EUCALC

Explore sustainable European futures

Report on emissions reduction potential under agricultural practices and dietary change

D4.4

November/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	Report
Work Package	4
Document Title	Report on emissions reduction potential under technological and dietary change
Main authors	Costa L., Baudry G., Seydewitz T.
Partner in charge	PIK
Contributing partners	IMPERIAL
Release date	November 2019
Distribution	Public

Short Description

This report makes use of the EUCalculator model to evaluate the mitigation potential of the European agricultural system according to the combined changes in agricultural practices and behavioural shifts.

Our results point for two major conclusions, as it follows: The first is that GHG reduction potential in the EU's agricultural sector appears to be much larger than the currently reported in other policy-guiding scenarios e.g., DG AGRI (2019). The second is that the intensification of agricultural production alone will not deliver substantial GHG reduction in the agricultural sector by 2050. To unlock the full potential of GHG reduction a substantial shift in current diets towards healthy standards and reduction of food waste is required. In such a scenario, the potential for reductions increases to over 60% in 2050 (compared to 2015).

Quality check	
Name of reviewer	**Date**
Giuseppe Forino	**05-11-2019**

Statement of originality:

This report contains original unpublished work except where clearly indicated otherwise.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.

Table of Contents

List of Tables

List of Figures

List of abbreviations

GHG – Green House Gases

ESD – Effort Sharing Decision

EEA – European Environmental Agency

ETS – European Union Emissions Trading System

NETS – Non-European Union Emissions Trading System

RES – Renewable Energy Supply

1 Executive Summary

The agricultural sector is a major user of natural resources and has a complex relationship with the environment. At the same time, it can provide solutions to the overall climate change problem by reducing emissions and by sequestering carbon while preserving viable food production.

Acknowledging the important role of the agricultural sector, this report makes use of the EUCalculator model to evaluate the mitigation potential of the European agricultural system resulting from transformational pathways regarding agricultural practices and behavioural shift. The transformational scenarios simulate the GHG emissions in agricultural systems following substantial dietary shifts towards less carbon-intensive healthy diets (Springmann et al, 2018) and a generalized move towards a 100% agroecology strategy (Poux and Aubert, 2018) by 2050. In addition, the report also explores the GHG impacts for the more conventional pathway of preserving current dietary patterns combined with a strategy agricultural intensification achieving its maximum feasible technical potential (FAO, 2018).

Our results point for two major conclusions. The first is that there is a large scope for GHG reduction in the agricultural system of Europe that should be explored. This is at odds with current decarbonisation scenarios (e.g., E3MLab & IIASA (2016), DG AGRI (2019)) that shield the agricultural sector to transformational levels of ambition required in sectors such as transport or buildings in 2030 and 2050 (European Commission 2018).

The second major conclusion is that the intensification of agricultural production alone will deliver at best 30% reductions of GHG by 2050 (compared to 2015). In order to unlock the full potential of GHG reduction a substantial shift in current diets towards healthy standards and reduction of food waste is required. In such a case the potential for reduction increases to over 60% in 2050. Coupled with the change in dietary habits there are two alternative pathways to achieve the same amount of reduction. One can opt for the further intensification of agricultural production, increasing the efficiency in term of CO_2/Kcal produced. The other one can favour the adoption of agroecology means of production. Both strategies entail the same amount of GHG reduction but different consequences for ecosystems.

2 Introduction

2.1 The importance of agriculture in EU's mitigation plans

Current emissions from the agriculture sector

In 2017, according with the EEA Greenhouse Gas (GHG) inventories, emission from agriculture of the current 28 Member States of the European Union (EU28) accounted for a total 439 million tons of CO_2eq - this represented 10.2% of total EU-28 GHG emissions in 2017[I]. In 1990, the emission from agriculture for the same geographic aggregation was of 543 million tons of CO_2eq, which implies a reduction of circa 19% compared to 2017. Nevertheless, a look into more recent developments shows a more stagnant picture. If one considers the emission levels in agriculture from the year 2005 (a references year for many of the targets we will explore in this report), then one verifies that agriculture emissions have partially stagnated in the EU28. More specifically, comparing emissions numbers between 2010 and 2017 one verifies that emissions have increased about 0.5% a year[1]. This recent trend is in opposition to the general need of reducing GHG across all sectors. Should these trends prevail into the future, then more effort will be required from other sectors in order to reach country-specific 2030 GHG targets.

Current compliance of emissions with the 2020 and 2030 targets

Although the agriculture sector accounts only for 10% of European GHG emissions, one should keep in mind that several countries will very likely already miss their 2020 targets by a few percentage points. According to GHG projections available from Member States, with existing national policies and measures in place, the 2020 emissions under the Effort Sharing Decision (ESD) scope are expected to be lower than the 2020 targets in 20 Member States.

Table 1- Comparison of agricultural emissions in 2005 and those suggested by the ECO30 scenario by 2030 (values refer to Mt of non-CO_2 GHG)

Country	Agricultural emissions in year 2005[2]	Agricultural emissions in ECO30 scenario in 2030[3]	% of change
France	75.51	72.78	-3.61
Germany	61.74	60.94	-1.30
Spain	40.12	37.54	-6.42
Poland	28.36	34.55	21.81
United Kingdom	41.67	46.47	11.53
Italy	31.37	28.97	-7.66
Romania	21.01	15.66	-25.45
Ireland	18.40	21.48	16.71
Netherlands	18.28	19.59	7.15

[1] Source of percentages are own calculations from authors.
[2] EEA https://www.eea.europa.eu/data-and-maps/data/data-viewers/greenhouse-gases-viewer
[3] Technical report on Member State results of the EUCO policy scenarios https://ec.europa.eu/energy/sites/ener/files/documents/20170125_-_technical_report_on_euco_scenarios_primes_corrected.pdf

Greece	8.93	8.17	-8.48
Czech Republic	7.66	6.87	-10.34
Belgium	10.12	10.68	5.55
Denmark	10.59	10.36	-2.19
Hungary	5.93	6.59	11.21
Portugal	6.74	8.02	18.99
Bulgaria	5.15	5.53	7.34
Austria	6.93	7.4	6.71
Sweden	6.94	6.85	-1.24
Finland	6.23	5.84	-6.27
Lithuania	4.17	5.51	32.19
Croatia	3.24	2.77	-14.47
Latvia	2.38	2.14	-10.14
Slovakia	2.52	2.45	-2.68
Slovenia	1.68	1.64	-2.61
Estonia	1.16	1.3	11.72
Cyprus	0.53	0.71	33.46
Luxembourg	0.64	0.67	5.14
Malta	0.08	0.09	18.69
TOTAL	**428.08**	**431.67**	**-0.82**

In Austria, Belgium, Cyprus, Finland, Germany, Ireland, Luxembourg and Malta, existing measures will not be enough to meet their 2020 ESD targets. Currently reported additional measures do not change this prospect[4]. Despite the clear difficulties of Member States in meeting the short terms targets, the agricultural sector seems to have been spared from having to comply with significant reduction for the 2021-2030 period. Country-level results from two core policy scenarios, EUCO27 and EUCO30 (E3MLab & IIASA, 2016) suggest that nearly no reductions in GHG emissions from the agricultural sector are necessary between 2005 and 2030, see Table 1.

At an aggregated level, emissions of non-CO_2 GHG emissions from agriculture in the EU28 for the year 2005 were reported at 428.08 Mt. Integrating the same geographic scope for non-CO_2 GHG emissions from agriculture reported in the ECO27 scenario results in 431.67 Mt. This is less than 1% reduction between 2005 and 2030 for the all of the EU28. At the country level the differences range between changes of -25% in Romania to increases of over 18% in Portugal, Malta, Cyprus and Poland. Big emitters like Germany and France reported in 2005 emissions that are respectively only 1.3% and 3.6% higher than those in required by 2030 in ECO27. Given that 1) the ECO27 scenario was designed to achieve the 2030 targets as agreed by the European Council and 2) its reductions in GHG agricultural emission in the EU28 is close to zero, most of the decarbonisation efforts will have to be done in other sectors. This is unfortunate. Would the agricultural sector comply with the 30% reduction as defined in ESD, a total of 115.6 Mt of GHG emissions would be saved and potentially provide an important leeway for emissions in other sectors, for example transport.

[4] EEA Report No 16/2018, Trends and projections in Europe 2018, Tracking progress towards Europe's climate and energy targets. Luxembourg: Publications Office of the European Union, ISBN 978-92-9480-007-7

"Exporting" the problem of EU food consumption – trade

In EU countries food consumption footprints, including GHG emissions from primary production, international trade and land use change, differ considerably across Member States, ranging between 1460 CO_2-eq/cap/year in Portugal and 610 CO_2-eq/cap/year in Bulgaria. The EU-wide average was of 1070 CO_2-eq/cap/year in the year 2010 (Sandström et al, 2018). Most emissions from the production and trade of the EU food supply are caused by the consumption of domestic products or imports from other European countries, 64%, followed by Latin America (25%), Asia (7%) and Africa (3%). Given the traditionally lower emission-intensity across economic sectors in EU28 when compared with the same economic activity elsewhere (Costa & Moreau, 2019), a shift in agricultural production from EU to Africa or South America might result in a disproportional rise in consumption emissions of agricultural production. Of these, the share of animal products in the diet has been identified as the most important factor determining the footprint of food consumption. Following IPCC guidelines, Caro et al (2014) estimated non-CO_2 emissions from beef, pork, and chicken produced in 237 countries over the period 1990–2010, and assigned emissions to the country where the meat is ultimately consumed. Europe plays a minor role in terms of global emissions embedded in trade of meat outside its borders.

