Farming for Change
Charting a course that works for all

Food, Farming & Countryside Commission

In its 2019 report, Our Future in the Land, the Food Farming and Countryside Commission argued that "farming can be a force for change, with a transition to agroecology by 2030." The FFCC's confidence in an agroecological future was built on IDDRI's original Ten Years for Agroecology (TYFA) report (2018), which showed a transition to agroecology is both desirable and achievable at a European scale. Sitting alongside the growing body of work, in the UK and internationally, making the case for agroecology, the TYFA Europe model has established an important foundation from which to explore a just transition to more sustainable food systems and land use, supporting progress towards the Sustainable Development Goals.

The model, built on an ambitious scenario for the future of farming (including phasing out synthetic pesticides and mineral fertilizers and redeploying natural grasslands) showed that with the widespread adoption of healthier diets (fewer animal products, more fruit and vegetables), the adoption of agroecological practices across Europe could meet several challenges at once. Agroecology could supply enough food for 530 million Europeans, while maintaining export capacity, reducing agricultural GHG emissions by 47% compared to 2010, and helping to restore biodiversity, and protect natural resources.

At the European scale the approach was conceptually sound, but what of the practical implications of this scenario for UK food and farming? Could similar conclusions be drawn at the country scale? By exploring the multiple demands on farming and land use together rather than apart, this research progresses the debate on the future of food and agriculture in the UK through a system-wide view of its complex relationships and consequences. This research applies the TYFA Europe model to the UK. It shows that:

- A transition to agroecology is feasible and achievable, keeping the country fed, balancing trade without exporting production, and reducing diet-related ill-health.
- Emissions will be reduced by 55-70%, and this could be further improved if we account for the removal of imported deforestation via soya, reductions in food waste, and adopt the GWP* method of accounting for methane emissions.
- 1.8m hectares (10%) of current agricultural land will be released for ecosystem restoration.
- Biodiversity will be dramatically improved across all productive land by farming for more diversity in crops, grasslands and livestock and reducing synthetic fertilizers, pesticides and nutrient losses.
- A transition to agroecology works best at scale across the UK, allowing these interdependent benefits to develop in synergy across farms, communities, and landscapes.

There are some who argue that society's multiple challenges are best met by simply intensifying food production in some places to enable more land to be spared for nature recovery, and to help tackle climate change. But often the consequences of this approach – for health, rural communities, farm businesses, and offshoring impacts (amongst others) – are not properly taken into account. Global intensification of food systems has led to incalculable damage – to the climate, to nature, to health and wellbeing, to food security and to economic resilience. Diet-related diseases plague those in the Global North, while across the Global South many do not have access to healthy and safe food. The question of how land is used is at the heart of the debate, about how to improve the food system. A transition to agroecology offers a more integrated, sustainable, and inclusive pathway for food, farming and land use.

This research provides further detailed evidence that it is a plausible pathway for the UK's food security and resilience. Sharing our findings with farmers and growers, environmentalists and citizens groups around the UK, we have found widespread support for a broad and inclusive pathway that recognises and responds to the many interdependencies in the food system that people navigate and manage every day. 800 participants took part in eight open inquiry sessions with 30 different expert perspectives on agronomy, land management, economics, culture, and policy, as well as on the different policy perspectives from Wales, Scotland, and Northern Ireland.

These sessions have affirmed that the agronomic and land management aspects of agroecology are readily achievable right now. For many, agroecology already makes economic sense, but this is not yet the case for all. The increasing number of collaborative farmer networks is an essential ingredient to facilitating change, but many also say that current conditions still lock farmers and future generations into siloed, chemical input agriculture, based on outmoded assumptions on yield, and productivity.

This publication is an important contribution to shaping a new, more sustainable, and fair future for UK food and farming. It provides clear evidence of the potential for agroecology to change the whole food system. Using regenerative farming methods, making healthy food easily available for all, resourcing people to make decisions that are right for their localities – agroecology helps to grow resilient and adaptable communities by addressing critical environmental, societal and civic challenges simultaneously. This report shows a transition to agroecology by 2030 is not only desirable, but achievable for individuals, businesses and communities across the United Kingdom, and, with the right enabling policy, and market conditions, can be the foundation of a society more responsive to current needs and more resilient to future environmental and economic shocks.

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Modelling an agroecological UK in 2050 – findings from $TYFA_{REGIO}$

Xavier POUX (AScA-IDDRI), Michele SCHIAVO (IDDRI), Pierre-Marie AUBERT (IDDRI)

Abstract

Based on the Ten Years For Agroecology (TYFA) scenario for the EU (Poux, Aubert, 2018), this report provides a more detailed analysis of the UK food system under an agroecological future. Using a newly adapted modelling platform ($TYFA_{regio}$), which combines assumptions about both the supply (agro-ecological production) and the demand sides (sustainable diets), it evaluates the biophysical and ecological impacts of an expansion of agroecology in the EU.

First, this report describes the modelling framework used for the characterisation of three agrarian regions in the UK. Then, it outlines the assumptions made about diet change and agroecological production patterns to recreate the UK food system. Finally, it presents the model outcomes in terms of plant and animal production, land use, biodiversity, climate change and ultimately the net food balance (if diet changes occur).

KEY MESSAGES

The adoption of agroecological practices would deliver strong and positive biodiversity outcomes due to the absence of synthetic inputs use, the higher share of truly semi-natural vegetation in all agrarian regions and the presence of green and ecological infrastructure (ponds, hedges, meadows, etc.), while it would reduce crop yields by 17% to 25% across UK agricultural regions.

Closing nutrient cycles at the regional level would lead to a relative despecialisation of UK regions in terms of the balance between arable and permanent grassland.

The primary diet change required under this scenario is the halving of consumption of animal products, thus freeing up land to produce plants for direct human consumption. Under this assumption, 7% of utilised agricultural area (UAA) could be used for purposes other than domestic production.

The GHG emissions reduction could reach -38% compared with today (with potential to offset 60% or more of remaining emissions through an afforestation scenario). The main source of these reductions comes from decreases in nitrogen related emissions.

While today the UK is a net importer of all major foodstuffs except for milk, the application of TYFA assumptions allows the UK to stop imported deforestation and improve its physical trade balance for the main food commodities.

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Modelling an agroecological UK in 2050 – findings from $TYFA_{regio}$

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1. BACKGROUND: EXPLORING THE AGROECOLOGY PATH

1.1. Agroecology and sustainable intensification in light of global and local challenges

The world's food systems, including the UK's, must address economic, social and environmental sustainability issues. Over the last decades, it has become increasingly clear that environmental sustainability creates the foundation for the future of all food systems.

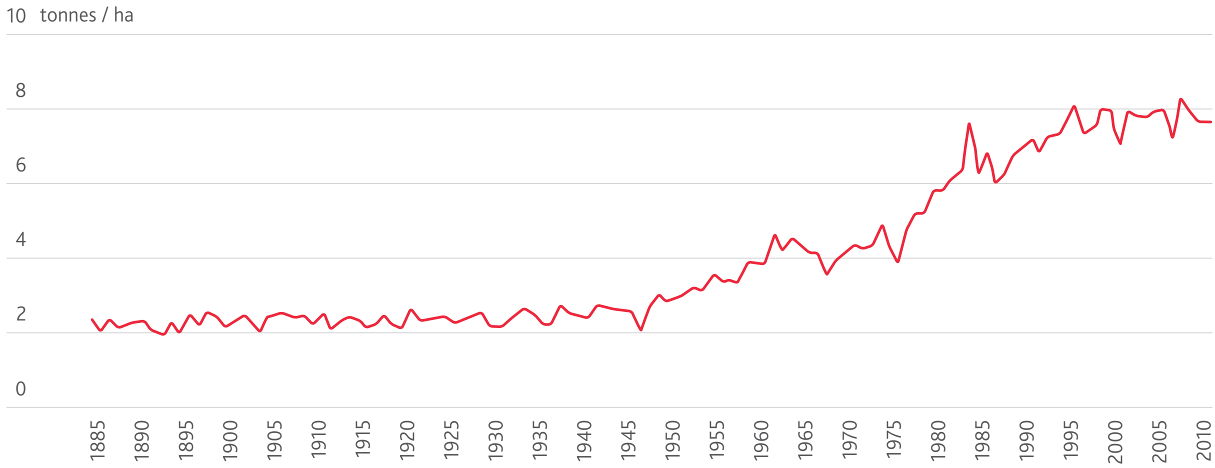
It has also become clearer that the continuation of the current input-intensive farming paradigm is not sustainable in the long run. Its impacts on climate (IPCC, 2019), biodiversity (FAO, 2019 ; IPBES, 2019), food quality (HLPE, 2017 ; Monteiro *et al.*, 2019), landscapes, soils and nutrient management (Campbell B.M. *et al.*, 2017) have previously been documented at the world, national and regional levels (see also McIntyre *et al.*, 2009). The success of the "intensification paradigm" in terms of economic growth, job provision and its ability to supply cheap food must thus be juxtaposed with its negative environmental and social and health effects (Benton & Bailey, 2019). As these environmental impacts have most likely contributed to yield stagnation (Ray *et al.*, 2012), serious questions remain about the long-term productive potential of highly intensive agroecosystems. Figure 1.

Looking in particular at the UK case (Figure 1), recent developments show both a plateau and increased variability of yields over the last decade. Climate change is one key explaining factor (Moore & Lobell, 2015), but the simplification of agro-ecosystems resulting from intensification has also resulted in a decrease in their capacity to provide ecosystem services (Dainese *et al.*, 2019). And this is not only taking place in the UK, but in all developed countries.

In this context, two paradigms are proposed to address the environmental and socio-economic challenges:

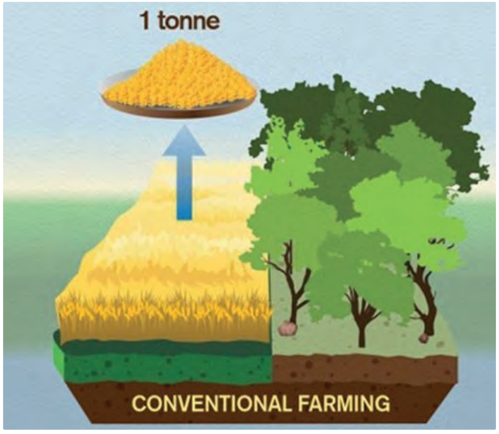
— The "sustainable intensification" paradigm (Garnett *et al.*, 2013) calls for more efficient use of (synthetic) inputs

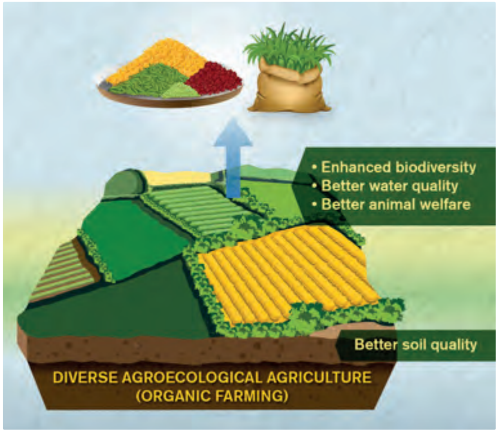
FIGURE 1. UK wheat yields 1885-2011



Source: DEFRA

FIGURE 2. The conceptual frame of Intensification (left) leads to simplified landscapes assessed through Life Cycle Analysis focusing on their physical outputs and the efficiency of the inputs. The conceptual frame of agroecology leads to complex landscapes, providing diverse ecosystem services which assessment cannot only rely on LCA





Source: Chalmer University

to facilitate maximal production on minimal land.[1] The expected performance of high yield farming (Balmford *et al.*, 2018) saves land for environmental use (e.g. woodland for either carbon sequestration or rewilding) or, alternatively, energy biomass production. Conceptually, this paradigm refers to a land sparing strategy.

— The agroecological paradigm relies as much as possible on ecological processes to design and manage farming and agricultural systems at all levels, from the plot to the landscape (Francis *et al.*, 2003). Under this approach, external synthetic inputs use is minimised to limit the impacts beyond farmland and to promote genuinely biodiversity-friendly habitats on farms. Conceptually, this paradigm refers to a land sharing strategy. In Western Europe, current yields are already close to their maximum agronomic potential thanks to a high level of inputs in use (Mueller *et al.*, 2012). Given these high yields, agroecology cannot promise even higher yields and thus is strongly questioned: Can it deliver enough food to feed a growing world population with changing eating habits? Can it limit farmland expansion in other areas of the world? Will it free up some land for climate purposes? (Aubert *et al.*, 2019).

Against this backdrop, this report explores the options to transition to a fully agroecological UK food system as well as how such a transition would address the multifaceted challenges identified above. It takes as a starting point a number of limits of the sustainable intensification (SI) paradigm that have been well identified:

— While SI focuses on the efficient use of inputs–fertilisers and pesticides–per ton produced, it does not directly consider the absolute level of inputs used (Balmford *et al.*, 2018). In the case of pesticides, however, negative impacts can occur at very low absolute doses (Gibbs *et al.*, 2009 ; Mancini *et al.*, 2019). The efficient use of pesticides, even measured in active dose per ton, may be harmful for biodiversity, natural resources, and human health. The lack of an assessment of absolute pesticide doses under SI is therefore a major shortcoming.

— SI prioritises off-farm biodiversity over on-farm biodiversity in a land sparing perspective (Phalan *et al.*, 2011). In the UK and more widely in the European context, this approach tends to overlook three key aspects:
  - i. The fact that an irreplaceable share of biodiversity stands inside agricultural land (Halada *et al.*, 2011),
  - ii. Intensive farming has off-farm impacts due to runoff polluting freshwater resources, adjacent terrestrial ecosystems—sometimes remotely affected by aerial dispersion of fine particles—and marine ecosystems (eutrophication, pollution) (Lode *et al.*, 1995 ; Beketov *et al.*, 2013 ; Hallmann *et al.*, 2017).
  - iii. Biodiversity within agricultural landscapes provides ecosystem services, making it a production factor (see for a synthesis Dainese *et al.*, 2019) required to maintain yields in the long run. Figure 2.

