016) (AZO Materials 2016) (Nickel Institute 2019)
Aluminium[t]	1	0	0	0	0	0.245	0	1.95	0	(Joshi 2008)
Glass[t]	0	0	0	0	0	0.7	0	0	0	(Grahl 2004)

4.5.2.2 Main Assumptions Table

Table 47 - Assumptions made in developing the above table. Weights in kg unless otherwise stated. References are also provided in the above table

Variable	***Weight (kg)***	***Battery***	***Variable***	***Weight***	***Battery***
LDV_ICE	1,353 kg	15 kg	*HDVH_FCV*	19,280 kg	N/A
LDV_EV	1,938 kg	40 kWh	*2W_ICE*	117 kg	3 kg
LDV_PHEV	1,748 kg	8 kWh	*2W_EV*	178 kg	5 kWh
LDV_FCV	1,648 kg	N/A	*2W_PHEV*	154 kg	1 kWh
HDVL_ICE	1,893 kg	22.5 kg	*2W_FCV*	148 kg	N/A
HDVL_EV	2,955 kg	300 kWh	*Bus_ICE*	10,000 kg	45 kg

HDVL_PHEV	2,501 kg	60 kWh	*Bus_EV*	14,330 kg	200 kWh
HDVL_FCV	2,433 kg	N/A	*Bus_PHEV*	12,920 kg	50 kWh
HDVM_ICE	6,500 kg	30 kg	*Bus_FCV*	12,180 kg	N/A
HDVM_EV	10,147 kg	650 kWh	*Trains*	100,000 tons	N/A
HDVM_PHEV	8,589 kg	130 kWh	*Tramways*	50,000 tons	N/A
HDVM_FCV	8,355 kg	N/A	*Planes*	400 tons	N/A
HDVH_ICE	15,000 kg	45 kg	*Ships*	30,000 tons	N/A
HDVH_EV	23,417 kg	1000 kWh	*Phones*	150 g	5 Wh
HDVH_PHEV	19,820 kg	200 kWh	*Computers*	5 kg	0.1 kWh

4.5.2.3 Other Assumptions Table

Table 48 - Other assumptions that entered the model concerning energy producing technologies

Variable	***Assumptions***	***Source***
PV-CSI[MW]	90% of PV produced	(Blagoeva, et al. 2016)
PV-thinfilm[MW]	10% of PV produced	
Wind-Onshore[MW]	<4 MW	
Wind-Offshore[MW]	>4MW	

4.5.3 Variable ‘Other’ for unaccounted mineral usage

The granularity of the mineral module depends upon the granularity of the input variable from the other modules. Numerous aspects associated with the industry module has not been modelled and therefore a factor had to be applied to account for the non-modelled variables. Table 49 below summarizes the other factors applied to the model. Note that these factors are applied simply based on the historical time series (1990 – 2015) and are kept constant until 2050.

Table 49 - Other variables unaccounted in the inputs that have an importance for mineral consumption in the European Union and Switzerland

Mineral	**Other Sectors**	**Other (%)**	**Sources**
Aluminium	High Tech & Engineering (13%)	13	(European Commission: Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs 2017) (European Commission: Directorate-General for
Copper	Jewellery (5%) ; Oxides and dopants (3%) ; Electrolytic refined Copper (2%)	10	
Cobalt	Hard Materials (10%) ; Catalyst (7%) ; Ceramics (5%) ; Magnets (5%) ; other (8%)	35	
Graphite	Lubricants (5%) ; Pencils (4%) ; other (10%)	19	
Steel	Mechanical Engineering (14%)	14	

Lead	Extruded products (4%) ; Miscellaneous (5%)	9	Internal Market, Industry, Entrepreneurship and SMEs 2017)
Lithium	Cement production (9%) ; Lubricant (8%) ; Rubber and plastics production (4%) ; Pharmaceuticals (4%)	25	
Manganese	Chemical Manufacture (5%)	5	
Nickel	Compounds (13%) ; Leisure equipment (4%)	17	
Phosphate	Food additives (10%) ; Fireworks (4%)	14	
Potash	Chemical manufacture (8%)	8	

4.5.4 Conversion parameters

Certain minerals in the module are accounted in the processed form, namely steel and aluminum. Table 50 shows the parameters applied to obtain the raw material namely bauxite and iron to get the amount of raw minerals.

Table 50 - Parameters applied to obtain the raw material demand

Material	*Mineral*	*Factor*	*Explanation*
Steel	**IRON**	1.18	2 tons of Iron and 0.575 tons of scraps are necessary to make 1.7 tons of crude steel (Çiftçi 2019)
Aluminium	**BAUXITE**	4	4 tons of Bauxite is necessary to make 1 tons of aluminium (HistAlu s.d.)

5 Database for historical data and calibration

[redacted] Agriculture, land-use, land-use change & forestry

Table 51 is presenting the main databases that have been used in the agriculture, land-use, land-use change and forestry modules.