Similarly to Sandström et al, (2018), Caro et al (2014) also identify that most of the traded emissions in meat products take place within EU28 borders. Trades among European countries are in fact quite substantial. In particular, meat exported from France to Italy and Greece embodied 1.4 Mt and 1.2 Mt of CO_2-eq emissions, respectively. Meat exported from Ireland to the UK embodied 1.0 Mt of CO_2-eq emissions. The internal emissions are greater than those caused by EU consumption from elsewhere. In fact, Caro et al (2014) identify that the largest flow of emissions traded in meat products is as a response of the demand from Russia - 0.2 Mtons of CO_2-eq emissions (see Figure 1).

Given that the majority of emissions embedded in European agricultural products are domestic (meaning they take place within the Member States), increasing the self-sufficiency of EU28 in terms of agriculture productions has limited scope in reducing emissions. On the other hand, an overall increase of GHG emissions will occur if the EU28 imports agricultural products from elsewhere rather than producing them domestically.

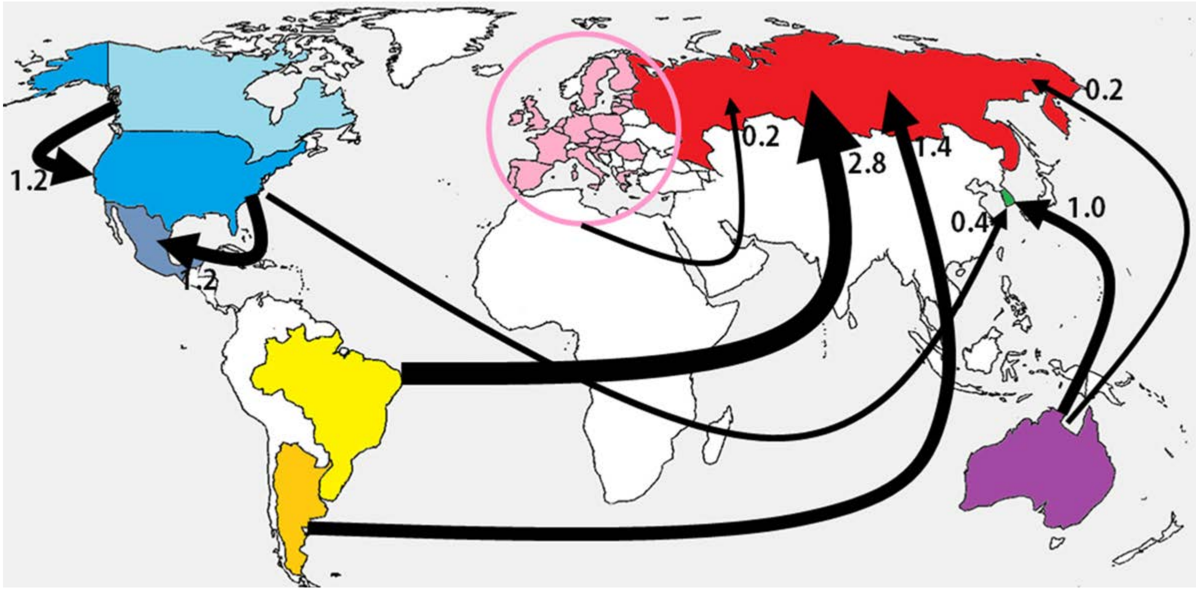

Figure 1- Largest interregional fluxes of emissions (Mtons of CO_2-eq) embodied in trade of meat (aggregated to include beef cattle, pig and chicken meat) between largest net exporting-importing countries in the world (from Caro et al, 2014).

Previous scenarios of diet-shifts & changing agricultural practices

Over the recent years, evaluations of the mitigation potential and environmental benefits implied in dietary shifts have been a common presence in scientific literature, both at the global level (Springmann et al, 2018) and for particular countries (Milner et al, 2015). Systematic reviews point for reduction potential as high as 70–80% of GHG emissions and land use, and 50% of water use from adopting sustainable dietary patterns (Aleksandrowicz et al, 2016). Furthermore, the reduction in environmental footprints was generally proportional to the magnitude of animal-based food restriction.

2.2Trade-offs in the coupled socio-agricultural system

Trade-off analysis has become an increasingly important approach for evaluating system level outcomes of agricultural production (Klapwijk et al, 2014). Two of these important trades-offs are 1) feeding a growing and more affluent population while keeping GHG agricultural emissions in check, and 2) rowing large amounts of bioenergy required for global climate targets while keeping land expansion from endangering biodiversity.

At the global level, trade-offs/synergy analysis between mitigation and food security has revealed that closing the yield gap by 50% for crops and 25% for livestock by 2050 would decrease agriculture and land-use change emissions by 8% overall. Nevertheless, the way how the gaps are closed has a strong influence in the amount of GHG saving. Opting for sustainable land intensification to reduce the yield gap would increase GHG savings by one-third when compared with a fertilizer intensive pathway (Valin et al, 2013). An alternative option to feed a growing demand for calories is to expand current agricultural areas. For a scenario where calorie demand doubles with respect to the levels in the year

2000, selective extensification[5] was found to save 6 billion metric tons of carbon compared with a business-as-usual approach[6] (Johnson et al, 2014).

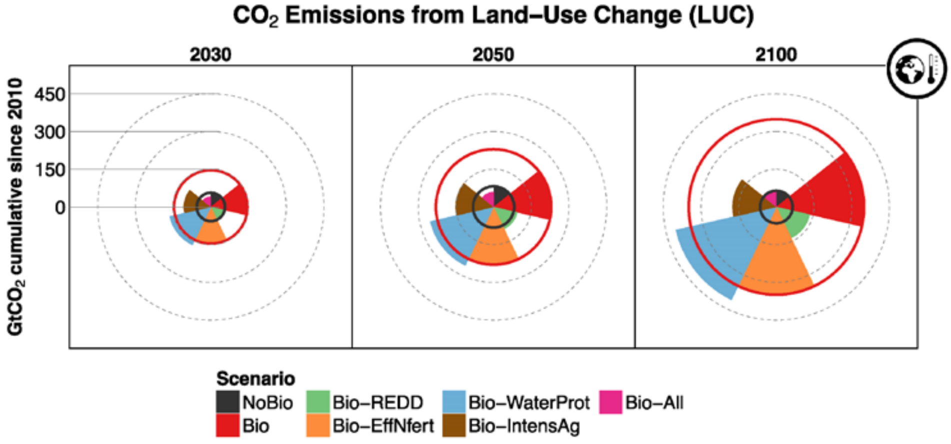

Figure 2- Cumulative CO_2 emissions from land-use change for a 300Ej demand of bioenergy in 2100

Strong decarbonisation targets will require agriculture to become an integral part of the global energy supply system, most noticeably through the provision of various kinds of biomass as a primary energy carrier. Such has raised considerable concerns about the sustainability of bioenergy due to potentially unfavourable negative impacts on biodiversity and food production for human consumption (Tomei & Helliwell, 2016). For a global low demand of bioenergy at around 100Ej by 2055 (in 2015 global bioenergy including wastes consumption was of 51 EJ[7]) there is no need for further land expansion, provided average global technological change rates can be maintained at recent levels (Lotze-Campen et al, 2010). It is estimated that increasing the amount global demand for bioenergy to 300Ej by 2100 results in global cumulative emissions CO_2 between 2010 and 2030 of about 150Gt (see Figure 2), compared to circa 60Gt without demand for bioenergy.

Importantly, it seems that the trade-offs have been mostly looked at from an energy-supply perspective without considering significant changes in the type and amount of food-demand. While population expansion has been the largest driver for agricultural land use change in the past, dietary changes are a significant and growing driver of future land use. The types of food commodities consumed therefore more important than the quantity of per-capita consumption in determining the agricultural land requirement (Alexander et al, 2015 and 2016). Global studies point that the perpetuation of present-day diets will not lead to land savings even in the advent of continuous technology change. Supplying the projected global population of 9 billion people in 2050 with the present diet and agricultural technology of Northern America would mean that cropland area had to be almost doubled. Doing the same exercise using Western Europe as a reference for diets and agricultural production efficiency would still lead to an area expansion by more than 70% (Kastner et al, 2012).

---

[5] Expansion takes place preferably in areas with the highest ratio of total calories produced to the loss of carbon with extensification.

[6] Expansion takes place in a uniform manner across areas.

[7] International Energy Agency, Bioenergy and biofuels (2017)
Direct link: https://www.iea.org/topics/renewables/bioenergy/

Given the described in sections 2.1 and 2.2, a trade-off analysis for Europe would have to comprise both an explicit consideration of changing diets in addition and the exploration of a broad range of agricultural practices. In addition, considerations of trade will have to be made given the marked difference of agricultural footprints in countries across the globe.

It should also be pointed out that while global and continental analyses of trade-offs on food security and environmental concerns might be plentiful, at the national level the exercises become scarcer. This is somehow at odds with the policy-making and target setting at the EU-level, which have both a continental and a country-specific setting. This report moves towards bridging these two scales by employing the EUCalculator model to evaluate country-specific but EU-consistent evaluation of trade-offs in the agricultural system.