1.2. Developing agroecology in the UK context

Agroecology is increasingly being acknowledged as a promising way to address environmental challenges (Wezel *et al.*, 2016 ; Poux & Aubert, 2018). In light of its spread in Europe, a number of questions arise as to its country-by-country implications: What does an agroecological landscape look like in the UK? Will agroecology produce enough to feed the UK population

1 As mentioned by Godfray (2015), in many discussions revolving around sustainable intensification, the focus has often been put more on the "intensification" component than on the "sustainable" one; in the remainder of this document we will use "intensification" or "sustainable intensification" interchangeably.

without increasing its offshore impacts? What is the mitigation potential of agroecology, in particular with respect to the role it gives to ruminant livestock in terms of fertility and biodiversity management? Will the generalisation of agroecology leave enough space for restoring wild ecosystems? Following earlier work published in 2018 and 2019 at the EU level (Poux & Aubert, 2018 ; Aubert *et al.*, 2019), this study seeks to provide insight on these questions.

Our work on the EU level shows that the generalisation of agroecological practices together with the phasing-out of plant protein imports would deliver the following results:

— Despite a 35% drop in overall production (in kcal) compared to 2010, an agroecological EU provides healthy food for Europeans thanks to the adoption of healthier and more sustainable diets, notably a reduction in the consumption of animal products;
— It would reduce Europe's food footprint and increases its contribution to world food security by shifting it from being a net importer of calories to a net exporter (Schiavo *et al.*, 2021);
— It leads to a 40% reduction in GHG emissions from the agricultural sector;
— It restores biodiversity and natural resources within agricultural landscapes thanks to the redeployment of semi-natural vegetation and agroecological infrastructure, in particular permanent grasslands.

These results were obtained, however, by modelling the EU food system at a macro level. There is thus the need to finetune the analysis to better take into account heterogenous regions.[2] This will allow us to explore if, and under what conditions, these results hold across the variety of EU agrarian systems (for a presentation of the concept of agrarian system see Cochet, 2012).

This report proceeds in the following parts. Part 2 details the modelling tool used to address these questions and explains how the original model was adapted and regionalised. Part 3 highlights how the key assumptions made in the original TYFA model have been adapted to the UK context. Part 4 then presents the primary findings of the model with respect to food production, impacts on biodiversity, and climate mitigation potential. It also stresses the importance of dietary change, and particularly a sharp reduction in animal protein consumption, to make the spread of agroecology a credible option in the UK.

2 This is particularly important regarding Nitrogen (N) management. Our earlier work at the EU level demonstrates the possibility of closing the N cycle without using synthetic N. However, this overall balance at the EU level might hide strong spatial heterogeneity wherein N surpluses in some areas do not in fact cover N shortages in others and vice versa, leading to both N-related environmental problems in N-surpluses areas and lower yields in N-shortages areas.

2. AN ORIGINAL MODELLING APPROACH TO TACKLE THE UK FOOD SYSTEM CHALLENGES

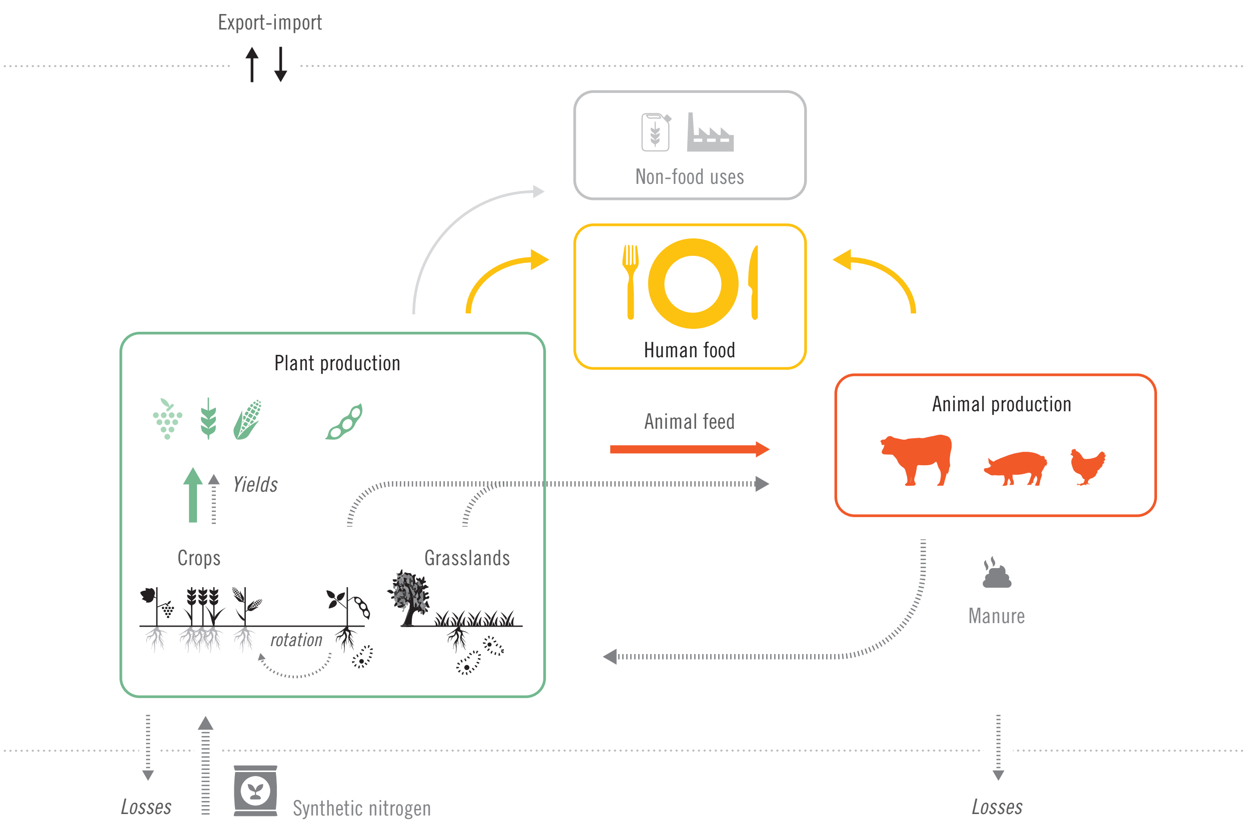
2.1. The challenges of the UK food system

The UK's food system faces similar challenges as those of European countries. These challenges can be grouped into the following themes:

— The need to improve the quality of diets from both a health and a sustainability perspective. There is a high prevalence of obesity, type 2 diabetes and cardiovascular disease in the UK, which is associated with unbalanced diets (Blundell *et al.*, 2017). Sugar consumption is particularly high, exceeding on average 100 g per day while fruit and vegetable consumption is often half of what is recommended at 250 g per day. The consumption of 100g of protein per day, of which two thirds comes from animal products, is far above the 60g per day needed to cover the nutritional needs of an adult of 70 kg (EFSA, 2017), and causes significant environmental damage (Westhoek *et al.*, 2011).
— The need to reduce, or at least not increase, the offshore impacts of the UK food system – which is today the result of a low level of self-sufficiency for fruits and vegetables and the predominance of intensive livestock systems dependent upon imported soybean cakes.
— The need to restore biodiversity within agricultural landscapes. While improvements to the perimeters of farmland are important (e.g. hedges, landscape features), a reduction in the absolute level of input use will further support biodiversity and allow for the possibility to rewild non-agricultural areas.
— The need to foster farming system adaptation and resilience: through diversified farming systems, enhancing the biological capacity of soils, developing landscape features to limitdrought, and by limiting exposure to wind and soil erosion. Wooded features, agroforestry and silvopasture are identified as means in this perspective.
— The need to reduce GHG emissions (both methane and nitrous oxide) while increasing the potential for carbon sequestration in both agricultural soils and forests.

To assess how these challenges can be addressed by agroecology, we developed a modelling platform called $TYFA_{regio}$ that we will describe in the subsequent section. This platform can be used to zoom in on the UK to assess country-specific food balance issues. Based on the $TYFA_m$ biomass balance model, $TYFA_{regio}$ simulates different EU and UK food balances based on various assumptions about human diets and crop and livestock systems.

FIGURE 3. Rationale structure of $TYFA_m$



Plant production and associated land use, determined by yields
Animal production and associated feed requirements
Symbiotic nitrogen fixation
Nitrogen flows between compartments

Source: authors

2.2. $TYFA_m$

The development of the original TYFA scenario was based on a biomass balance model called $TYFA_m$, which has a similar structure to other simulation platforms designed over the last 10 years and used in recent food system scenario exercises. Agribiom (Dorin & Joly, 2020), GlobAgri (Mora *et al.*, 2020) and SOL (Schader *et al.*, 2015 ; Muller *et al.*, 2017) are all good examples of such platforms (see Figure 4). $TYFA_m$'s input variables are the human and non-human demand for food, a waste coefficient, the characteristics of crop and livestock systems and the level of export for some specific food commodities (cereals, wine and dairy products). The output variables of $TYFA_m$ are the total level of production (for both crop and livestock), the land use and the nitrogen balance by 2050. For these outputs, $TYFA_m$ respects three basic equations:

— For all commodities: $Uses_{(food, animal feed, seed, non-food uses)}$ x waste coefficient = production – export + import
— For feed: feed available ≥ livestock feed requirements.
— For nitrogen: nitrogen inputs to cropland > nitrogen outputs of cropland.

$TYFA_m$ takes the EU-27 (2007-2013)[3] as its unit of analysis. This region is studied as one "European Farm," which does not take into consideration the heterogeneity of the area. This approach has two implications. First, it only includes the flows between the EU and the rest of the world. Second, the input and output variables are based on average values for the EU, both for production and consumption. Figure 3.

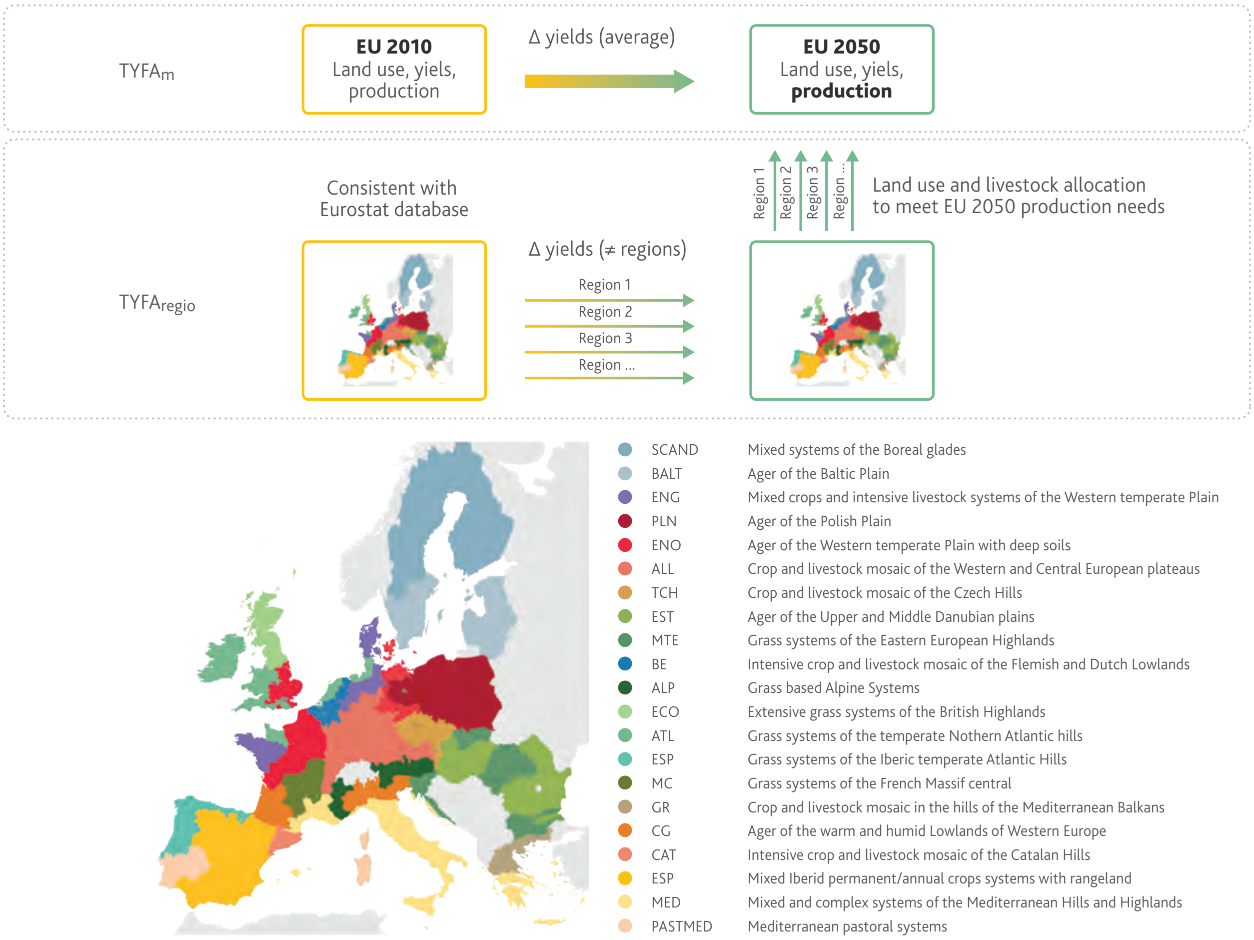
2.3. $TYFA_{regio}$

$TYFA_m$ does not consider regional heterogeneity, which precludes the possibility to analyze how and if nitrogen cycles are closed at a territorial level. To improve upon these issues, we developed $TYFA_{regio}$ which allows for a better spatial representation at a more detailed scale.