Table 51 – 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 animal, carcass yields of animal being slaughtered	FAOSTAT: ▪Livestock Primary ▪The future of food & agriculture, alternative pathways to 2050	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
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	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

[CH_4/head]				
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	-	-

[redacted] Biodiversity

Table 52 - Database for biodiversity module

Dataset	Description	Main sources	Hypotheses to fill gaps	Data quality check
Protected area [%]	Proportion of terrestrial extend of a country protected	World database of protected areas (UNEP-WCMC and IUCN, 2019)	not applicable	Official data source; considered reliable.
Land cover [%]	Type of land (e.g. agricultural, urban)	ESA CCI-LC[81](ESA, 2017)	not applicable	Official data source based on satellite images; considered reliable.

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[81] http://maps.elie.ucl.ac.be/CCI/viewer/download.php

Protected area under human pressure [%]	Human footprint in protected areas	Jones et al. (2018)	not applicable	Peer reviewed article; considered reliable

[redacted]Water

The historical data collected for the water module, the data sources as well as the hypotheses for data completion are described in Table 53.

Table 53 - list of historical data used in the Water module

Dataset	**Description**	**Main sources**	**Data quality check**	**Hypotheses & computation**
Household water use [m3/capita/year]	Average household water use per inhabitant within a year	Household water use data per country from 1991 to 2013: [Reynaud A., 2015]	Good quality data from reliable, coherent and credible source (JRC) However data is not available for all years	We extrapolate missing "in-between" data, or keep last value constant.
Livestock population share [%]	Share of different animal sub-categories within the following animal groups: Sheep, poultry, hens, pigs, bovines, dairies and others.	FAOSTAT	Good quality data from reliable, coherent and credible source (FAO)	

In EUCalc, climate scenarios are defined by a lever which allows the user to set climate ambitions for Europe and the world. These climate scenarios have a direct influence on water availability which are mostly driven by precipitation. We obtain water availability scenarios thanks to the JRC, who simulated the local water availability for all relevant European regions with a monthly time-step. Their historical datasets cover the period 1981-2010, while their projections run up to 2100. These projections were simulated for both the RCP 4.5 and RCP 8.5 scenarios. The influence of the lever position on the selection of a specific water availability dataset is described in Table 54.

Table 54 – Description of datasets used for future water resources according to the level of the Climate lever

Climate lever	Water resources data description
Level 1	RCP 8.5 dataset
Level 2	RCP 4.5 dataset
Level 3	RCP 4.5 dataset with static value from 2048 to 2050
Level 4	RCP 4.5 dataset with static value from 2030 to 2050

Moreover, we distinguish historical data used to compute values within our model (see Table 53) from data used to calibrate the results of the model. Table 55 presents the list of datasets used to calibrate the results from the water module.

Table 55 - calibration data used in the Water module

Dataset	Description	Main sources	Data quality check	Hypotheses & computation
Water demand public sector [m3/month]	Water demand for households and services per region and per month	Historical data for water demand in the public sector from 1981 to 2010 with monthly values for all EU28+1 countries and sub-regions: provided by JRC	Good quality data from reliable, coherent and credible source (JRC)	-As 2006 is the year for which JRC data are the most robust, we calibrate our results on year 2006* -we aggregate values at into yearly values (m3/year) to be compared with our yearly results*
Water demand livestock sector [m3/month]	Livestock water demand per region and per month	Historical data for water demand in the public sector from 1981 to 2010 with monthly values for all EU28+1 countries and sub-regions: provided by JRC	Good quality data from reliable, coherent and credible source (JRC)	*Same comments as above

Water demand energy sector [m3/year]	Water demand for energy per region and per month	Historical data for water demand in the public sector from 1981 to 2010 with monthly values for all EU28+1 countries and sub-regions: provided by JRC	Good quality data from reliable, coherent and credible source (JRC)	*Same comments as above
Water demand industry sector [m3/year]	Water demand for industry per region and per month	Historical data for water demand in the public sector from 1981 to 2010 with monthly values for all EU28+1 countries and sub-regions: provided by JRC	Good quality data from reliable, coherent and credible source (JRC)	*Same comments as above
Irrigation water consumption [m3/year]	Water consumed by irrigation per region and per month	Historical data for water demand in the public sector from 1981 to 2010 with monthly values for all EU28+1 countries and sub-regions: provided by JRC	Good quality data from reliable, coherent and credible source (JRC)	*Same comments as above

[redacted] Minerals

5.4.1 Calibration

The calibration process for mineral consumption is twofold. The calibration data is downloaded from the British Geological Survey website for mineral production (mining), import and export (raw and refined) (British Geological Survey 2016). Equation 1 is then applied to the data in accordance with the method in (European Commission: Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs 2017) and (European Commission: Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs 2017) and the result is, if available, verified through other sources.

$$Min\_calib\_mineral[t] = mineral\_production[t] + mineral\_import[t] - mineral\_export[t]$$

Equation 1 - Calibration equation

Table 56 - Calibration data sources and their verification sources when available

Mineral	**Data Verification**
Bauxite (Aluminium)	(European Aluminium Association 2017) (Passarini, et al. 2018)
Copper	(International Copper Study Group 2019) (Passarini, et al. 2018)
Cobalt	(P., et al. 2018)
Graphite	(MineralInfo 2016)
Iron (Steel)	(Passarini, et al. 2018) (EUROFER: The European Steel Association 2018)
Lead	
Lithium	(European Lithium n.d.)
Manganese	
Nickel	(The Nickel Institute 2013)

6 References

In this section, references are organised by module, namely "Agriculture and LULUCF", "Biodiversity", "Water" and "Minerals".

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