3 Future scenarios for food & agriculture in Europe

3.1 Methodology

The present report aims at assessing the potential for emissions reduction under agricultural practices and dietary changes. Given the multiple factors that may indirectly affect this potential, a *ceteris-paribus* approach enables us to consider how the agri-food system could contribute to the global mitigation effort. In other words, the agri-food system features will be integrated and compared against a common setting for all the other sectors, including the macro-economic drivers (e.g. demography):

Box 1 – EURef - Baseline

In brief: The baseline scenario reproduces, as far as possible, the main sectoral assumptions and outputs of the EU-Reference scenario (EURef) by the year 2050 as detailed in Capros et al (2016). Accordingly, it portraits an Europe of limited progress towards decarbonization beyond the sectoral policies currently implemented and without a significant movement towards the adoption of sustainable lifestyles. In terms of GHG emissions, the baseline scenario achieves ~43.3% reduction in 2050 compared to year 2015 (in Capros et al. 2016, emissions savings are of 47.7% for the same time frame).

Global mitigation effort: There is only a minor effort in tackling emissions beyond the expected past trends in efficiency gains. Therefore the EU fails in achieving long-term published emission reduction ambitions. This also takes into account the possibility that some emission reductions are achieved, but climate sensitivity is such that these ambitions make no real difference to the amount of warming in 2100. As results, a 4 degree scenario by 2100 is possible.

Demography: This level is aligned with the baseline population projection in Eurostat (2019 update)[8]. Under this scenario population of EU28 reaches 533 Million in 2050. There is a moderate increase of more population moving into urban areas from about 72.5% to 80% (in line with current trends) but lower

[8] https://ec.europa.eu/eurostat/web/population-demography-migration-projections/population-projections-data

than the strongest urbanization scenario available for Europe.

Lifestyles: Behavioural change evolves largely following past observed trends. Individual travel demand continues to rise and by 2050 it is circa 20% higher than currently. A similar increase takes also place in the amount of living residential area per person. Diets change very little apart from the slow decline in bovine meat and a moderate shift towards eating more vegetables. The number of appliances per household increases and so does the demand for packaging.

Buildings: In the building sector the annual renovation rate tops at 1% with most of the renovations being shallow (that is, achieving only -30% energy savings). The efficiency of boilers increases slowly across the stock to an average of 85% for gas boilers and 81% for oil boilers. No increase in district heating with the share in building heating supply following the historical trend pre 2015. Finally, the appliance efficiency is set to 38%.

Transport: Car use continues to grow. No effort to reduce urban sprawl, or to invest in rail and public transport infrastructure. This leads to a quasi-status-quo in 2050 compared to 2015 levels. By 2050, Low Emission Vehicles (Gas, Plug-in Hybrid) represent 6% of new sales and Zero Emission Vehicles (Battery Electric Vehicles and Fuel Cell Electric Vehicles) represent 2% of new sales. Finally, by 2050 biofuels represent 7% of total road fuels in 2050, no biofuels for marine and aviation.

Manufacturing: Material switches range from 3% (substitution of conventional wall insulation with cellulose) up to 20% (substitution of concrete with timber in buildings). The improvement rate of material efficiency ranges between 2 and 8%. No major energy efficiency measures in the manufacturing and production sector are observed. Slightly more ambitious energy efficiency measures in the manufacturing and production sector take place. The estimated range of increased energy efficiency is between 5% (wood products) and 16% (food, beverages and tobacco) across sectors.

Energy: The transition to RES is slow. Coal power plants are closed only as they reach end of life, and planned new coal power plants in countries enabling coal in the mix are coming online. Carbon capture evolves very slowly and no more than 10% of energy the emissions are captured by 2050. New on- and off-shore wind power capacities follow the current trends and so does new PV and CSP capacities, by 2050 both new wind and solar capacities exceed 200 GW each.

3.2 Scenario narratives

The European Calculator is an exploratory model by essence and enables one to consider a wide range of possible setting that can: (1) match the existing "state of the art" scenarios, (2) but while exploring how the agri-food system sustainability could be affected by various factors in these scenarios (e.g. diets, bioenergy demand or global temperature); (3) or else yield new insights and new storylines, such as how do the impacts of diets shifts without agricultural practices improvement – or the other way around – affect the sustainability of the agri-food system?

There is no such thing as agri-food system sustainability regardless without an alignment between agricultural practices and the diet patterns. In other words, sustainability emerges from the smart combination of the diets and practices, which are driven by multiple factors at the crossroads of technology and lifestyle patterns. In order to capture this spectrum of possible settings, the following section provides narrative descriptions of the scenarios used in the report to evaluate the potential GHG emission reduction under various agricultural practices and dietary change (see Figure 3). The storylines highlight the main scenario characteristics, relationships between key driving forces and the dynamics of their evolution.

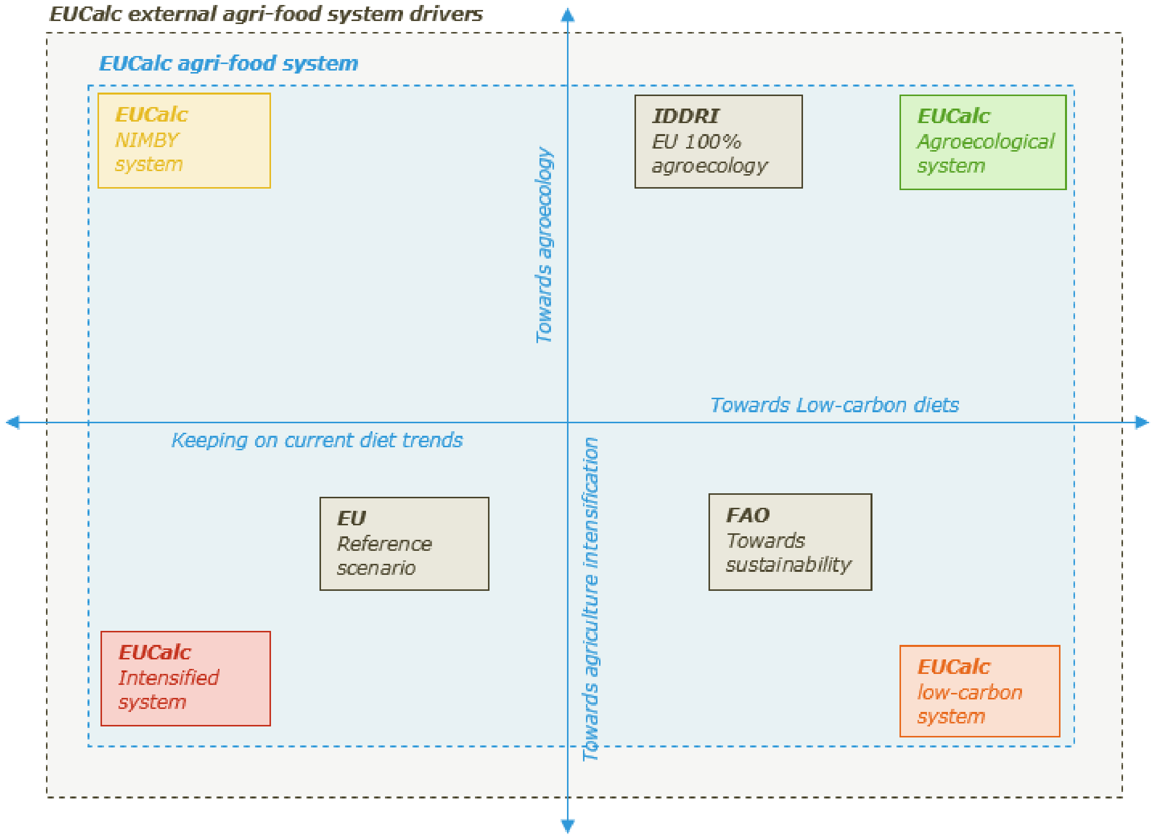

Figure 3- Scope of the EUCalculator exploratory pathways for the agri-food system [grey boxes refer to state of the art scenarios, colored ones refers to EUCalculator scenarios]

The present report will consider 4 heterogeneous scenarios including EUCalculator '**Intense**', '**Low-Carbon**', '**Agroecology**', and '**NIMBY**'. The following boxes present each scenario narratives in brief:

Box 2 - Intense: intensified agricultural production system without low-carbon diet shift

In brief: The Intense scenario portraits a future in which agricultural practices regarding crop and livestock production is intensified according to the maximum technical potential. The European dietary habits are assumed to continuing following the historical trends. Therefore, the *Intense* scenario explores a technologically challenging pathway for the agricultural production system in which society fails to shift towards low-carbon diets. Land sparing approach possibly enables to extend forest area but in a limited extent given the European dietary habits. The scenario considers an acceleration of the current trends and challenges technology more than management practices.

Literature Mapping: Intense scenario can be considered an hybrid pathway combining the EURef scenario storyline with FAO's (FAO, 2018) most ambitious agriculture yields for 2050 pathways.

Lifestyle: Calorie requirements of the European population evolve according to the country-specific linear trends of body mass extracted from NCD Risk Factor Collaboration 2016 (NCD-RisC, 2016). The composition of European diets evolves according to past (2000-2013) linear trends for each food group considered until the year 2050. Food waste at the consumer level is kept constant to values observed in 2013 using the food-group specific factors in Gustafsson et al, 2013.