This regional approach serves as a meso-level analysis to connect both local/landscapes issues with macro issues. $TYFA_{regio}$ allocates grassland, livestock and crop land use across 21 agrarian regions. It also calculates a nitrogen budget at

3 The EU-27 region used in $TYFA_m$ includes the UK and does not include Croatia.

FIGURE 4. Structure of TYFA$_m$ and TYFA$_{regio}$



Source: authors

the level of each region to determine whether the balance is respected.

As mixed crop-livestock farming systems are central to agroecology in TYFA, introducing more diversity in agricultural systems is key when regionalising TYFA's assumptions. In practice, this requires today's crop production regions become home to herbivores and grasslands and that those currently specialised in cattle reintegrate crops into the mix to meet cereal and other crop needs. These assumptions and the associated results do not however reflect a specific optimisation scenario, but rather one plausible set of assumptions among a set of wider possible combinations that meet TYFA$_{regio}$'s hypotheses.

Based on Eurostat data at NUTS2 level, 21 archetypal European agrarian systems were characterised using the following criteria: land use, yields, yield potential, total production (including grass, density and type of livestock) and total animal production (Figure 4). In accordance with TYFA$_m$ settings, we chose 2010 (as an average of 2005, 2007, 2010 and 2013 data, to reduce variability) as the reference year to define European agrarian systems. Then, we explored the potential evolutions of these systems by 2050 under the TYFA hypotheses. Three groups of regions appear from the regionalisation process: ager (specialised in crop production), grass, and mosaic/mixed areas. The first group of regions is made up of land with significant crop cover. In those regions, there are ones where the dominant crop is wheat or barley (e.g. ager in most of Poland or in Baltic regions) or maize used as fodder (e.g. the plains in the southwest of France and the north of Italy). In the second group of regions, grassland dominates the agricultural landscape. Regions in this group can be quite heterogeneous, varying from alpine or Mediterranean zones with extensive grass production to higher grass yield zones created by the Atlantic climate located in north-western Europe. Finally, the third group includes mosaics, which are highly concentrated in central Europe, and mixed systems that are found throughout the continent (e.g. most of Spain excluding the Atlantic coast, the boreal regions in Finland and Sweden, and the Mediterranean hills and highlands). Regions in this category are characterised by a balanced share of cropland and grassland. The main difference between mosaics and mixed systems is the scale at which livestock and crops are mixed. In mosaics, this amalgamation occurs locally, while in mixed systems it takes place at a higher level. Figure 4.

2.4. From $TYFA_{regio}$ to $TYFA_{UK}$ Figure 5.

The UK can be divided into three $TYFA_{regio}$ regions: The ager of the western temperate plain with deep soil (aENO), the grass systems of the temperate northern Atlantic hills (hATL); and the extensive grass systems of the British highlands (hECO) (Figure 5). aENO is in the eastern part of the UK and covers most of England. The hATL system covers the southwestern part of Great Britain and Northern Ireland. The hECO region is in the northern part of UK, specifically in Scotland and northern England.

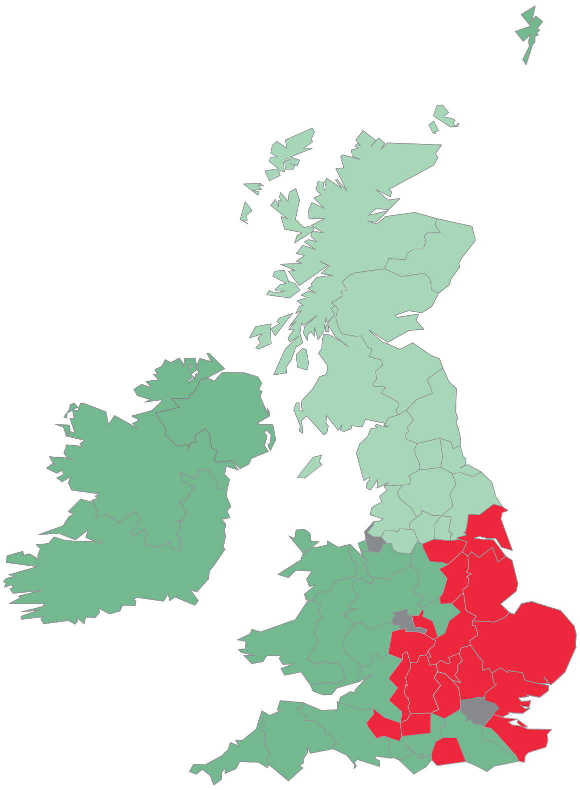
Each of these regions includes internal heterogeneity. For example, the hATL zone counties of Dorset, Wilts, Cheshire, and Sussex also include arable farmland. The hECO zone is also home to large variation, from the fertile and productive arable land of the southeast and the rough grazing of the highlands. Similar diversity exists in each zone.

Despite this heterogeneity, the variability of the $TYFA_{regio}$ parameters (such as yields or livestock densities) is always higher between two regions that within a given region. In this respect, the size of the regions chosen as analytical units is a key factor: the bigger they are, the greater their internal heterogeneity. Fig 6.

We briefly characterise the three regions present in the UK:

— The aENO region is characterised by deep and highly fertile soils, with a high yield potential for crops such as wheat and barley.
— Due to the significant rainfall provided by the Atlantic climate and the presence of deep soils, hATL has a high yield potential for grass and cereals. This zone is defined by its large cattle and sheep population.
— The combination of high latitude and altitude constrains crop production in the hECO region. As a result, large permanent grasslands where sheep and cattle graze dominate the landscape.

FIGURE 5. Division of the UK using $TYFA_{regio}$ regions



Source: authors

While the hECO region is unique to the UK, the aENO and hATL regions also occur in other areas in continental Europe (e.g. the aENO system in the Parisian basin in France). For this reason, we used a two-stage methodology to reconstruct the UK's agricultural system starting from $TYFA_{regio}$ regions. In the first stage, we extracted the UK system from the original European regions based on Eurostat data: the share of UAA for agricultural production and the share of LU for animal production. For example, the aENO region in the UK represent 24% of aENO arable land and 27% of aENO herbivores livestock units in total. The UK represents 43% of hATL UAA, arable and livestock units of all kinds. Based on these different shares, the second step consisted in recombining the three systems in order to create a unique UK unit for our analysis. The primary condition underlying this methodology is that the extracted UK region closely resembles the original EU region. We checked this condition and found a strong correlation between the two systems (UK's share and all EU). This condition was, however, unmet for sheep and dairy cows. Sheep are over-represented in the UK, beef under-represented and dairy cows over-represented compared to the baseline Eurostat data.[4] For this reason, we used a correction coefficient to rebalance the size of these two animal populations in the UK. Despite the replacement of beef with sheep, all other key variables (land use, yields and overall herbivore density) are close enough to carry out the analysis based on the two-step methodology of first extracting EU modelling results by zone and then summing up the results to create a complete map of the UK.

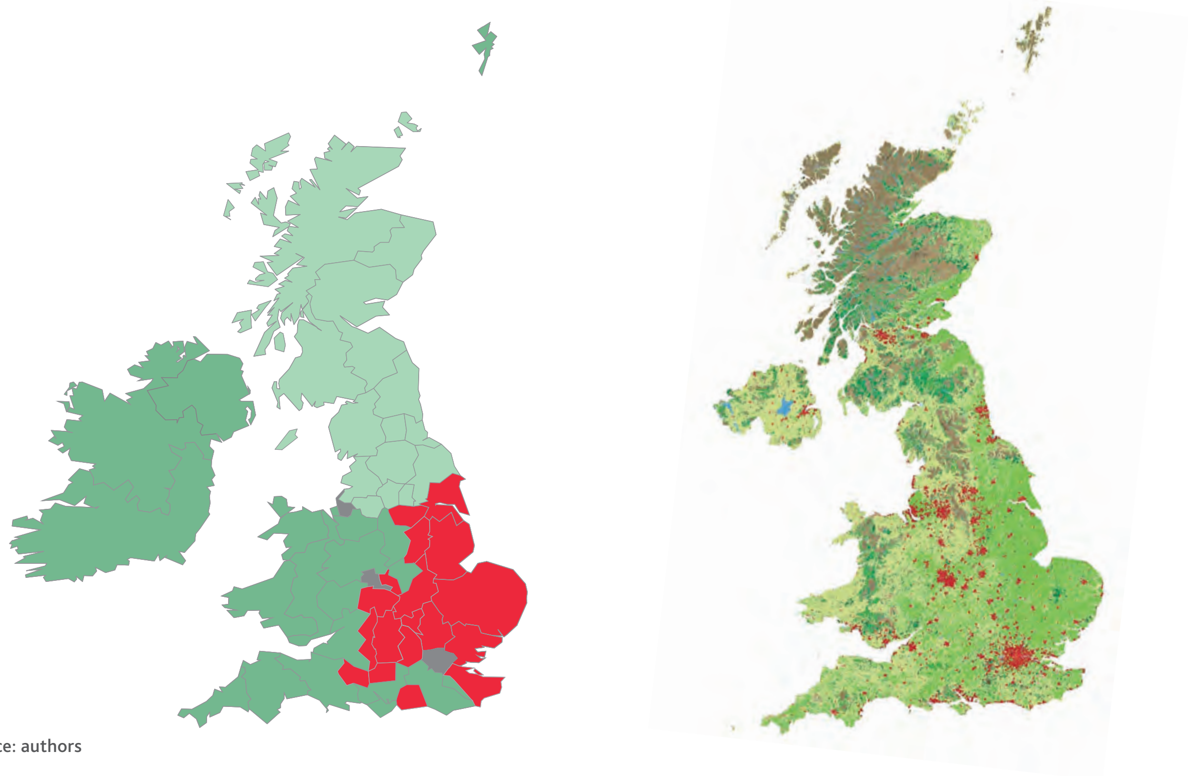
2.5. Data sources for TYFA UK baseline

Different databases were used to gather the data needed to set the UK baseline.

For the regional land use, livestock structure and detailed production outputs (yields), we used EUROSTAT at the NUTS 2 level. This statistical level divides the whole UK into 40 different units grouping districts in England and Northern Ireland, unitary authorities in Wales and council areas in Scotland. 2010 is the reference year used in the $TYFA_{regio}$ database as it is also the year used for modelling the EU. This EUROSTAT database only covers the UAA of farms, leaving out commons (around 1.2 m

4 This situation originates from the British traditional specificity of using a higher share of sheep production (relative to beef) for wool and human consumption than other regions in the continental Europe. On the other hand, the presence of cattle has been reduced in the UK due to competition from Ireland.

FIGURE 6. There are variations in terms of land use inside $TYFA_{regio}$ UK regions, but these variations are fewer than those between regions, having in mind the boundaries of Nuts 2 units (right map displays Corine Land cover land use – red areas in Corine map is urbanised areas).



Source: authors

ha total) that therefore could not be included in our model. This gap represents 4% of all UAA in England, and 10% combined in the three other nations, 8% and 12% of all permanent grassland and rough grazing areas, respectively.

We used 2017 data from DEFRA to characterise food balances. We used these more recent data sets for imports and exports, as the 2010 data (used to characterise production) is liable to be out of date. Because of this change, there is a slight discrepancy between the sum of regional production and the national food balance. Overall, the figures for production and land use remain unchanged, so the methodology is not undermined by this change.

We finally used the 2017 FAO diet database to characterise the average UK diets—but not accounting for waste and losses. Commonly used for international comparisons, this database was also used for $TYFA_m$.

Because of the use of data from different databases and multiple calculation methods, the results should be understood as orders of magnitude with a certain margin of uncertainty. Even if the raw results are indicated with a certain degree of precision (to the nearest hectare or ton, for example), they should be understood in relation to each other and not as absolute numbers.

3. MODEL ASSUMPTIONS

3.1. Towards a sustainable and healthy diet in 2050

The adoption of healthier, more balanced diets is a key element in the TYFA scenario. In this study, we applied the sustainable diet outlined in TYFA (based on nutritional guidelines (EFSA, 2017)[5]) to the UK. Since the current average UK diet is similar to Europe's, we used the same diet for both in 2050.[6] In other words, the changes necessary to reach a sustainable diet in the UK are comparable to those that the average EU resident needs to make.

The TYFA diet is built according to three sets of constraints: nutritional benchmarks, existing eating habits and environmental challenges (biodiversity and climate change). It has an

5 We respected the following recommendations: total carbohydrate intake is between 45% and 60% of total caloric intake, total lipid intake is between 30 and 40% of caloric intake, and fibre intake is 37 g/day, above the recommendation of 30 g/day/person.

6 The average UK diet is close to the EU28 diet except for higher consumption of potatoes, carbonated beverages and sugar. The consumption of animal produce is also slightly above the EU average.

average caloric requirement of 2,300 kcal/person/day[7] based on the current age pyramid and a normal level of physical activity. The protein intake is 80 g/day/person with a maximum of 35 g for animal protein.

The TYFA diet is slightly lower in calories and includes a reduction in animal products and sugar and an increase in plant protein and fruits and vegetables relative to the current average UK diet (Figure 8).

To maximise biological nitrogen fixation, and because of their recognised nutritional benefits, the TYFA diet is rich in legumes. At the same time, since poultry and pig fed with cereals directly competes with human consumption, the diet includes low levels of consumption of these monogastric animals. Lastly, as TYFA aims to maintain extensive grasslands to protect biodiversity, the TYFA diet only slightly reduces current amounts of bovine and ovine meat consumption. **Figure 7.**

Alongside the average diet presented above, the model assumes that food waste decreases by 10% and that the UK population grows from 65.8 million inhabitants to 77.5 million in 2050, following the medium-term projections from the Office for National Statistics. The waste improvement coefficient in the model is modest intentionally so that the focus remains on the agronomic dimension of the agroecological scenario. An assumption of a 20% decrease in waste (like that made in the Courtauld Commitment) or larger, like the 50% reduction set out in the Land Use report of the CCC (CCC, 2018), would have been consistent with policy options, but would have created ambiguity about whether the results were caused by the waste reduction or rather by the agronomic assumptions.