Agricultural practices, input-use and GHG emissions: Both livestock and crop production systems are intensified (FAO, 2018). The food and feed self-sufficiency are assumed to continuing the historical trends (Capros et al, 2013). Crop yields are increasing but while increasing input requirements in terms of fertilizers and pesticides (FAO, 2018). Livestock yields are also increasing but while decreasing the animal living condition and increasing food losses and wastes (e.g. illness). Bioenergy production is assumed to follow the EURef pathways (see section 3.1, Box 1). Lands can be spared thanks to the intensification of the production system, enabling afforestation/reforestation. Cropland consists of monocultures, and feedlots are used as the main livestock production system.

Box 3 - Low-Carbon: intensified agricultural production system with low-carbon diet shift

In brief: The Low-Carbon scenario follows the agricultural practices pattern of Intense but while considering a strong movement towards a convergence of European dietary patterns with the health guideline in WHO and the flexitarian diet proposed in (Springmann et al, 2018). Therefore, the Low-Carbon scenario explores a pathway that is challenging for both the agricultural production system and the lifestyle patterns. Land sparing approach possibly enables to extend forest area in a large extent given the shift for low-carbon diets.

Literature Mapping: The Low-Carbon scenario philosophy is the most represented in the literature, joining both intensified production systems and low-carbon shifts.

Lifestyle: Calorie requirements of the European population are reduced reflecting lifestyle changes that favours eating just the necessary amount of calories to guarantee that the current obesity prevalence in Europe drops by 50%. Regarding diets, there is a widespread adoption of a flexitarian diet as proposed in Springmann et al, (2018). This means that meat consumption in kept at 38g per day with 13g per day of red meat. Sugars and sweeteners are kept at below 5% of calorie intake; and fruits and vegetables consumption to be over 600g/day. Food waste at the consumer level is reduced by 75% by 2050.

Agricultural practices, input-use and GHG emissions: Both livestock and crop production systems are intensified (FAO, 2018). The food and feed self-sufficiency are assumed to continuing the historical trends (Capros et al, 2013). Crop yields are increasing but while increasing input requirements in terms of fertilizers and pesticides (FAO, 2018). Livestock yields are also increasing while decreasing the animal living condition and increasing food losses and wastes (e.g. illness). Bioenergy production is assumed to follow the EURef pathways (see section 3.1, Box 1). Lands can be spared thanks to the intensification of the production system, enabling afforestation/reforestation. Cropland consists of monocultures, and feedlots are used as the main livestock production system.

Box 4 - Agroecology: agroecology production system with low-carbon diet shift

In brief: The Agroecology scenario follows the aim of achieving agricultural systems that are 100% agroecological as described in Poux and Aubert (2018) while considering at the same time a successful dietary shift towards a healthy (WHO) and low-carbon diet (Springmann et al, 2018). The Agroecology scenario explores a pathway that is challenging for both the agricultural production system and the lifestyle dietary patterns. Contrary to Intense and Low-Carbon scenarios, technological shifts refer to novel management approaches. Agroecology offers a land sharing option that enables carbon to be stocked through agroforestry and sylvopasture options.

Literature Mapping: Agroecology scenario can be considered a pathway combining the agroecology production standards (Poux and Aubert, 2018) and the deployment of the low-carbon diet as proposed by (Springmann et al, 2018).

Lifestyle: Calorie requirements of the European population are reduced reflecting lifestyle changes that favours eating just the necessary amount of calories to guarantee that the current obesity prevalence in Europe drops by 50%. Regarding diets, there is a widespread adoption of a flexitarian diet as proposed in Springmann et al, (2018). This means that meat consumption in kept at 38g per day with 13g per day of red meat. Sugars and sweeteners are kept at below 5% of calorie intake; and fruits and vegetables consumption to be over 600g/day. Food waste at the consumer level is reduced by 75% by 2050.

Agricultural practices, input-use and GHG emissions: Both livestock and crop production systems follow the agroecology standards (Poux and Aubert, 2018), leading to decrease crop yields and maintaining livestock yields. Cropland is under agroforestry management and low-no tillage is the standard, leading to increase the cropland carbon stock. Grasslands are also under agroforestry management. The food and feed self-sufficiency are assumed to continuing the historical trends (Capros et al, 2013). Neither synthetic fertilizers nor pesticides are used by 2050, and energy-use per ha is reduced. Food losses and wastes are limited and highly reduced compared with 2015.

Box 5 - NIMBY: agroecology production system without low-carbon diet shift

In brief: The NIMBY scenario considers a shift of the European agricultural system towards agroecology, while considering the current trends in terms of diets. Without a diet shift, the extensive agroecology approach leads to higher land competition, possibly leading to domestic and non-domestic deforestation through the livestock land and feed requirement. NIMBY enables to increase the local agri-food system sustainability while possibly decreasing the global agri-food system sustainability.

Literature Mapping: NIMBY scenario is investigating the limit of the agroecological approach given the current dietary trend.

Lifestyle: Calorie requirements of the European population evolve according to the country-specific linear trends of body mass extracted from NCD Risk Factor Collaboration 2016 (NCD-RisC, 2016). The composition of European diets evolves according to past (2000-2013) linear trends for each food group considered until the year 2050. Food waste at the consumer level is kept constant to values observed in 2013 using the food-group specific factors in Gustafsson et al 2013.

Agricultural practices, input-use and GHG emissions: both livestock and crop production systems follow the agroecology standards (Poux and Aubert, 2018), leading to decrease crop yields and maintaining livestock yields. Cropland is under agroforestry management and low-no tillage is the standard, leading to increase the cropland carbon stock. Grasslands are also under agroforestry management. The food and feed self-sufficiency are assumed to continuing the historical trends (Capros et al, 2013). Neither synthetic fertilizers nor pesticides are used by 2050, and energy-use per ha is reduced. Food losses and wastes are limited and highly reduced compared with 2015.

3.3 Scenarios as European calculator pathways

The following section aims at presenting the rationales and lever setting of the European Calculator that enable to match the previously detailed scenario. When comparing against EURef scenario, "*not explicit in EURef*" refers to features considered in EURef but not explicitly quantified, while "*not considered in EURef*" refers to features out of the EURef scope.

3.3.1 Lifestyles: towards a low-carbon diet?

3.3.1.1 Levers for the scenarios explored

The lever settings for diets, food waste and calorie requirements in Table 2 are based on the groundwork carried in Del 1.3 and 8.3 (Costa et al, 2017, 2019). The calorie ranges for diets (by food group, e.g., poultry, cereals, etc…) reflect the spectrum of possible changes investigated in the literature. This range is bounded between the calorie demand of diets following past observed trends until 2050 and those resulting from a generalized convergence of the entire population of countries towards the adoption of diets that comply with the health standards of WHO and flexitarian diet, as also proposed in Springmann et al, (2018).

In addition to change in diets, the granularity of the EUCalculator model also allows to make considerations on the evolution of food waste at the consumer level (waste at the farm level is dealt with in agricultural practices). In this case the scenarios proposed range between stagnation to current levels of food waste until the year 2050, or the compliance of Sustainable Development Target 12.3 that states "b*y 2030, halve per capita global food waste at (…) and consumer* *levels."* The consumer-level shares of food waste are derived as a proportion of calorie availability as detailed in Gustafson et al (2013).

Table 2- Diet composition and food-waste settings for the following scenarios

Lever setting		Main variables	Values by 2050
Intense	1 ambition level	Calorie requirements [kcal/cap/day] Food waste [kcal/cap/day] Pig calories [kcal/cap/day] Poultry calories [kcal/cap/day] Bovine calories [kcal/cap/day] Milk calories [kcal/cap/day] Fruits calories [kcal/cap/day] Vegetable calories [kcal/cap/day] Cereals calories [kcal/cap/day]	2572 521 160 80 44 370 80 60 695
Low-Carbon	1 ambition level	Calorie requirements [kcal/cap/day] Food waste [kcal/cap/day] Pig calories [kcal/cap/day] Poultry calories [kcal/cap/day] Bovine calories [kcal/cap/day] Milk calories [kcal/cap/day] Fruits calories [kcal/cap/day] Vegetable calories [kcal/cap/day] Cereals calories [kcal/cap/day]	2386 130 55 25 14 370 357 261 689
Agroecology	4 ambition level	Calorie requirements [kcal/cap/day] Food waste [kcal/cap/day] Pig calories [kcal/cap/day] Poultry calories [kcal/cap/day] Bovine calories [kcal/cap/day] Milk calories [kcal/cap/day] Fruits calories [kcal/cap/day] Vegetable calories [kcal/cap/day] Cereals calories [kcal/cap/day]	2386 130 55 25 14 370 357 261 689
NIMBY	4 ambition level	Calorie requirements [kcal/cap/day] Food waste [kcal/cap/day] Pig calories [kcal/cap/day] Poultry calories [kcal/cap/day] Bovine calories [kcal/cap/day] Milk calories [kcal/cap/day] Fruits calories [kcal/cap/day] Vegetable calories [kcal/cap/day] Cereals calories [kcal/cap/day]	2572 521 160 80 44 370 80 60 695
EURef	1 ambition level	Calorie requirements [kcal/cap/day] Food waste [kcal/cap/day] Pig calories [kcal/cap/day] Poultry calories [kcal/cap/day] Bovine calories [kcal/cap/day] Milk calories [kcal/cap/day] Fruits calories [kcal/cap/day] Vegetable calories [kcal/cap/day] Cereals calories [kcal/cap/day]	2572 521 160 80 44 370 80 60 695

Finally, the scope of dietary change is completed by the explicit inclusion in the EUCalculator model of scenarios for total calorie requirements of the population, ranging between a) continuation of the past trends in body weights constructed from the historical data in NCD Risk Factor Collaboration (NCD-RisC 2016) and b) the reduction of body weights so that obesity in a given country is cut by half by the year 2050.

3.3.2 Agriculture: towards a sustainable food production system?

The first sub-section presents the EUCalculator tool lever setting corresponding to each scenario. The second sub-section provides the lever setting for the external agri-food system drivers - *common setting for all scenarios* - that are following as much as possible the EURef scenario.

3.3.2.1 Levers for the scenarios explored.

The lever setting for the *climate smart cropping system* is based on an extensive literature survey (Baudry et al, 2019a) and aimed to capture the whole spectrum of what is technically possible ranging from the most intensive (large scale monocultures) to the most extensive (agroecology) approaches (Capros et al., 2013; FAO, 2018; Madeira et al, 2017; Poux and Aubert, 2018; Sánchez-Muros et al, 2014). Table 2 presents the EUCalculator lever setting that matches EURef, Intense, Low-Carbon, Agroecology, and NIMBY scenarios.

Table 3- Climate-smart cropping system setting for the following scenarios

	Lever setting	Main variables	Values by 2050
Intense	A ambition level	Wastes & Losses [%] Crop-yields [kcal/ha] Fertilizer-use [kg/ha] Pesticide-use [kg/ha] Energy-use [toe/ha] Residue for soil retention [%] Agroforestry cover [%]	+50% for cereals by 2050 +29% for cereals by 2050 +44% by 2050 Following historical trends -14% by 2050 Following 2015 trends none
Low-Carbon	A ambition level	Wastes & Losses [%] Crop-yields [kcal/ha] Fertilizer-use [kg/ha] Pesticide-use [kg/ha] Energy-use [toe/ha] Residue for soil retention [%] Agroforestry cover [%]	+50% for cereals by 2050 +29% for cereals by 2050 +44% by 2050 Following historical trends -14% by 2050 Following 2015 trends none
Agroecology	D ambition level	Wastes & Losses [%] Crop-yields [kcal/ha] Fertilizer-use [kg/ha] Pesticide-use [kg/ha] Energy-use [toe/ha] Residue for soil retention [%] Agroforestry cover [%]	-81% for cereals by 2050 -25% for cereals by 2050 No synthetic fertilizers by 2050 no pesticides by 2050 -21% by 2050 Following sustainable rates All croplands
NIMBY	D ambition level	Wastes & Losses [%] Crop-yields [kcal/ha] Fertilizer-use [kg/ha] Pesticide-use [kg/ha] Energy-use [toe/ha] Residue for soil retention [%] Agroforestry cover [%]	-81% for cereals by 2050 -25% for cereals by 2050 No synthetic fertilizers by 2050 no pesticides by 2050 -21% by 2050 Following sustainable rates All croplands
EURef	B ambition level	Wastes & Losses [%] Crop-yields [kcal/ha] Fertilizer-use [kg/ha] Pesticide-use [kg/ha] Energy-use [toe/ha] Residue for soil retention [%] Agroforestry cover [%]	Not explicit in EURef Not explicit in EURef 6% efficiency increase by 2030 Not explicit in EURef About -0.86%/year until 2050 Based on UNFCCC rates Not explicit in EURef

Main references: Historical data are mainly based on FAOSTAT and Eurostat databases. Focusing on future time series, the food wastes and losses, the yields and input-uses are mainly based on (FAO, 2018; Gustafsson et al., 2013; Poux and Aubert, 2018). Residues-use and allocation are following the recommendations of (Searle and Malins, 2016). Finally, agroforestry values are based on (den Herder et al., 2017).

The lever setting for the *climate smart livestock system* is based on an extensive literature survey (Baudry et al, 2019a) and aimed to capture the whole spectrum of what is technically possible ranging from the most intensive (feedlots) to the most extensive (extensive use of grassland) approaches (Capros et al., 2013; FAO, 2018; Madeira et al., 2017; Poux and Aubert, 2018; Sánchez-Muros et al., 2014). Table 4 presents the EUCalculator lever setting for the climate-smart livestock production system:

Table 4- Climate-smart livestock system setting for the following scenarios

Lever setting		Main variables	Values by 2050
Intense	A ambition level	Wastes & Losses [%] Livestock-yields [kcal/lsu] Livestock-slaughter rate [%] Manure-management methods [%] Enteric emission [kgCH4/lsu] Livestock grazing intensity [lsu/ha] Sylvopasture cover [%]	+44% for meat by 2050 +12.2% for bovine by 2050 +100% for bovine by 2050 AD (see bioenergy-capacity) Constant, e.g. 5 for goats 3.8 lsu/ha none
Low-Carbon	A ambition level	Wastes & Losses [%] Livestock-yields [kcal/lsu] Livestock-slaughter rate [%] Manure-management methods [%] Enteric emission [kgCH4/lsu] Livestock grazing intensity [lsu/ha] Sylvopasture cover [%]	+44% for meat by 2050 +12% for bovine by 2050 +100% for bovine by 2050 AD (see bioenergy-capacity) Constant, e.g. 5 for goats 3.8 lsu/ha none
Agroecology	D ambition level	Wastes & Losses [%] Livestock-yields [kcal/lsu] Livestock-slaughter rate [%] Manure-management methods [%] Enteric emission [kgCH4/lsu] Livestock grazing intensity [lsu/ha] Sylvopasture cover [%]	-81% for meat by 2050 0% for bovine by 2050 0% for bovine by 2050 AD (see bioenergy-capacity) Constant, e.g. 5 for goats 1 lsu/ha All pastureland
NIMBY	D ambition level	Wastes & Losses [%] Livestock-yields [kcal/lsu] Livestock-slaughter rate [%] Manure-management methods [%] Enteric emission [kgCH4/lsu] Livestock grazing intensity [lsu/ha] Sylvopasture cover [%]	-81% for meat by 2050 0% for bovine by 2050 0% for bovine by 2050 AD (see bioenergy-capacity) Constant, e.g. 5 for goats 1 lsu/ha All pastureland
EURef	B ambition level	Wastes & Losses [%] Livestock-yields [kcal/lsu] Livestock-slaughter rate [%] Manure-management methods [%] Enteric emission [kgCH4/lsu] Livestock grazing intensity [lsu/ha] Sylvopasture cover [%]	Not explicit in EURef Increase by 42% (milk) Not explicit in EURef AD (bioenergy-capacity) Increasing with yields Not explicit in EURef Not explicit in EURef

Main references: Historical data are mainly based on FAOSTAT and Eurostat databases. Focusing on future time series, the food wastes and losses and the yields are mainly based on (FAO, 2018; Gustafsson et al., 2013; Poux and Aubert, 2018). Finally, agroforestry values are based on (den Herder et al., 2017).

Finally, the lever setting for the *land management* is mainly based on the UNFCCC inventories for land-use change patterns as well as the carbon dynamics. Same as forestry sector, it is worth mentioning that the EURef (Capros et al., 2013) scenario's approach focuses on CO_2 and explicit carbon and land-dynamics patterns were either not explicitly detailed or not considered, such as wetland, settlements and other lands dynamics. Table 6 presents the EUCalculator lever setting for the land management:

Table 5- Land-management setting for the following scenarios

	Lever setting	Main variables	Values by 2050
Intense	A ambition level	Spared-land allocation [ha] Settlement dynamics [ha] Wetland dynamics [ha] Other land dynamics [ha] Crop-rotation [ha]	Unmanaged lands
Low-Carbon	A ambition level	Spared-land allocation [ha] Settlement dynamics [ha] Wetland dynamics [ha] Other land dynamics [ha] Crop-rotation [ha]	Reforestation/afforestation
Agroecology	D ambition level	Spared-land allocation [ha] Settlement dynamics [ha] Wetland dynamics [ha] Other land dynamics [ha] Crop-rotation [ha]	Reforestation/afforestation
NIMBY	D ambition level	Spared-land allocation [ha] Settlement dynamics [ha] Wetland dynamics [ha] Other land dynamics [ha] Crop-rotation [ha]	Reforestation/afforestation
EURef	B ambition level	Spared-land allocation [ha] Settlement dynamics [ha] Wetland dynamics [ha] Other land dynamics [ha] Crop-rotation [ha]	Reforestation/afforestation Not considered in EURef Not considered in EURef Not considered in EURef Not explicit in EURef (*wetland, settlement and other lands are explicitly constant at their 2013 level*)

Main references: Historical data are mainly based on FAOSTAT and UNFCCC countries inventories.

3.3.2.2 Levers that stay on EUREF

The following Table presents the lever setting that is common to all scenarios in order to enable a fair comparison between the different scenarios.