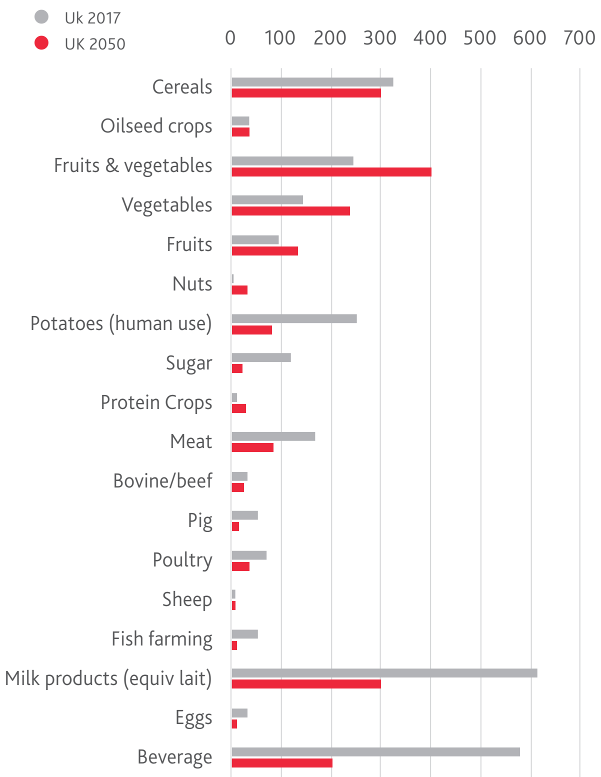
3.2. The agroecological assumptions

Figure 8 summarises the agronomic assumptions of the TYFA scenario. Though they have been made at the EU level, they remain valid for $TYFA_{regio}$. **Figure 8.**

A key aspect for the development of TYFA is achieving nutrient management at a more local level. This ambitious goal requires a set of changes to occur. First, plant protein imports are phased out to limit hidden N imports in feed and to reduce imported deforestation. Second, legumes/pulses are reintegrated into crop rotations to supply N to fields, therefore limiting or ending the use of synthetic N. Third, reconnecting crop and livestock systems allows for the recycling of N and the transfer N from extensively managed grasslands to croplands.

The development of biodiversity-friendly farming systems in TYFA also relies on the total phase out of synthetic pesticides (insecticides, fungicides and herbicides). There is significant evidence on the detrimental impacts of pesticides on biodiversity, extending beyond where they were applied (Geiger *et al.*, 2010 ; Pelosi *et al.*, 2014 ; Pisa *et al.*, 2015 ; Woodcock *et al.*, 2016). Other benefits of phasing out pesticides include

FIGURE 7. UK diet in 2017 and in TYFA UK 2050 (g/day)



Source: FAO and authors

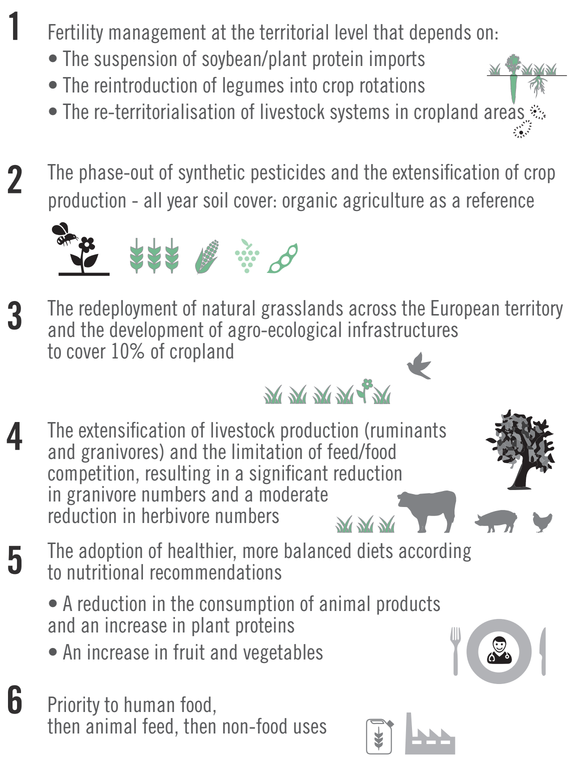
improved health conditions for agricultural workers and eradicating traces of pesticides in food and water.

The absence of synthetic fertilisers and pesticides makes TYFA's cropping system similar to that of organic agriculture. For this reason, the TYFA assumptions about crop yields in 2050 are based on the meta-analysis by Ponisio *et al (Ponisio et al., 2015)*. These yield assumptions were further refined to better reflect the impacts of climate change. Following the European Environmental Agency's methodology (EEA, 2017), climate coefficients were assigned to different regions based on the projected impacts of climate on yields. In northern Europe, where yields are projected to increase, a + 15% coefficient was applied to 2050 organic yields. Conversely, a -20% coefficient was applied in southern Europe. In the UK, EEA maps suggest there will be no changes in yields in the hECO and aENO regions and that yields will increase slightly in the hATL zone. These changes translate into a yield decline of 25% for cereals in the aENO and hECO zones and of 17% in the hATL zone, for example (compared to 2010 averages).

Natural grasslands and agroecological infrastructure make up a significant amount of land under TYFA because of their role in biodiversity conservation, carbon sequestration and nutrient management. In particular, extensively managed permanent grasslands and pastures need to represent at least 20% of the UAA in all regions. On top of that, 10% of UAA has been allocated for agroecological infrastructure such as hedges, trees, ponds, stony habitats and sunken paths—thus going beyond the

7 This number of calories represents the effective caloric intake. It does not include any kind of waste, which the model computes separately.

FIGURE 8. The set of assumptions used in TYFA



Source: authors

20% of semi natural habitats indicated as an optimum by Garibaldi et al (2020).

Under TYFA, animal production is also more extensive than it is currently. Ruminants (dairy, beef, sheep and goats) are fed limited concentrate feed (typically made of cereals and protein crops) and a higher amount of grass from pasture in order to reduce the feed and food competition, preserve grasslands and produce omega-3-rich products with proven nutritional benefits (Couvreur *et al.*, 2006). As a result, ruminant physical productivity (quantity of milk or meat per animal) decreases but with gains in criteria such as hardiness or the ability to eat fodder made of perennial species available year round.

Two dairy systems are also modelled. The first is a grass-fed system in which most of the fodder comes from permanent pastures. For these grass systems, we estimate milk production to be 5,000 kg milk/year/cow. The second is a mixed system existing in the lowlands, where cattle eat permanent pasture, temporary grasslands, cereals and legumes and produce 5,700 kg milk/ year/cow. Both systems require the use of resilient cow breeds and allow for longer lifespans for the animals (9 years for mixed, 11 for grass fed), a later first freshening at three years and a lower replacement rate. Beef and sheep will be raised in an extensive production system and be pasture-fed.

Under TYFA, monogastric (pigs, broilers and laying hens) production is highly reduced, becoming only a way to rebalance N between areas, due to their being in direct competition with humans for cereals. For this reason, in the 2050 simulation, monogastrics are distributed among the various European systems according to N requirements while maintaining the 2010 proportions of pigs and poultry in the total LU of every region. The technical performance of monogastrics is modelled based on organic agriculture systems in Brittany, France. Their feed ration considers different lifecycle nutritional needs and include cakes produced by the oilseed and protein crop sectors with by-products of human food.

Finally, because priority is given to human food under the TYFA scenario, there is a complete phase-out of bioenergy crops, including for biofuel and biogas.

3.3. Farms and farmers in an agroecological UK: the challenge of diversity and mixed farming systems

The above generic assumptions are applicable at different levels of modelling. In TYFA$_m$, they have been used at the EU level and in TYFA$_{regio}$ at NUTS 2 level. The results on the farm level, as well as farmer decisions, cannot be accounted for in this work. Yet, the regionalisation of TYFA allows a much closer view of the individual farming systems of each region. The broad types of farming systems, which face different agroecological challenges, can thus be described as follows:

— Specialised extensive livestock systems, typically highland grazing systems for sheep and cattle (in this case, most of hECO and some parts of hATL). For such systems, managing cattle according to the growth cycle of roughage, limiting overgrazing and ensuring good habitat management are the biggest challenges. Farmers need solid knowledge of semi-natural forage production cycles, how to choose environmentally-compatible breeds, and techniques to help the systems adapt to climate change.

— Mixed systems, which combine crops and grass-based livestock systems, found in hATL, aENO and lowland of hECO. Organising the farm work, managing nutrient cycles and pest and weeds pose challenges to farmers working in these systems. While important features of such systems already exist, changes in scale, workforce organisation,[8] and the implementation of longer crop rotation periods (needed for the reintroduction of legumes, protein crops and/or ley farming) will require good management skills. Yet, one should note that the mixed nature of agricultural systems does not need to be reached at the farm level; as such, a certain level of specialisation of both arable and livestock systems is possible providing that the complementarity between crops and livestock can be organised at a territorial level (around some tens km maximum to give an idea) (Martin *et al.*, 2016).

— Horticulture and vegetable production is best facilitated by the climate in lowlands, so they should be grown there. These farms face numerous challenges: the management

8 Agroecology requires more labor to produce food, notably due to the limited use of inputs (Dorin *et al.*, 2013).

of a high diversity of vegetables, nutrient transfer through manure imported from other systems and longer rotations that for example intersperse vegetable growing cycles cycle with other crops or grass. The scenario foresees the significant development of these types of systems based on seasonal production. Such cyclical production would require a major increase in the agricultural workforce (Dumont & Baret, 2017) and a facilitating environment (nutrient management, marketing, support work, etc.).

At the farm level, the size and share between different types of crops (from cereals to root crops and legumes), forages (from maize, leguminous crops to roughage) and animals (ruminants vs. monogastric) will vary, according to geography, crop and grass productivity and land tenure. Farming in Wales is not and will not be the same as in eastern England. If despecialisation towards mixed plant and livestock systems is the common pattern for agroecology, this mixed nature is far from being uniform.

Ecological landscape features that support production must also be considered when discussing farming system structure. As presented above, the TYFA UK model assumes that 10% of all cultivated land—including permanent crops—is used for permanent and natural green infrastructure. This totals around 600,000 ha in 2050 as opposed to 330,000 ha in 2010 that fall into the category "fallow land and green infrastructure," corresponding to an 80% increase.

Extensive pastures make up the bulk of agroecological features of total area covered. But important services will be provided by local species-diverse hedges, the introduction of trees in silvopasture or agroforestry systems (for climate and pest management), and the building and maintenance of stone walls and ponds. Eco-engineering through choosing suitable plant varieties, plots and management practices for such ecological landscape features is an important support job for farmers.

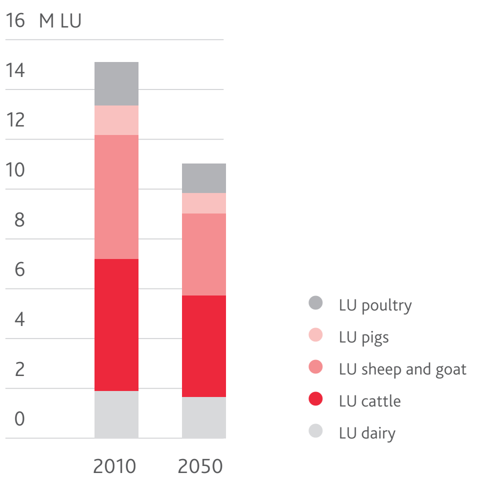
4. WHAT WOULD AGROECOLOGY MEAN FOR THE UK?

4.1. Results for livestock and land use

In this section, we analyse the $TYFA_{regio}$'s results for livestock number and land use in the UK. In both cases, we compare the 2050 simulation results with the baseline data taken from DEFRA 2017.

In the TYFA scenario, livestock ensures nutrient transfers between grassland and cropland. The amount of livestock in the UK in 2050 under TYFA was derived from the equilibrium needed to close the nitrogen cycle at the lowest territorial level possible, the historical trends for livestock in the UK and the need to cover domestic animal product consumption—considering diets less rich in animal products. Specifically, TYFA's agronomical assumptions implies a despecialisation of hATL and hECO regions away from livestock and an increase in animal numbers in the aENO region. In regions where grass dominates the landscape, $TYFA_{regio}$ increases the amount of land allocated to crops such as barley, oats or wheat. The shift from non-cultivated grassland to arable land of all kinds (including fodder crops) increases arable land by nearly 400,000 ha, adding 25% more arable land to the hATL region (moving from 30% of UAA to 37%). While this increase is striking, since the 1950s the UK as a whole has experienced a decline of nearly 1.6 m ha of arable land due to the transition to livestock raising in the hATL region (House of the Commons, 2019). This assumption means that by 2050, formerly arable land that was turned into improved grassland in past decades would be returned to its arable state. Changes are less significant in the hECO region, with only an increase of UAA from 19% to 22% of total land excluding commons.

FIGURE 9. Change in livestock units between 2010 and TYFA UK 2050



Source: authors

Livestock is reintroduced in the aENO region, which has become increasingly specialised in crop production over recent decades. As a result of the changes, UAA will decrease from 66% to 57% and grasslands will increase from 33% to 40% in 2050.

These assumptions have major impacts on livestock numbers, which decline from their 2017 levels for all animal types by the following percents: dairy cows (-14%), cattle (-23%), sheep and goats (-34%), pigs (-30%) and poultry (-34%) (Figure 9).