Table 6- Other agri-food system drivers

	Lever setting	Main variables	EURef: Reference scenario
Food self-sufficiency	B ambition level	Meat self-sufficiency [%] Crop self-sufficiency [%]	Not explicit in EURef Not explicit in EURef
Protein alternative	B ambition level	Algae-based meals [%] Insect-based meals [%]	Not considered in EURef Not considered in EURef
Biomass hierarchy	B ambition level	Industrial wastes to bioenergy [%] Industrial wastes to fertilizer [%] Industrial wastes to feed [%] Industrial wastes to other [%]	Not explicit in EURef Not explicit in EURef Not explicit in EURef Not explicit in EURef
Bioenergy capacity	B ambition level	Biomass-based electricity [MW] Biogas [MW] Biodiesel [ktoe] Biogasoline [ktoe] Biojetfuel [ktoe]	Biomass & wastes: 57 GW Not explicit in EURef Not explicit in EURef Not explicit in EURef Not explicit in EURef Biofuels 23.43 Mtoe Bioenergy: 183.7 Mtoe
Climate-Smart Forestry	B ambition level	Faws-share [%] Gross increment [m3/ha] CSF-management [m3/ha] Natural losses [%] Burnt wood share [%] Harvest-rate [%] Growing stock (FAWS) [m3/ha] Growing stock (non-FAWS) [m3/ha] Deforestation [ha]	Not explicit in EURef 4.3m2/ha (net) by 2050 Not explicit in EURef Not explicit in EURef Not explicit in EURef 688 Mm3 (harvested) by 2050 Not explicit in EURef Not explicit in EURef 8Mt (CO_2)

<u>Main references</u>: EURef scenario (Capros et al., 2013); EUCalculator agri-food system lever setting (Baudry et al., 2019a, 2019b)

The EURef scenario is not detailing the food self-sufficiency ratio, which can be a critical issue regarding land-use and embedded GHG emissions. Given the EURef patterns, our best guess was to consider the historical trends to match EURef and EUCalculator inputs for food self-sufficiency.

EURef forestry features are mainly focused on the CO_2 perspective, making the match-making exercise more challenging. The lever setting for the *climate smart forestry* is based mainly based on (EFI & FAO, 2015; Gregg and Smith, 2010; Nabuurs et al., 2017).

Insect farming and microalgae bio-refinery take-off can possibly be a game-changer for GHG mitigation action. As it is not considered in most of future scenarios, we kept them at their 2015 levels. Nevertheless, we will detail how the feature could affect each of the scenarios in the result sections.

Although the bioenergy capacity aggregation is detailed in EURef, the feedstock mix and biomass hierarchy uses are not clearly mentioned. Such as the self-sufficiency lever, our best guess was to consider constant the contribution of wastes and residues to the different markets (bioenergy, fertilizers, feed, and others).

3.3.3 Other sectors

3.3.3.1 Levers that stay on EUREF

Table 7- Other levers setting

Lever setting		Sub-levers setting	EURef: Reference scenario
Boundary conditions	B ambition level	Population [hab] Urban Population [hab] Emissions after 2050 [Gt CO_2]	552.4 Million inhabitants Not explicit in EURef Not explicit in EURef
Building	1.5 ambition level	Building envelope [?] Appliance efficiency [%] Technology and fuel share [%]	85 kWh/m2 by 2050 From 4% to 100% Breakdown available in EURef
Transport	1.3 ambition level	Passenger efficiency [%] Passenger technology [%] Fuel mix [%]	Not explicit in EURef Breakdown per mode in Gpkm 2.3% electricity by 2050 6.6% biofuels by 2050
Manufacturing	1.5 ambition level	Material efficiency [%] Technology efficiency [%] Fuel mix [%] Carbon capturing [%]	Not explicit in EURef Available per industry Breakdown available (Mtoe) Not explicit in EURef (only energy)
Power	1.4 ambition level	Coal phase out [GW] Wind [GW] Solar[GW] Balancing strategies [TWh]	40 GW >200 GW >200 GW Not explicit in EURef

4 Results

The following sections explore the results in terms of GHG change of the scenarios detailed in section 3.3 for the EU28+Switzerland and for individual countries.

4.1EU-level

At an aggregate, GHG emissions in EU28+Switzerland ranked at 485.7Mt[9] CO_{2eq} in 2015, see Figure 4A. Under the considered time-frame GHG emissions are projected to fall sharply in the Low-Carbon and Agroecology scenarios to circa 173.6 and 160.2 Mt CO_{2eq}, respectively, by the year 2050. For the Intense and NIMBY scenarios GHG reduction from the year 2015 are also noted but at a lower extent. For example, under the NIMBY configuration, the EUCalculator model returns 443.9 Mt CO_{2eq} by 2030 and 330.3 Mt CO_{2eq} by 2050, respectively a 8.6% and 32% reductions compared to 2015, see Figure 4B. A similar pattern in absolute and relative emissions is observed for the Intense scenario.

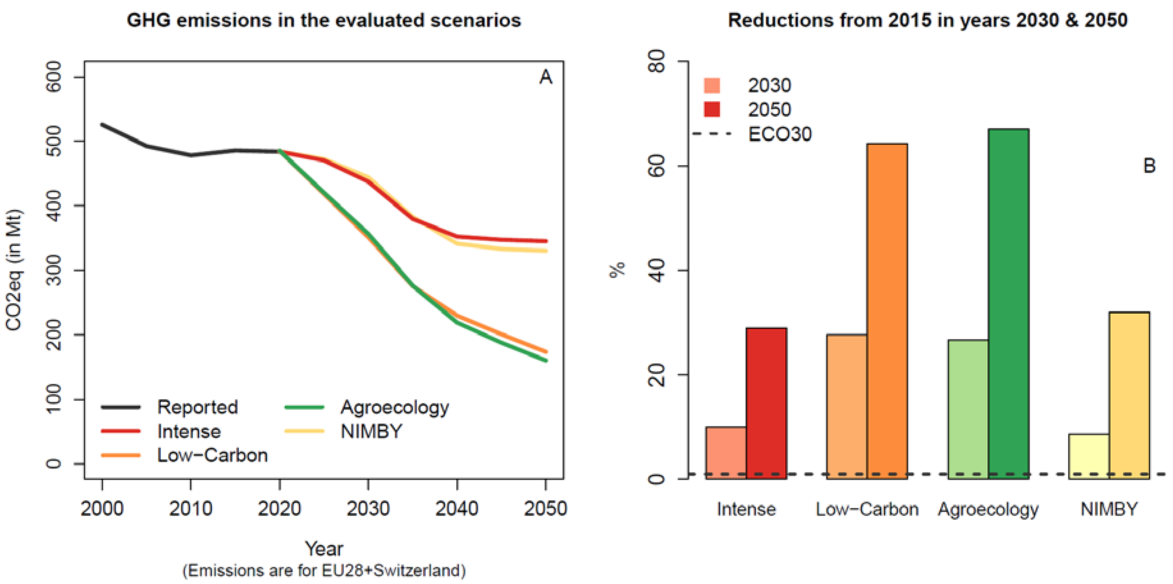

Figure 4 - GHG emissions for EU28+Switzerland from the EUCalculator model according to the Intense, Low-Carbon, Agroecology and NIMBY scenarios

At the aggregated level scenarios modelled in the EUCal highlight one important aspect. Relying on change in agricultural practices alone – be it via the intensification of agricultural production systems or a generalized adoption of agroecology practices – severely hinders the scope of GHG reductions, particularly in the short-term. For example, under the Intense and Nimby, GHG reductions range between 8.6 and 10%, see Figure 4B. This is larger than the 1% reductions is reported in the ECO30 scenario (see Figure 4B and also Table 1). For the scenarios Low-Carbon and Agroecology, reductions by 2030 are found to be, for both cases, of about 27%. These reductions come at the costs of strong societal changes towards a far less carbon-intensive diet and substantial

[9] The emissions reported by the EUCalc are higher than those in Table 1 from the EEA. The reason for this difference is due to the fact that 1) in the EUCal model we report for emissions for EU28+Switzerland (while in EEA Switzerland is not considered), and 2) the EUCalc reports on total emissions while the values in Table 1 refer to non-CO_2 emissions only.

reductions of food waste. Independently of the scenario chosen, it seems plausible to assume that a combination of a middle of the road strategy from the extreme ones explored in this report would provide much higher GHG reductions in the agricultural sector that the ones currently considered under the ESD framework. This is relevant to the extent that as carbon budgets get scarcer and scarcer due to inaction, it becomes harder and harder to justify why all sectors are not asked to do their fair share.

4.2Country-level results

One of the advantages of the EUCalculator model is its country-level granularity and the ability to perform sensitive analysis. For example, one can take the Intensive and the Low-carbon scenarios[10] (in both there is an intensification of agricultural practices) and evaluate the relative contribution of emissions reductions brought about changing diets and reducing food waste.

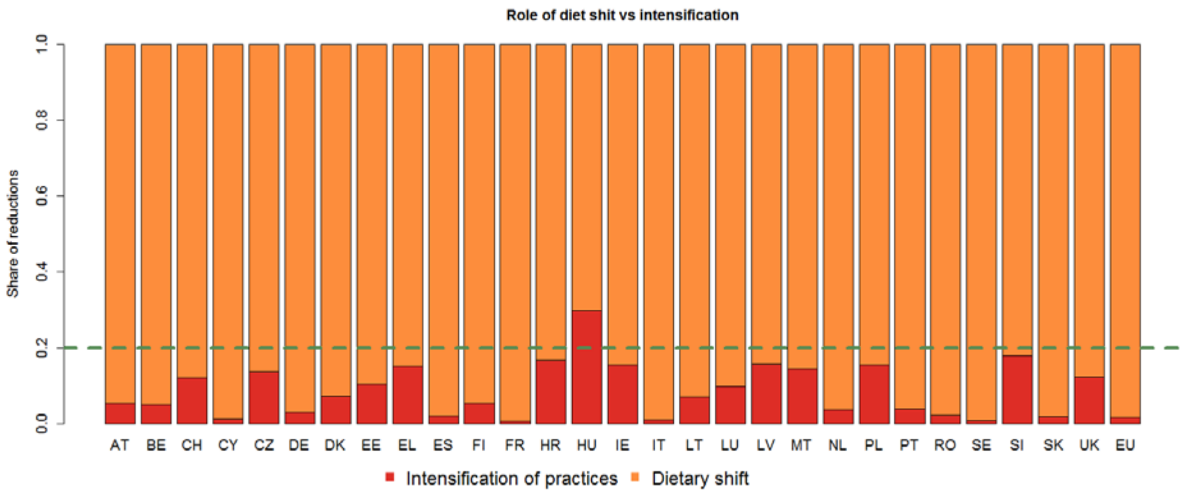

Figure 5 - Contributions of dietary shift and intensification practices to GHG reductions

In all countries evaluated dietary shifts are associated to a disproportionately high share of emission reductions by 2050 from the agricultural sector, referenced to the EUREF emissions from agriculture in the same year (greater that 80% of the total reduction, dashed-line in). This highlights that the large potential of dietary shifts shown in Figure 4 at an aggregated level is geographically consistent across the entire European Union and Switzerland. For some extreme cases like France, Germany or Sweden, just to mention a few, more that 97% of the GHG reductions in the Low-carbon scenario are attributed to dietary shifts, meaning that in terms of emissions alone any move towards the intensification of the agricultural system in these countries would have no discernible repercussions in aligning the agricultural sector with meaningful climate protection targets.

The differences in the role of intensification in these countries can be found on the heterogeneous agri-food systems. For example, while the Swiss diet is comparable to the German one in terms of carbon-intensive products such as meat, given the current production system (extensive), intensification would enable significant GHG emission reductions.

[10] There is no difference between the scenarios regarding the changes in agricultural practices. In both of them there is an intensification of agricultural productions towards the maximum technical feasibility.

The role of intensifying practices is more important (in relative terms) in countries like Hungary, Slovenia, Croatia or Poland. This is expected as the output value of agricultural industry in Central-East Europe has suffered a stronger decline until 2010, than those from West Europe (Zsarnóczai & Zéman 2019). In addition, yields and nitrogen application across crop-type groups are particularly high in Western and Central Europe, whereas Eastern Europe is characterised by lower yields and nitrogen application (Levers et al, 2016). Despite its small role across Europe, intensification of agricultural practices can nevertheless yield agriculture GHG reduction shares between 15 to 30% for Greece, Croatia, Hungary, Ireland, Latvia, Poland and Slovenia (see Figure 5).

Nevertheless, low-carbon pathways are not necessarily the most sustainable pathways, and one should also investigate extensive pathways when diets make it relevant. That is, for the cases where both dietary shifts and agroecology practices are widespread (Agroecology scenario, see Figure 6) the reductions at the country level are observed to range between circa 25% in Luxembourg to 86% in Bulgaria. For the EU28+Switzerland the fraction of reduction under the Agroecology scenario is 67%. The differences of potentials in countries reflect both the current efficiencies of the agricultural system and the national dietary pattern.

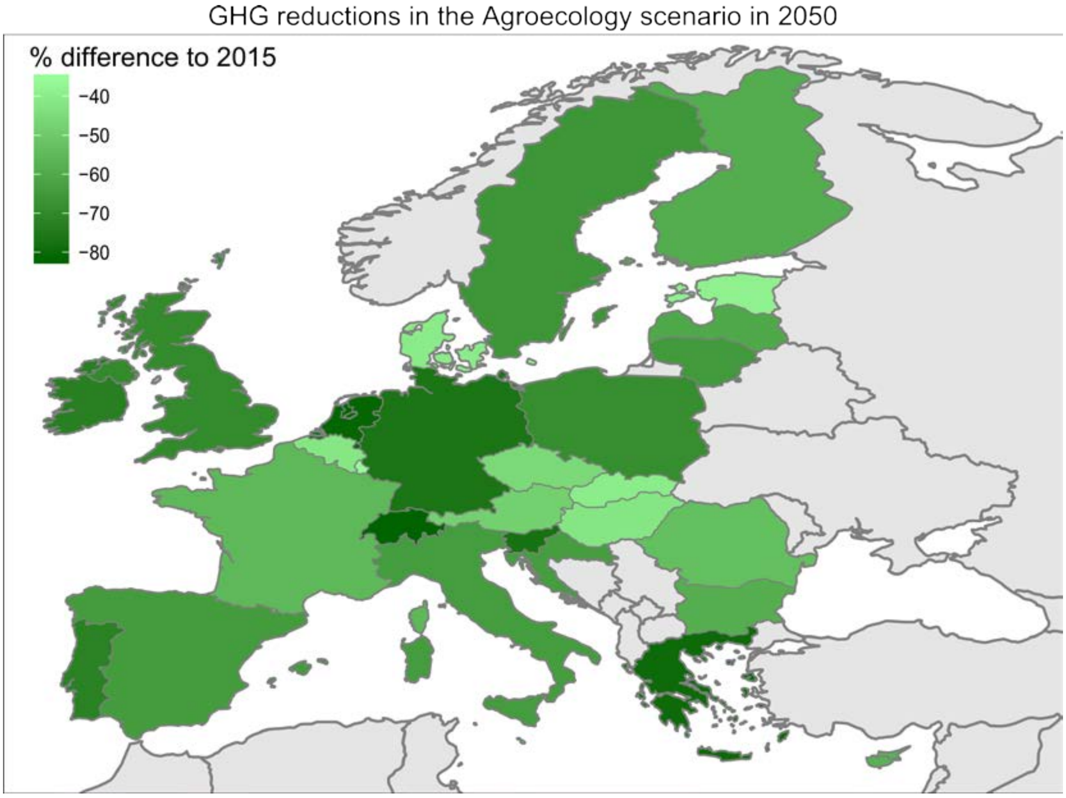

Figure 6 - Country distribution of GHG reduction under the Agroecology scenario (% decrease in 2050 from the 2015 value)

The same exercise done in Figure 5 regarding the role of diet shift/intensification practices in the reduction of GHG emissions in the Low-carbon scenario can be now done for the case of dietary shift/agroecology standards using the Agroecology scenario in comparison to the NIMBY scenario. The results are shown on Figure 6 and it can be observed that the role of agricultural practices (following agro-ecological standards) across countries in the Agroecology scenario follows a very similar pattern to that shown in Figure 5 for the Low-carbon scenario.

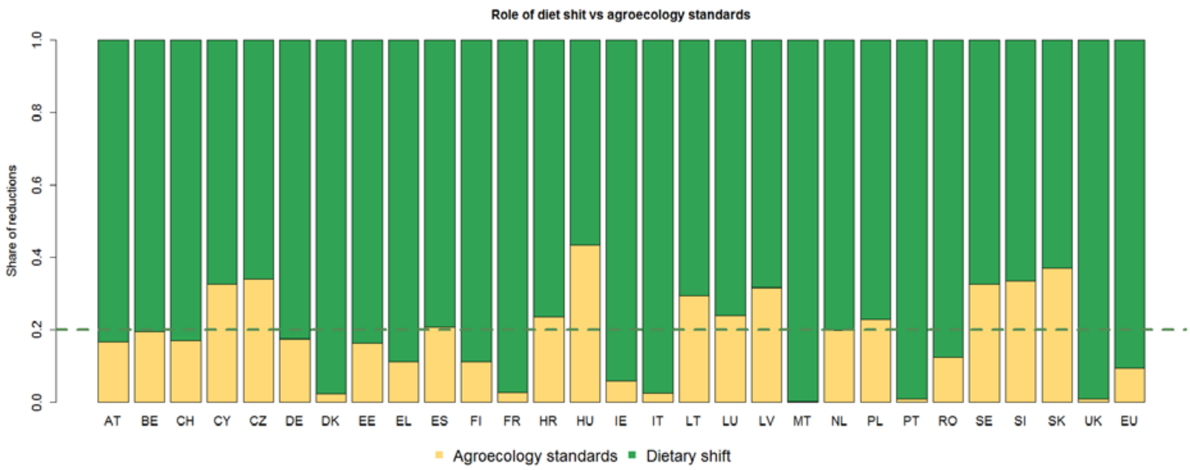

Figure 7 - Contributions of dietary shift to GHG reductions in the Agroecology scenario

The magnitude of the contribution is somehow different though. Although he pattern is similar the magnitude the role of agro-ecological standards of farm practices was found to be more important for emissions savings that agriculture intensification (see for example Sweden, Slovenia and Hungary). This can be explained by very ambitious farm management standards entailed in the Agroecology scenario. For example, farm waste and losses are about 6 times lower compared with 2015. In contrast, under the Intense scenario waste and losses in the farm management continue to increase. This seems to be offsetting the emissions increase expected from the relative decrease of yields in the Agroecology scenario.

5 Discussion

This report makes use of the EUCalculator model in order to explore two alternative strategies for reducing GHG in the EU28+Switzerland agricultural systems between 2015 and 2050. Our results (see Table 8 for summary) highlight the large potential for GHG reduction entailed in a synchronized shift towards less-carbon intensive dies and food waste, and the generalized adoption of agroecology standards for production in Europe.

Table 8 - Summary of main results by scenario explored. Reduction of GHG emissions are reported as % change to the year 2015.