Despite the high GHG emissions per unit of output, ruminant populations only slightly decrease relative to 2017 under TYFA. The number of head of ruminants is large compared with other scenarios addressing climate change but is offset through a substantial reduction in other categories of animals. Keeping sheep and cow populations is necessary to conserve grasslands and also contributes to the extensification of the associated dairy production. The lower productivity per animal in extensive systems means that more cows are needed to produce the same amount of milk. In addition, the ratio of dairy beef per kilo of milk produced increases due to the increase in dairy progeny. This increase occurs due to changes in dairy herd management causing higher numbers of lactations, increasing the number of offspring (fattening heifers and calves) produced during the lifespan of each dairy cow. This management shift happens concurrently with a shift back to mixed milk and meat breeds that can more easily consume grass and other forages.

The large amount of ruminants limits the volumes of meat to be provided by pigs and poultry, limiting the herd sizes of these animals. Figure 9.

According to the evolution of diets and the despecialisation of crop and pasture areas, TYFA$_{regio}$ remodels land use in the UK for the year 2050 (Figure 10). The areas dedicated to pulses (x7 for pulses, but the starting point is nearly null), root crops and vegetables (+60%) in the total amount of arable land largely increase, while the area dedicated to cereals and oilseed is reduced by approximately 5% and 20%, respectively. Cereal cropland is further diversified, with wheat and barley production decreasing to add course cereals such as oats and cereal mixes to the production mix.

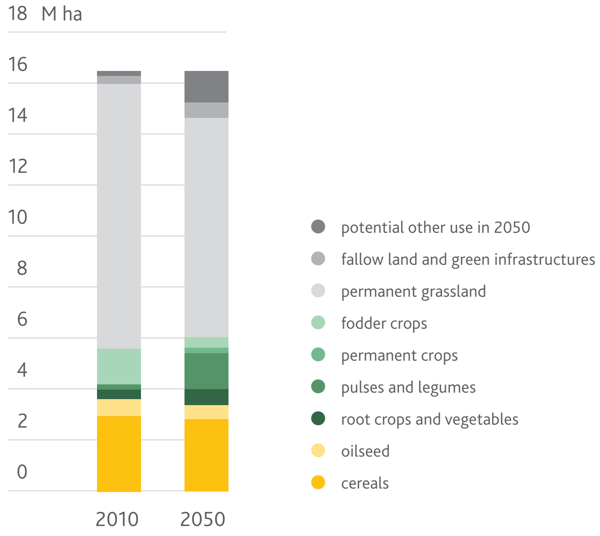
As UK residents eat more fruit, permanent tree crops such as apples, pears, plums, cherries, apricots and peaches take up a greater share of arable land. This allows the UK to reach a similar level of land use for fruit trees as in the 1960s, over 80% of which has since been lost. For both fruit and vegetables, the development of rustic varieties and of a move towards more consumption of in-season products in accordance with climate patterns in 2050 is foreseen. These two sectors do not require a significant amount of land, yet the two changes detailed above do require adjustments in current eating and growing trends.

Grassland in the hATL and hECO regions declines by 30% and 25%, respectively, as does the land allocated to fodder crops (a 70% reduction), both due to diversification. The stronger decrease in the land allocated to fodder crops compared to that allocated to grassland results from the fact that the latter provides more ecosystem services than the former. A third 1/3 of the area freed up due to this decline goes to myriad other uses and 2/3 to other crop production. In aENO, the area of permanent grassland nearly doubles, at the expense of arable land.

Fallow land and potential other uses of land (the latter destined to afforestation) also increase dramatically under the TYFA UK scenario (by 80% and 10 times baseline levels, respectively, representing 11% of total UAA). It is worth noting the special case of the "fallow land and ecological infrastructure" category, whose ecological function changes between 2010 and 2050. In 2010, this land use functions as an ecological buffer in a largely intensive agrarian environment. In 2050, all agricultural land is managed extensively by mixing a variety of crops and different types of land use, including extensive grasslands that play a key role in the agroecosystem's structure. Therefore, the ecological infrastructure of 2050 completes agricultural systems that support much higher level of biodiversity that seen today. In practice, some of this land could be used for grazing and added to the "permanent grasslands" category.

As mentioned in Part 2, data for the use of commons by livestock was unavailable and we thus calculate the share of forage they supply. This means that our results exclude the forage which the commons contributed in 2010, although this is incorrect. The apparent productivity of on-farm grassland is thus overestimated in the baseline and while the change of productivity is

FIGURE 10. Change in land use between 2010 and TYFA UK 2050



Note: the figures are only for UAA in farms; Commons are not counted and can be assumed as remaining useful for forage supply

Source: authors

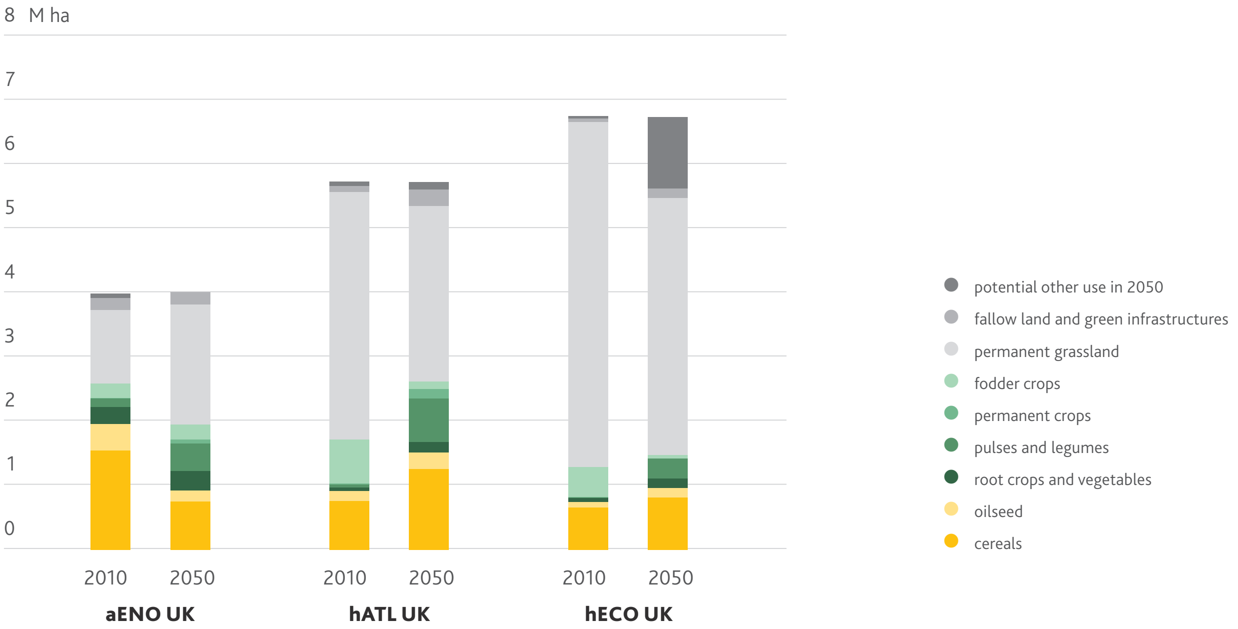
calculated in relative terms (as a % of change between 2010 and 2050), the overestimation is maintained in the 2050 projection. This implies that commons are still needed in 2050. Figure 10a.

Figure 11b. shows the breakdown of changes across the TYFA UK regions. Figure 11b.

In general, the hATL and aENO regions would converge under TYFA towards equal amounts of arable land and permanent grassland. The hECO region remains predominantly covered by grasslands. This latter zone also offers the greatest opportunity to transition land towards other purposes.

It should be noted that the feasibility and the full implications of the projected land use changes under TYFA, that would occur on nearly 30% of current UAA, cannot be fully assessed with TYFA$_{regio}$. This is due to data limitations and to the granularity of the analysis. However, long-term analysis of land use change in the UK shows that changes of this order of magnitude have taken place before, increasing the plausibility of such future changes.

FIGURE 10 bis. Change in land use between 2010 and TYFA UK 2050



Source: authors

4.2. Agroecology's contribution to biodiversity and natural resource preservation in the UK

Agroecological farming has been designed to produce certain environmental results. Its two main features contribute significantly to this goal:

- The elimination of synthetic fertiliser and pesticides;
- The complexification of landscapes through the integration of semi-natural vegetation and agroecological infrastructures, providing diverse habitats for flora and fauna.

4.2.1. Impacts of the elimination of synthetic fertilisers and pesticides

Despite their diversity, all kinds of agroecological farming systems described previously share a common principle: production without synthetic fertilisers, notably nitrogen, and pesticides.

Regarding nitrogen, $\text{TYFA}_{\text{regio}}$ is calibrated to create a positive nitrogen balance (uptake—supply) in every region. For the three regions in the UK, each zone has at least 110% of its nitrogen needs met due to the spatial reallocation of livestock and the inclusion of legumes in crop rotations and in cover-cropping. Such a slim margin requires careful management of nitrogen in agroecological farming systems. Because organic nitrogen is released more slowly into useable forms than synthetic nitrogen, yields and runoff are both limited in this production system.

This absence of synthetic fertiliser on arable land is key to the development of soil micro-organisms, notably bacteria and mycorrhizae, with positive effects on soil life and structure and the capacity to develop complex networks supporting plant communities.

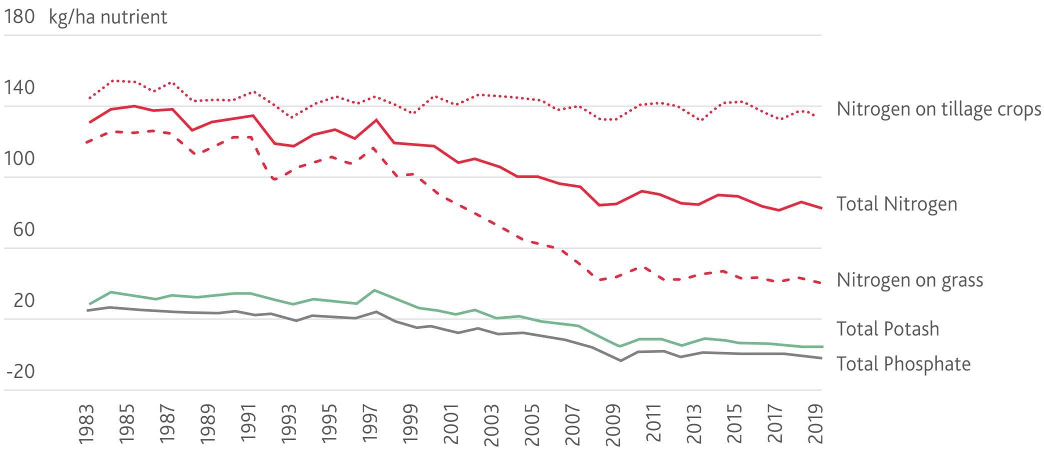
- At the same time, the generalisation of mixed agroecological farming systems leads to important transfers of nitrogen from non-fertilised pastures and semi-natural vegetation to crops through mowing or grazing. The ongoing net biomass export leads to low-nitrogen soils in pastures, favouring the growth of spontaneous leguminous plants and other plant species. This floral species richness, with plants that flower throughout the year, supports insect communities—including pollinators—and the resulting natural food pyramid. The ability of semi-natural ecosystems to produce enough biomass to feed herbivores without endangering their productivity is key, but requires a careful management of stocking density. **Figure 12.**

This change in the management of both crop and pastures would be a boon to biodiversity in permanent grassland and crops that currently receive too much nitrogen, at 150 and 60 kg N/ha/year, respectively—with surpluses occurring in as much as 60 to 90% of all UK grasslands (see Figure 14).

Figure 13. Figure 14.

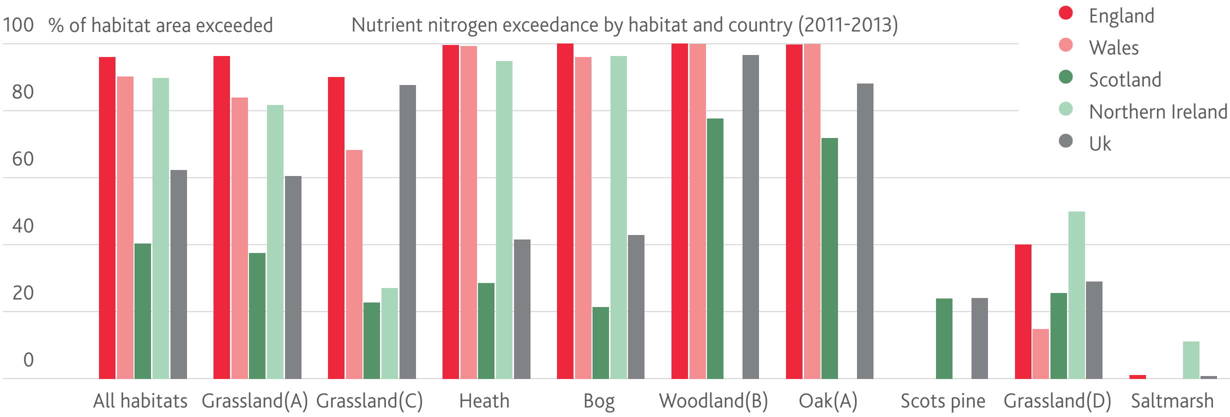
FIGURE 11. Such species‑rich grassland results from the management of nitrogen in agroecological farming systems

FIGURE 12. Development of fertilisers use on crops and grass



Source: DEFRA agrienvironmental indicators

FIGURE 13. The role of nitrogen in habitat richness or poverty – why today's most UK valuable habitats are altered, and why changing nitrogen management would reverse the trend



Grassland (A) – Acid grassland ; Grassland (C) — Calcareous grassland; Heath — Dwarf shurb heath; Woodland (B) — Boradleaved woodland (managed); Oak (A) — Acidophilous oak (unmanaged); Scots pine (unmanaged); Grassland (D) — Dune grassland

Source: authors

FIGURE 14. An archetypal mixed agroecological farming landscape

Source: authors

4.2.2. Towards greater landscape heterogeneity

Two aspects contribute to increase landscape heterogeneity under an agroecological scenario. On the one hand, ending the use of synthetic inputs has major—and often overlooked—implications at the landscape level:

— It leads to a better balance between semi-natural vegetation (nutrient source) and crops (nutrient sink)
— In arable lands, nutrient, weed and pest management requires diversifying crop rotations, combining legumes and protein and oil crops, root crops, vegetables, etc, and mixing them with permanent landscape elements that also play a role in pest management (e.g. hedges hosting pest predators).
— In places dominated by extensive permanent pastures that are unfit for crop production, biodiversity exists in the different types of grassland and rangeland that form semi-natural habitats.

The high biodiversity of extensive, no-input permanent pastures—those found in extensive livestock systems—are already central to high nature value farmland in the UK today. Characterised by the dominance of semi-natural vegetation in land use (Andersen, 2003), these type 1 HNV farming systems are found in the highlands or in the hills (Lomba *et al.*, 2014 ; Strohbach *et al.*, 2015).

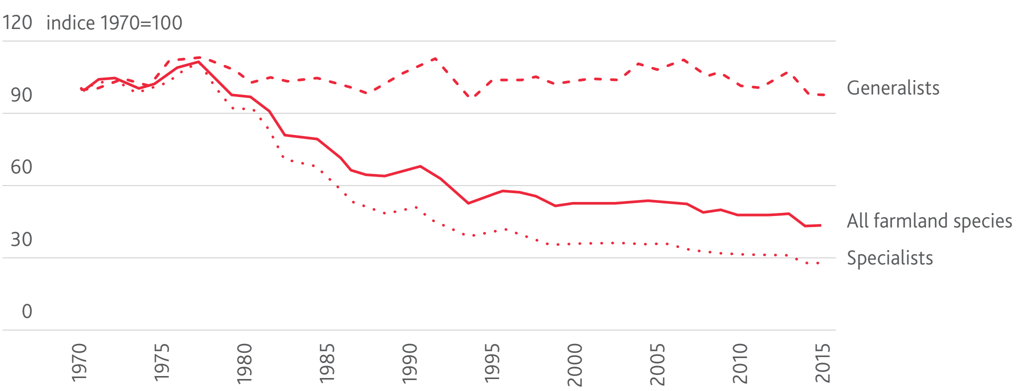
TYFA goes further than keeping permanent grassland: the low-input, low-stocking density conditions it entails allow for high biodiversity. Biodiversity deserts caused by fertilised grassland and early mowing no longer occur in the absence of synthetic fertilisers and imported feed.

From a broader perspective, the TYFA scenario lowers the demand put on British animal production, allowing for afforestation of today's permanent pastures. As stated above in the land use analysis, our results point to the possibility of 10% of current UAA being dedicated to alternative use. The extent and location of such alternative use depends on local spatial planning, which also accounts for ecological and social factors. What this could look like varies significantly, from silvopastoralism for climate change adaptation to afforestation covering some tens of hectares in places where such wooded habitats would bring biodiversity. Different types and sizes of trees will encourage rich biodiversity. In particular, the planting of large swaths of forest would create niches for large mammals such as deer and boars.

In mixed landscapes that combine low-input crops and permanent pastures, high biodiversity results from the diversity of crops and, less importantly, semi-natural vegetation. In comparison with the UK's current biodiversity-poor landscapes, agroecology would bring high biodiversity potential. Figure 15 displays a visual representation of such an agroecological landscape. Figure 15.

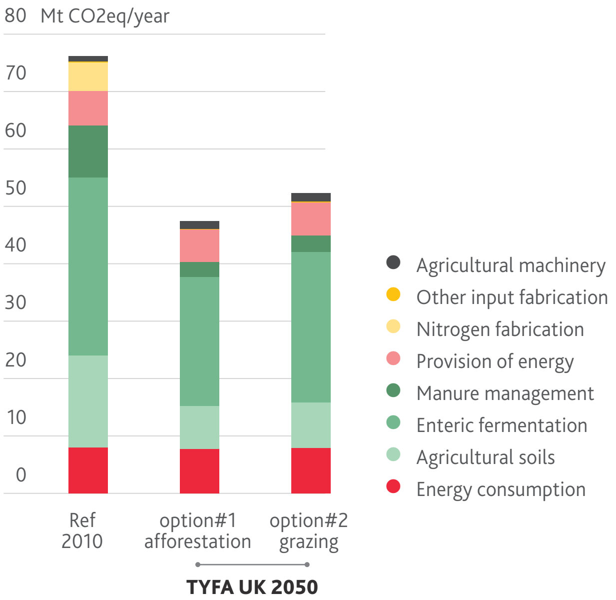
Three levels of analysis are needed to fully comprehend the biodiversity in type 2 High Nature Value farming systems (Wang & Loreau, 2016):

FIGURE 15. Improving both input and landscape management through agroecology would turn the curve of farmland bird index up



Source: DEFRA agrienvironmental indicator; BTO; RSPB

FIGURE 16. Emissions reduction of TYFA UK compared to 2010 (options #1 and #2)



Source: authors

1. The agricultural unit level. This level is composed of individual parts of the diversified agroecological landscape—pasture, meadow, no-input crop, no-input orchard, hedge—and hosts a specific plant and animal community by itself. While permanent pastures and meadows are amongst the richest components of such a landscape because they are permanent, every unit benefits some segment of wildlife: hedges for many insects, birds and small mammals; cereals for messicole plants and small animals, orchards, etc.

2. The farm-adjacent habitat level. The edge effect, occurring between two different habitats or ecotones, allows flora and fauna to move between agricultural and other lands. For example, a small rodent may spend most of its time in a hedge, but will benefit from having a wheat field in proximity complement its diet. Such complementarity exists at every level of the landscape, and is more powerful when the habitats are themselves rich in biodiversity. There is little value in connecting a single-species trimmed hedge with a high-input wheat field.

3. The landscape level. The quality of biodiversity overall depends on the sum of its units and the spatial distribution of these units, which together make up the landscape level. The resulting emerging richness cannot be explained only by the sum of each unit/unit placement, but from a holistic point of view. In this perspective, we again find the potential role of introducing a variety of woody elements in the landscape as they enrich the agroecological biodiversity potential.

This understanding of the structure and function of agroecological HNV landscapes is paramount in differentiating it from an approach which maintains intensive agricultural practices with simply the addition of landscape features on field perimeters. The latter approach might involve the planting of trees in field crops for a kind of simplified agroforestry pattern, developing hedges or planting forests. This approach is of some interest compared with the same landscape without any wooded element. But it cannot achieve, by nature, a really high level of biodiversity as it lacks the very basis of a rich agroecosystem: the richness of each of its components, starting at the micro-level. Without this fundamental layer of microbes—bacteria, fungi, insects, earthworms, etc.—it is impossible to have a full trophic chain. A tree in a monoculture landscape will offer a good refuge for a bird of prey, but what if there are no small animals to catch? This situation highlights the importance of low input farmed landscapes. We cannot simply hold on to the fact that many current scenic British landscapes combine grassland and cropland. We need to go further. For biodiversity to flourish, the whole cycle –from input management to landscapes, to landscapes to input management—must be taken into account.

In an agroecological scenario, the observed decline of the index of plant species richness in most valuable habitats (stream sides and neutral grassland) could be reversed, with positive butterfly effects on other biodiversity indicators such as insects and farmland birds. Figure 16.

4.3. Climate change: when agroecology delivers for climate

In this section, we analyse the impact of TYFA UK scenario on climate change. Firstly, using the ClimAgri® calculator (Eglin *et al.*, 2016)[9], we measured the difference in GHG emissions between the baseline in 2010 and our simulated scenario. Second, based on a literature review, we estimated the additional carbon sequestration potential gained from the land use change foreseen in TYFA UK.

Two options are considered in this analysis. The first option assumes that all agricultural land that has the potential to be used for purposes other than agriculture/grazing (see Figure 10a and Figure 11b) is afforested. Under the second option, all of this land is used for extensive grazing in high nature value sheep grazing systems in the highlands (with an average value of 0.15 LU/ha) (Scottish Government, 2017). There are two main differences in these options' contribution to climate change mitigation. Option one maintains lower methane emissions and stores more carbon on newly freed land. Option two brings other benefits, particularly for landscape composition, cultural and semi-natural habitat conservation issues and the provision of sheep feed.

It should be noted that these options are extremes between which additional moderate scenarios that balance afforestation and semi-natural grazing can be envisioned.

9 Rather than restricting itself to the UNFCCC categories, ClimAgri® measures agricultural GHG emissions in a sectoral and comprehensive way. As such, the emissions from along the entire food production chain are assessed. Direct emissions include classic non-CO_2 emissions (CH_4, N_2O) coming from soil and management and enteric fermentation as well as CO_2 emissions from farm-level energy use. Indirect emissions include CO_2 and non-CO_2 emissions from the fabrication of inputs in addition to the energy used by upstream processes.

4.3.1. Reduced livestock and agroecological farming practices curb GHG emissions

Option one and option two, described above, have different impacts on GHG emissions. In option one, direct and indirect GHG emissions from agriculture decrease by 38%, whereas they only decrease by 32% in option two due to more enteric fermentation from sheep grazing (Figure 17). In addition, since a significant share of current plant protein imports come from deforested areas in South America and these imports are eliminated in both options, the total emissions reduction could even be higher.

GHG emissions are also significantly reduced (N_2O and CO_2 in particular) from the phase-out of chemical fertilisers. In the UK in 2010, emissions from agricultural soils represented almost 25% of total direct agricultural emissions. By eliminating the use of synthetic nitrogen and by significantly improving the level of nitrogen use efficiency, N_2O emissions from the application of nitrogen to soils significantly decrease by 53%, while emissions from the fabrication of nitrogen are eliminated.

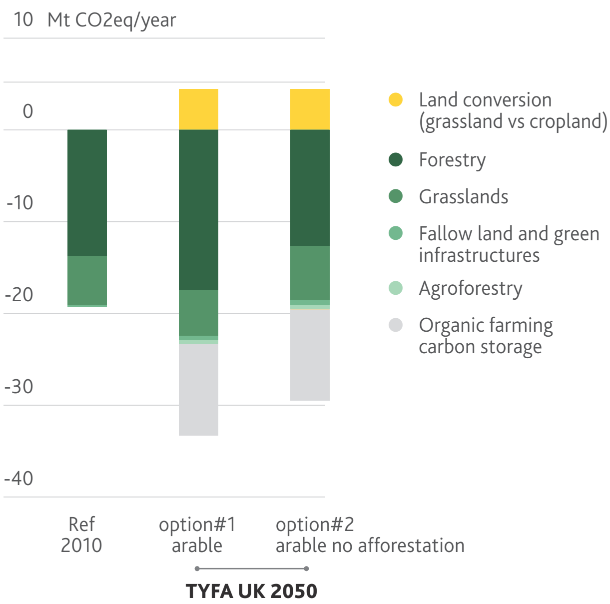
Emissions from manure management also significantly diminish by 72%. This decrease comes mainly from reducing livestock numbers and from improving the management of bovine manure through straw use, thereby eliminating liquid manure. Emission reductions are less important in absolute terms for sheep, pork and chicken systems (2 Mt CO_2eq compared to 4 Mt CO_2eq for cattle), but significant in relative terms (77% compared to 69% for cattle).

Emissions decrease from enteric fermentation by around 28% in option one and by 17% in option two. This decrease could be greater if ruminant populations were significantly reduced. The choice to maintain ruminant populations in the TYFA UK scenario highlights the key role of natural grassland in biodiversity conservation and the need to have enough animals to graze those grasslands in an extensive way. These grasslands for grazing have positive impacts on the nutrient transfer from grasslands, thereby diminishing the need for synthetic nitrogen fertiliser. To reduce enteric emissions, we made the hypothesis that half of the dairy and suckler cows would be given feed additive. These additives are already available and can bring down enteric emissions by 14% per cow according to the existing literature (Pellerin *et al.*, 2017). The use of these feed additives is limited to semi-intensified bovine herds that spend enough time in stables to allow their feed to be managed.

Direct emissions from energy consumption remain almost constant with only a 2% decline. Since in the TYFA scenario vegetable production should be as seasonal as possible, we decided to maintain the current area of heated greenhouses. No further hypotheses were made to increase the energy use efficiency for the heating of those greenhouses, nor for that of livestock buildings or agricultural machinery. It should also be noted that no specific hypotheses were made either to reduce emissions from energy consumption in the agricultural sector through the substitution of biofuels with biomass. Figure 17.

4.3.2. Significant carbon sequestration potential through afforestation

FIGURE 17. Maximum carbon sequestration originated from land use change in 2050 (options #1 and #2)



Source: authors

Based on coefficients taken from the literature (more details in Annex 6.1), we determined the maximum carbon sequestration potential under the TYFA UK scenario.

All results in this section should be viewed relatively rather than as precise numbers because of the great uncertainties regarding carbon sequestration rates and the evolution of forests and their management practices.