		Agri-food system practices	
		Intensified	**Agroecology**
Diet shifts & food waste	Current trends	**Intense** -10% GHG by 2030 -29% GHG by 2050 Intensification alone of agricultural systems without complementary dietary shifts results in low emissions reductions.	**NIMBY** -9% GHG by 2030 -32% GHG by 2050 Potential large trade-offs in regard to extra need for agricultural land due to lower yields.
	Low-carbon diets	**Low-Carbon** -28% GHG by 2030 -64% GHG 2050 Dietary shifts drive the total amount of reductions.	**Agroecology** -27% GHG by 2030 -67% GHG by 2050 Extra need for agricultural land due to lower yields mitigated by dietary shift.

We found no publication currently providing a country-level view of the relative contribution of diets change vs agricultural practice in GHG reduction for the agricultural sector – testify for the potential in using the EUCalculator model to inform on country-level decarbonisation plans. Still underexplored is the ability of the EUCalculator to provide a cross-sectoral view of trade-offs in variables such as land use, water needs for irrigation, fertilizer inputs etc. In Table 8 we hint at the possibility of a substantial trade-off between the amount of land required under the Agroecology and NIMBY scenarios. This will be subject of further work following up the EUCalculator project.

6 Conclusions

Our results highlight two major conclusions. The first is that there is a large scope for GHG reduction in the agricultural system of Europe that should be explored. This is at odds with current decarbonisation scenarios (e.g., ECO30 E3MLab & IIASA (2016)) that spare the agricultural sector to similar levels of ambition required in sectors such as transport of buildings in 2030 and 2050. The second major conclusion is that intensification of agricultural production alone will deliver at most 30% reductions of GHG in agriculture by 2050. In order to unlock the full potential of GHG reduction a substantial shift in current diets towards healthy standards and reduction of food waste is required. In such a case the potential for reductions increases to over 60% in 2050. Coupled with the change in dietary habits there are two alternative pathways to achieve the same amount of reductions. One can opt for the further intensification of agricultural production, increasing the efficiency in term of CO_2/kcal produced; or one favours the adoption of agroecology means of production. Both strategies entail the same amount of GHG reductions but different consequences for ecosystems.

7 References

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

Alexander, P., Rounsevell, M. D., Dislich, C., Dodson, J. R., Engström, K., & Moran, D. (2015). Drivers for global agricultural land use change: The nexus of diet, population, yield and bioenergy. *Global Environmental Change*, *35*, 138-147.

Alexander, P., Brown, C., Arneth, A., Finnigan, J., & Rounsevell, M. D. (2016). Human appropriation of land for food: The role of diet. *Global Environmental Change*, *41*, 88-98.

Baudry, G., Bouchet, A., Forstenhaeusler, N., Price, J., Raffray, M., Mwabonje, O., Woods, J., 2019a. D4.1_Land, land use, minerals, water and biodiversity input spreadsheets for calculator model. Imperial College London, University of East Anglia, EPFL.

Baudry, G., Bouchet, A., Forstenhaeusler, N., Raffray, M., Price, J., Mwabonje, O., Woods, J., 2019b. D8.4. - Integration of the resource's modules "Land allocation, biodiversity impact & forestry", "Water scarcity" and "minerals" modules. Imperial College London, University of East Anglia, EPFL.

Capros, P., De Vita, A., Höglund Isaksson, L., Winiwarter, W., Purohit, P., Bottcher, H., 2013. EU energy, transport and GHG emissions trends to 2050-Reference scenario 2013. European Commission.

Capros P, De Vita A, Tasios N, Siskos P, Kannavou M, Petropoulos A, Evangelopoulou S, Zampara M, et al. (2016).

Caro, D., LoPresti, A., Davis, S. J., Bastianoni, S., & Caldeira, K. (2014). CH4 and N2O emissions embodied in international trade of meat. *Environmental Research Letters*, *9*(11), 114005

Costa, L., & Moreau, V. (2019). The emission benefits of European integration. Environmental Research Letters, 14(8), 084044.

den Herder, M., Moreno, G., Mosquera-Losada, R.M., Palma, J.H.N., Sidiropoulou, A., Santiago Freijanes, J.J., Crous-Duran, J., Paulo, J.A., Tomé, M., Pantera, A., Papanastasis, V.P., Mantzanas, K., Pachana, P., Papadopoulos, A., Plieninger, T., Burgess, P.J., 2017. Current extent and stratification of agroforestry in the European Union. Agric. Ecosyst. Environ. 241, 121–132. https://doi.org/10.1016/j.agee.2017.03.005

DG AGRI 2019, EU agricultural outlook for the agricultural markets and income 2017-30, Agriculture and Rural Development. Brussels 19 December 2017.

E3MLab & IIASA (2016), Technical report on Member State results of the EUCO policy scenarios, December 2016 https://ec.europa.eu/energy/sites/ener/files/documents/20170125_-_technical_report_on_euco_scenarios_primes_corrected.pdf

European Commission (2018), A clean planet for all. A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy. *COM (2018) 773 final*.

EFI & FAO, 2015. State of Europe's forests. European Forest Institute.

FAO, 2018. The future of food and agriculture, Alternative pathways to 2050. FAO, Rome.

Gustafsson, J., Cederberg, C., Sonesson, U., & Emanuelsson, A. (2013). The methodology of the FAO study: Global Food Losses and Food Waste-extent, causes and prevention"-FAO.

Johnson, J. A., Runge, C. F., Senauer, B., Foley, J., & Polasky, S. (2014). Global agriculture and carbon trade-offs. Proceedings of the National Academy of Sciences, 111(34), 12342-12347.

Kastner, T., Rivas, M. J. I., Koch, W., & Nonhebel, S. (2012). Global changes in diets and the consequences for land requirements for food. Proceedings of the National Academy of Sciences, 109(18), 6868-6872.

Lotze-Campen, H., Popp, A., Beringer, T., Müller, C., Bondeau, A., Rost, S., & Lucht, W. (2010). Scenarios of global bioenergy production: the trade-offs between agricultural expansion, intensification and trade. Ecological Modelling, 221(18), 2188-2196.

NCD Risk Factor Collaboration (NCD-RisC 2016).Trends in adult body-mass index in 200 countries from 1975 to 2014: a pooled analysis of 1698 population-based measurement studies with 19.2 million participants. Lancet 2016, 387:1377-1396

Klapwijk, C. J., Van Wijk, M. T., Rosenstock, T. S., van Asten, P. J., Thornton, P. K., & Giller, K. E. (2014). Analysis of trade-offs in agricultural systems: current status and way forward. *Current opinion in Environmental sustainability*, *6*, 110-115.

Levers, C., Butsic, V., Verburg, P. H., Müller, D., & Kuemmerle, T. (2016). Drivers of changes in agricultural intensity in Europe. *Land Use Policy*, *58*, 380-393.

Madeira, M.S., Cardoso, C., Lopes, P.A., Coelho, D., Afonso, C., Bandarra, N.M., Prates, J.A.M., 2017. Microalgae as feed ingredients for livestock production and meat quality: A review. Livest. Sci. 205, 111–121. https://doi.org/10.1016/j.livsci.2017.09.020

Milner, J., Green, R., Dangour, A. D., Haines, A., Chalabi, Z., Spadaro, J. Wilkinson, P. (2015). Health effects of adopting low greenhouse gas emission diets in the UK. BMJ open, 5(4), e007364.

Nabuurs, G.-J., Delacote, P., Ellison, D., Hanewinkel, M., Hetemäki, L., Lindner, M., 2017. By 2050 the Mitigation Effects of EU Forests Could Nearly Double through Climate Smart Forestry. Forests 8, 484. https://doi.org/10.3390/f8120484

Poux, X., Aubert, P.-M., 2018. An agroecological Europe in 2050: multifunctional agriculture for healthy eating. IDDRI, Paris.

Sánchez-Muros, M.-J., Barroso, F.G., Manzano-Agugliaro, F., 2014. Insect meal as renewable source of food for animal feeding: a review. J. Clean. Prod. 65, 16–27. https://doi.org/10.1016/j.jclepro.2013.11.068

Sandström, V., Valin, H., Krisztin, T., Havlík, P., Herrero, M., & Kastner, T. (2018). The role of trade in the greenhouse gas footprints of EU diets. Global food security, 19, 48-55.

Searle, S.Y., Malins, C.J., 2016. Waste and residue availability for advanced biofuel production in EU Member States. Biomass Bioenergy, Biomass & Bioenergy special issue of the 23rd European Biomass Conference and Exhibition held in Vienna, June 2015 89, 2–10. https://doi.org/10.1016/j.biombioe.2016.01.008

Springmann, Marco, Michael Clark, Daniel Mason-D'Croz, Keith Wiebe, Benjamin Leon Bodirsky, Luis Lassaletta, Wim de Vries, et al., 2018. "Options for Keeping the Food System within Environmental Limits." Nature, October, 1. https://doi.org/10.1038/s41586-018-0594-0.

Tomei, J., & Helliwell, R. (2016). Food versus fuel? Going beyond biofuels. Land use policy, 56, 320-326.

Valin, H., Havlík, P., Mosnier, A., Herrero, M., Schmid, E., & Obersteiner, M. (2013). Agricultural productivity and greenhouse gas emissions: trade-offs or synergies between mitigation and food security?. Environmental Research Letters, 8(3), 035019.

Zsarnóczai, J. S., & Zéman, Z. (2019). Output value and productivity of agricultural industry in Central-East Europe. *Agricultural Economics*, *65*(4), 185-193.