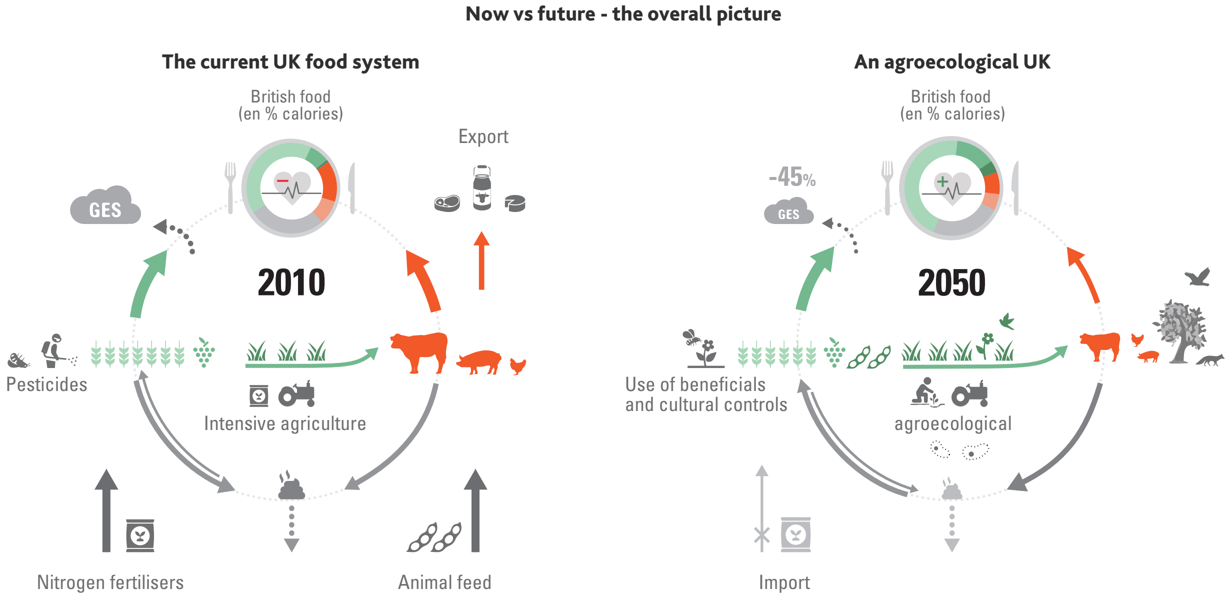
Our estimates suggest that an agroecological UK could at best increase its net annual carbon sequestration by around 55% relative to 2010 under option one and 36% under option two (Figure 18). This equals 30 Mt and 26 Mt CO_2 sequestrated respectively, representing 63% and 50%, respectively, of the carbon emissions of the agricultural sector in 2050.

Forests and agricultural soils serve as the most significant carbon sinks due to the spread of organic agriculture and its ability to increase soil organic matter (Gattinger *et al.*, 2012). 10 Mt $CO_{2\ eql}$ could be sequestered in agricultural soils, in both options one and two, which are similar on this aspect.

As compared with the baseline situation, option two (grazing) leads to a stable forest area (no net gain from afforestation), but a slight decrease in C sequestration from 14 to 12.5 Mt CO_2 (-10%) due to forest ageing. Afforesting 1.2 M ha—the core of option one—brings an extra 5 Mt CO_2 sequestration potential (total 17.4), thereby increasing forest carbon sequestration by 27% as compared with today.

We also assigned 10% of UAA to silvoarable and silvopastoral agroforestry (1.4 million ha of agricultural land with a planting density of 188 trees/ha) due to their ability to sequester carbon and to provide ecosystem services such as sheltering livestock, creating a habitat for pollinators, improving water retention

FIGURE 18. The TYFA UK scenario at a glance



Source: authors

and recycling nutrients. To model these systems, we made the simplistic assumption that agroforestry does not affect crop yields and does not divert land from agriculture. The carbon sequestration provided by these systems is modest, however, and represents around 6% of the total carbon sequestered under the TYFA UK scenario.

The amount of carbon sequestered in grassland and fallow land changes under the TYFA UK scenario relative to 2010. In the case of grassland, the carbon sequestration potential decreases by 3.4 Mt under option one due to the decrease in pastureland and increase in cropland by 444,000 ha. In option two, the greater share of grassland leads to a net loss of only 2.4 Mt CO_2 in carbon sequestration potential. For fallow land, carbon sequestration increases by 209% (from 0.2 to 0.5 Mt CO_2) because of the increased presence of green infrastructure. Figure 18.

4.4. Healthy and sustainable diets ensure a positive national food balance under TYFA UK

Thus far, the positive climate and biodiversity impacts of the TYFA UK scenario has been highlighted. This section addresses the effect of these changes on the national food balance. Because of the TYFA agroecological system and the TYFA$_{regio}$ reallocation of EU crops and livestock, the structure of the UK's agricultural production changes. Specifically, the UK reduces production of most of its food commodities relative to 2017. At the same time, the UK population is projected to increase significantly by 2050, from 66 million inhabitants in 2017 to 77.5 million in 2050. The question is quite straightforward: to what extent do diet changes offset the challenges of a bigger population and lower yields?

The results from the TYFA UK model are that dietary change in conjunction with lower livestock numbers, less grain in animal diets and lower animal feed demand can compensate for these two pressures to maintain a positive food balance. Table 1 shows the main changes in production, the supply term of the equation.

TABLE 1. Change in domestic output of major commodities in m t between 2017 and the TYFA UK scenario.

	2017 (DEFRA 2017)	2050 (model)	Relative Change
Cereals	23 m t	18,7 m t	– 32%
Protein-oilseed	3,1 m t	4 m t	– 30%
Permanent crops	0,7 m t	4,2 m t	463%
Vegetables	2,7 m t	5,2 m t	93%
Sugar beet	8,9 m t	0,8 m t	– 91%
Potatoes	4,9 m t	1,9 m t	– 60%
Milk	15 m t	8,5 m t	– 44%
Beef	0,9 m tec	0,9 m tec	– 3%
Sheep	0,3 m tec	0,2 m tec	– 34%
Pig	0,9 m tec	0,5 m tec	– 44%
Poultry	1,8 m tec	1 m tec	– 47%
Eggs	0,7 m tec	0,4 m tec	– 47%

For most major products, production decreases significantly: by around 45% for milk and poultry and by around 30% for cereals and sheep (expressed in calories). Sheep grazing on 1.2 M ha (option two in the above discussion on climate) leads to a decline of 30% as compared to the similar 34% decline if the corresponding area is afforested (option one). The extensification of dairy and beef production allows for current production levels to be maintained but with more cows due to their longer but less productive lifecycles. Less important products see marginal changes in production levels, including increases for fruit and vegetables. For vegetables, 50% of the increase is explained by the current dynamics and 50% by increased demand (assuming local demand will foster local supply). It is assumed that fruit and vegetables can be grown on a wider scale, provided that the varieties used are adapted to climate and soil conditions. This entails a strong reduction in potatoes and sugar beet production that grow on the same type of fertile soils as fruit and vegetables.

Table 2 shows changes on the demand side.

TABLE 2. Change in domestic requirements for major commodities between 2017 and the TYFA UK scenario, in Mt (Source: authors)

Domestic needs	2017 (after DEFRA 2017 food balance sheet)	2050 (after TYFA UK calculations)	Change 2050/2017
cereals	25,3	13,9	-45%
oilseed	2,4	2,3	-4%
pulses and legumes	3,9	0,8	-78%
permanent crops	4,6	6,7	46%
sugar beet	14,1	0,7	-95%
potatoes	6,6	2,3	-66%
vegetables	4,8	8,3	75%
milk	14,2	8,5	-40%
beef meat	1,1	0,7	-37%
sheep meat	0,3	0,3	-17%
pig meat	1,4	0,4	-70%
poultry	2,1	1,0	-52%
eggs	0,9	0,4	-57%

Source: authors

The bulk of the changes in requirements result from reductions in animal product consumption. Demand for animal products from domestic suppliers declines accordingly by 40% to 70%, except for sheep products, which decline by only 17% because consumption remains relatively high due to cultural and land use reasons. The reduced needs for cereals and pulses also result from this reduction in the consumption of animal products. Production requirements for fruits and vegetables increase due to this diet change. The figure for sugar requires further analysis, as 2017 and 2050 figures are difficult to compare as they are based on different methodologies.

Table 3 sums up the results for the main commodities that can be produced in the UK and compares the change in the domestic supply ratio.

Table 3 figures give an estimate of the percent of domestic demand covered by domestic supply, while the color indicates export potential. As before, these results should be understood as relative. For cereals, for example, the UK moves from having a domestic supply-demand balance to becoming a minor exporter.

Despite a decline in overall production, the UK does not become dependent on imports due its residents' healthier and more balanced diets. The final food balance remains in the same range of coverage or improving for most commodities, except for sugar, for which the degree of external dependence will increase. The foreign footprint of the UK food system is reduced barring that of sugar. In particular, the 3 Mt of imported soya will no longer be needed due to the combination of lesser animal production, the shift towards autonomous forage systems for ruminants and the supply from domestic protein-oilseed crops. Despite this production shift, the UK can maintain the same amount of agricultural land and its level of self sufficiency while transforming its agricultural system to have positive effects on biodiversity, greenhouse gas emissions and the protection of natural resources. For some commodities such as cereals, pork and oil-protein crops, the UK may even become a net exporter. In the case of pork, the use of pig manure to rebalance the UK nitrogen cycle explains this surplus production (see section 3). For oil-protein crops, the surplus originates from reduced oilseed cakes requirements.

TABLE 3. Table 3. Percent of domestic demand covered by domestic supply in 2017 and 2050.

	2017 DEFRA food balance sheet	2050 TYFA UK calculations
Cereals	91%	112%
Protein-oilseed	49%	129%
Permanent crops	16%	63%
Vegetables	57%	63%
Sugar beet	63%	19%
Potatoes	74%	86%
Milk	106%	100%
Beef	81%	124%
Sheep	101%	80%
Pig	61%	114%
Poultry	90%	99%
Eggs	86%	107%

Note: The color indicates the range in which the domestic coverage stands, from dark orange (high deficit) to green (balance) and blue (potential for export).

Despite the upsurge of food production for these commodities, the UK remains a net importer of fruit and vegetables. This means that the increase in domestic production is not sufficient to meet the dietary requirements for these products, which increases significantly as a result of the healthier TYFA diet.

Overall, the food balance based on our model's assumptions creates a balance between the production of crops, most notably cereals, and animal products. Our assumptions result in a safe operating zone and a near balance between domestic supply and demand—although this balanced outcome was not prescribed, nor is it an end in and of itself (for example, it would make no sense for a country such as Belgium with a high population density). In the UK, however, it makes sense to balance livestock and crop production. Another option could have been for the UK to specialise in (grass-fed) animal production, leading to more exports in this sector, while reducing grain production and causing more imports. This option, however, produces two intertwined and undesirable consequences:

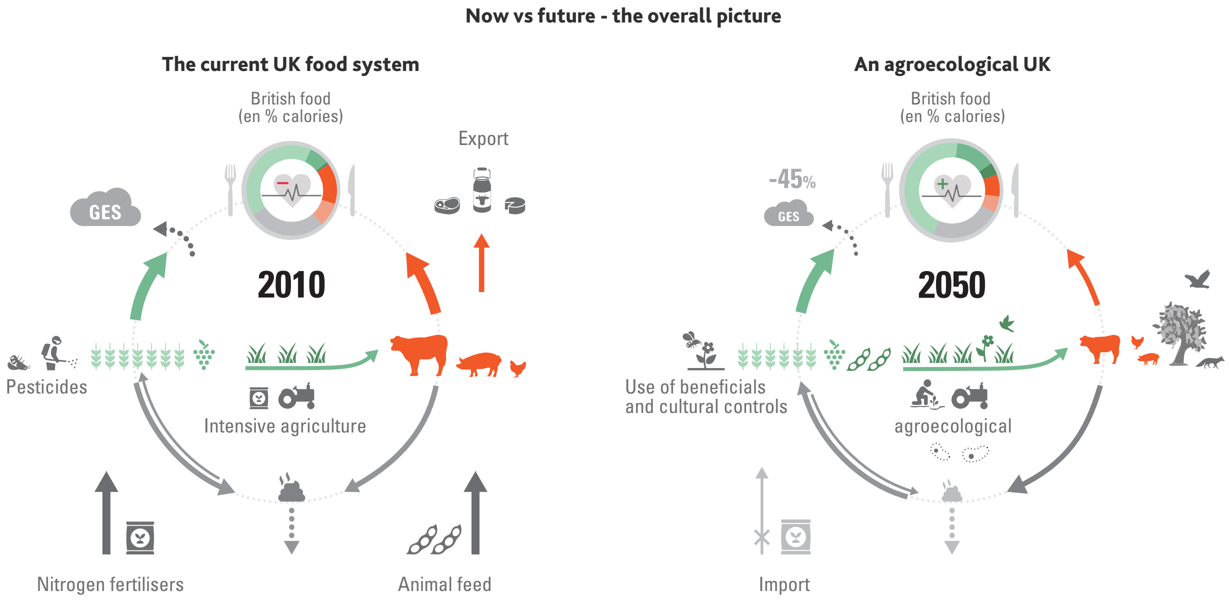
— Specialisation in livestock in the UK would lead to other places being without the manure and thus fertiliser needed for crops;
— Relegating cereal production to another place in the world creates offshore impacts, which are difficult to trace and can be avoided through mixed farming.

Apart from sugar, the TYFA model for the UK shows that agroecological farming improves the overall UK food balance and puts to rest questions of extensification's offshore impacts. This outcome results from the radical changes in diets and illustrates the significant effect of reducing animal product consumption. The phasing-out of industrial livestock, which does not meet societal demands for better animal welfare and environmental and human health, is a plausible narrative that underlies the agroecological transition. Such a scenario is also consistent with a larger reduction in pig/poultry production than in ruminant production.

The food balance analysis undertaken here considers only the products that can currently be produced in the UK, thus excluding those imported from tropical countries (coffee, cocoa, tea, etc.) and/or those that cannot be produced domestically with the same quality. For example, domestic demand and supply for fruit is balanced overall, but this does not mean that a good UK apple can't be traded for a good Italian orange. Finally, the discussion about the sustainability of coffee imports, for example, goes beyond the scope of this report and does not alter our conclusions in their broad terms.

4.5. The TYFA UK scenario at a glance

FIGURE 18. The TYFA UK scenario at a glance



Source: authors

5. ENVISIONING AGROECOLOGY IN THE UK—SECURING THE FUTURE

5.1. Agroecology is a credible, desirable option for the UK as long as diets change

This study, which used an original model to determine the effects of agroecology, adds new evidence to the current debate about the feasibility of agroecology/organic farming in a densely populated country like the UK. It shows that there is considerable room for maneuver given a significant reduction in the consumption of animal products. This precondition is coherent with previous studies in the field of global sustainable food systems, highlighting the need to halve the share of animal protein in Western diets—including the UK's—to remain within planetary boundaries (Westhoek *et al.*, 2014 ; Springmann *et al.*, 2018 ; Willett *et al.*, 2019 ; Mora *et al.*, 2020). The dietary changes required in TYFA are very similar to those in other scenarios addressing climate change. In this respect, TYFA's assumptions are equally disruptive as, for example, the assumptions of the CCC report; for reasons mentioned above, our assumptions are less ambitious regarding waste reduction.

Compared to other analyses, however, our approach leaves a greater share of ruminant products in the remaining animal protein supply because of their central role in the functioning of agroecological ecosystems. Without them, non-edible feed would remain unused, organic fertilisers from semi-natural vegetation would not be transferred to crops, and the ability to maintain or restore a high level of landscape heterogeneity (with significant positive impacts on biodiversity) thanks to permanent grassland will be lost.

Bearing in mind this diet change, the model providing evidence for this report shows that the generalisation of agroecology in the UK leads to an improved food balance with significant additional benefits not provided by input-demanding farming methods. Agroecology delivers benefits for natural resources management, soil health, biodiversity, landscapes and for human health. Phasing out synthetic pesticides and synthetic nitrogen is not a minor assumption: it plays a key role in the ability of the scenario to address environmental and health challenges.

Climate change mitigation is another important benefit of agroecology according to the model: despite maintaining a higher number of methane-emitting herbivores in extensive ranges, agroecology in the UK reduces overall emissions. This result is explained by the significant decrease in synthetic nitrogen use, specifically in its mineral form. Ruminants emit methane, but through this process they transform nitrogen in semi-natural vegetation into valuable fertiliser. Combined with the use of this climate-efficient source of nitrogen, the reduction of livestock numbers causes the good climate change mitigation performance of TYFA UK.

5.2. Why agroecology is irrefutably modern

Agroecological systems as modelled in TYFA take inspiration from the pre-chemical era, when farmers farmed with few or no inputs. A closer look at our assumptions illuminates how innovative TYFA's approach actually is. The modern, innovative nature of TYFA can be illustrated by yields. We used Ponisio et al's work (2015) to calibrate our yield assumptions, adjusting them according to climate change projections (with plausible average positive impacts in the case of UK). This results in an average yield of 5.7 t/ha for cereals in TYFA UK 2050 as compared to around 7.8 t/ha today. This yield decline appears minimal when juxtaposed to yields of the 1950s at only 2.5 t/ha. The same magnitude of change takes place in the dairy sector where we assume milk yields of 5.2 t milk/cow/year in contrast with current yields of 7.9 t milk/cow/year today. In other words, organic yields have increased and will continue to do so because of new knowledge and technology. Our better understanding of the soil microbiome and of methods of biological control in a wide landscape ecology perspective facilitates scientific revolutions able to support increased agroecological production while rejecting the of use of synthetic inputs. Creating an agricultural system that is free of synthetic pesticides requires looking towards the future to address the challenges that our modern societies face. In this vein, research on nitrogen fixation and the improvement of legumes of all kinds is paramount to advancing agroecology. Nitrogen fixation is after all a determinant of the overall productivity of synthetic nitrogen-free agro-ecosystems.

TYFA UK's approach to agroecology does not ignore production constraints, nor does it propose a fanciful ecological farming model that views yields and production as secondary issues. The outcomes of TYFA hold up because the resulting yields are reasonably high. Without such high yields, we would need to increase overall agricultural land use, although with a significant share for ecological features and afforestation; the latter two elements are additional modern component of TYFA inspired by the climate change agenda.

5.3. Revisiting the agroecology vs. intensification discussion: the risk assessment dimension

This document opens with an explanation of why agroecology has more biodiversity and health effects than does the pesticide- and fertiliser-dependent sustainable intensification. The TYFA UK model has shown that the criticism of agroecology's insufficient productivity levels and resulting excessive demand in land are unfounded, as long as diet changes occur.

The productivity issue deserves more attention. While agricultural systems under the TYFA UK scenario are less productive than current intensive agricultural methods and potential future intensification, productivity is still one of TYFA's central pillars. Our model suggests that agroecology is a credible option but does not fully disprove intensification's credibility. For example, intensification may have fewer socioeconomic costs than agroecology. Indeed, high level of production supports food and biomass industries.

The production potential of intensification means that it should not be ignored, as future innovations in genetics, machinery and precision farming may be both productive and efficient. This intensive model, however, is (i) not without risks that have already been highlighted by significant research and (ii) if intensification looks like the continuation and improvement of the current high input farming model, the fact that it delivers higher yields in the near future is a questionable assumption that needs to be examined if we consider current yield trends in Erreur : source de la référence non trouvée (as also discussed in the literature more globaly see Ray *et al.*, 2012 ; Wiesmeier *et al.*, 2015). Wheat yields are no longer increasing, and they are showing more and more variability. This trend has proved difficult to account for and is not correlated with a failure to use new technology or improved inputs (Brisson *et al.*, 2010). Agronomic limits due to landscape simplifications (Dainese *et al.*, 2019) and soil dysfunction (Wiesmeier *et al.*, 2015) combined with extreme climate events (Moore & Lobell, 2015) thus seem to play a prominent role.

If we consider that current yields are at risk of stagnating or decreasing, sustainable intensification must be considered in a different light. Its promised advantage over agroecology is more efficient farming, thereby generating economies of scale and delivering for agri-food and biomass industries. But if hoped-for yields and production levels are not reached, the whole set of socio-economic advantages is put at risk: efficiency may require input-insurance to limit variability, economies of scale might need public support to prevent lower returns than expected and cover costly investments; in the end, the viability and profitability of the model may not produce the desired results.

In comparison, the agroecological scenario is based on a decrease in production and does not try to maximise the production efficiency for capital intensive economic models. On the contrary, space is made for increased biodiversity, improved landscapes, and alternative land use. This approach is likely to sustain yields in the short and medium term. It appears conceptually more robust, although it is not exempt from risks on the production side. Compared to SI, it can be considered less risky in the longer term, even if the yields and production volumes are lower. We can conclude from this report that the development of agroecology and alternative socio-economic models at a large scale would increase the sustainability of the UK food system while decreasing its offshore footprint.

6. ANNEX

6.1. Coefficients used to estimate the carbon sequestration potential for various land use and land use changes

	tCO_2/ha/ year	Source
Forestry		
Existing forest before 2010 Post 2010 forest	90% of 2010 in 2050 4.0	https://www.carbon-forest.com/ and IDDRI treatment from (Thomson *et al.*, 2018)
Grasslands	0.55	(Conant *et al.*, 2017)
Fallow land and green infrastructures	0.55	(Conant *et al.*, 2017)
Carbon storage from conventional farming to organic farming	1.65	(Gattinger *et al.*, 2012)
Agroforestry	1.6	Same carbon sequestration rate as "post-2010 forest" multiplied by a factor that accounts for the different plant density between agroforestry and forest systems
Grassland to cropland conversion	-7.6	(Poeplau *et al.*, 2011)

6.2. Description of ClimAgri®

The ClimAgri® calculator was initially developed in 2009 by Solagro and Bio Intelligence Service for the French Environment and Energy Management Agency (Agence de l'Environnement et de la Maîtrise de l'Energie, or ADEME). The calculator aims at estimating direct and indirect greenhouse gases from agriculture and forestry at the national or departmental level in France. The calculator, which is based on Riedacker and Migliore's work on integrated environmental assessments (2006, 2008 and 2011), also estimates emissions of atmospheric pollutants, amounts of carbon stored in agricultural and forest soils, as well as forest biomass, renewable energy production and agricultural and forestry production. For the purpose of this exercise, the calculator was used solely for estimating *direct* and *indirect GHG emissions* from the *agricultural sector*, as well as carbon sequestration potential.

The categories of direct greenhouse gas emissions calculated by ClimAgri® are close to the ones reported to the UNFCCC. They include:

— Emissions linked to the consumption of energy: namely, CO_2 emissions linked to the combustion of fuel, gas, wood and coal for the purpose of running agricultural equipment, which include off-road vehicles and other agricultural machinery (UNFCCC 1.A.4.c.ii category) as well as stationary equipment (irrigation pumps, greenhouses, drying equipment and livestock buildings) (UNFCCC 1.A.4.c.i category);
— Emissions linked to the management of agricultural soils: namely, direct and indirect (linked to leaching and runoff) N_2O emissions linked to organic and inorganic fertilizers spread to crops, urine and dung deposited by grazing animals and crop residues (UNFCCC 3.D category); it also includes CO_2 emissions linked to liming (UNFCCC 3.G category);
— Emissions linked to enteric fermentation: namely, CH_4 emissions linked to enteric fermentation (UNFCCC 3.A category);
— Emissions linked to manure management (UNFCCC 3.B category): namely, CH_4 emissions linked to manure deposited within livestock buildings and pastures; and N_2O emissions linked to the storage of liquid and solid manure.

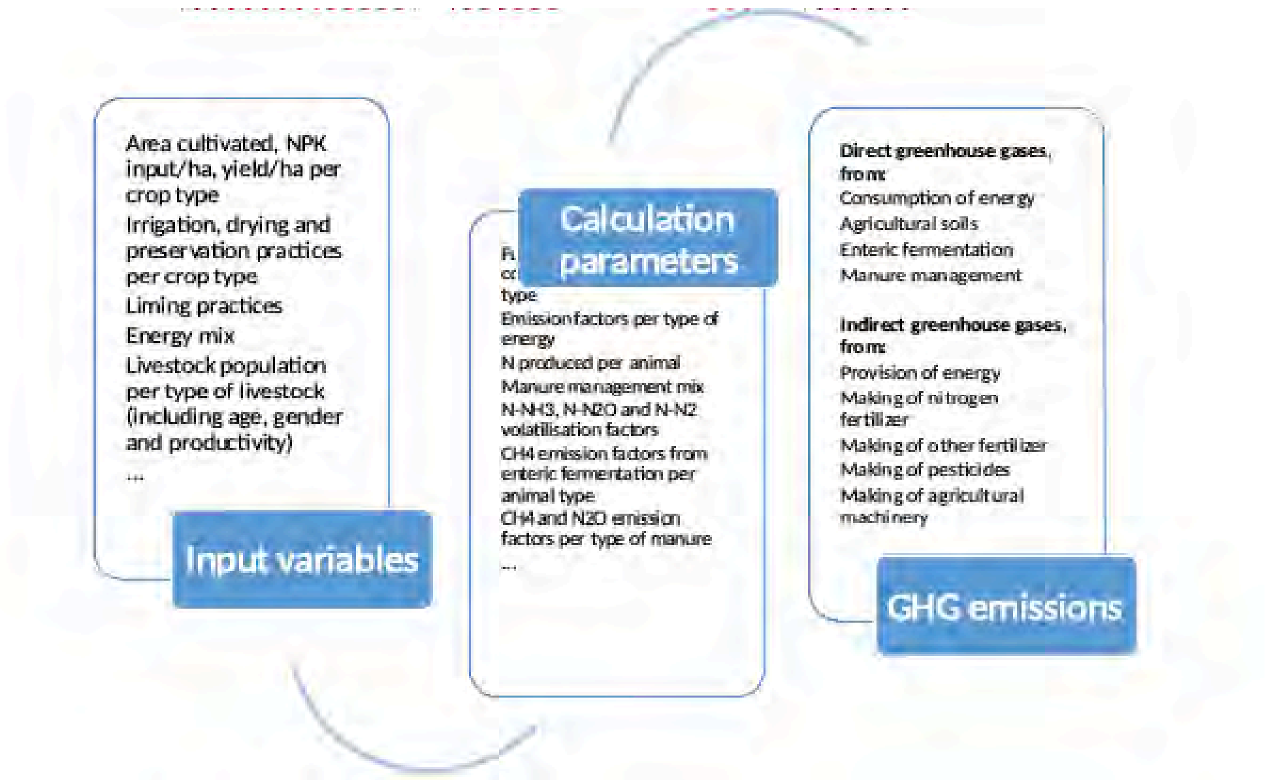
In addition, ClimAgri® also evaluates indirect greenhouse gas emissions, which include:

— Emissions linked to the provision of energy;
— Emissions linked to the making of nitrogen fertilizer;
— Emissions linked to the making of other fertilizer;
— Emissions linked to the making of pesticides;
— Emissions linked to the making of agricultural machinery.

In order to evaluate GHG emissions, the calculator takes into account a certain number of input variables linked to land use, livestock population and crop and livestock practices as well as parameters enabling to calculate GHG from crop and livestock (Figure 1).

Although ClimAgri® is mostly based on calculation methods similar to the ones used by countries when reporting agricultural emissions to the UNFCCC, differences remain, that are linked to the complexity of calculation, to the number of parameters used and to hypotheses that are made to tackle uncertainties when they exist. Coming up with a *reduction* potential by using ClimAgri® therefore implies not only to run the calculator for 2050, but also to run a first calculation to evaluate GHG emissions for a baseline—hereby set at 2010, in order to facilitate data collection. Running a first calculation to evaluate GHG emissions in 2010 also enabled to check the coherence of a certain number of hypotheses that were made to calibrate the calculator, which was originally designed to evaluate emissions from the agricultural sector in France, to the purpose of evaluating GHG emissions from the agricultural sector at the UK level.

Figure 19: Simplified operational scheme of the ClimAgri® calculator



6.3. Details of land use change broken down by TYFA$_{regio}$ areas

	cereals	oilseed	root crops & vegetables	pulses & legumes	permanent crops	fodder crops	permanent grassland	fallow land & green infra.	potential other use in 2050
aENO UK 2010	1 540	416	264	129	13	223	1 142	188	68
aENO UK 2050	748	170	309	425	61	232	1 870	192	0
Variation (%)	-51%	-59%	17%	230%	364%	4%	64%	2%	-100%
hATL UK 2010	755	155	60	47	11	690	3 847	88	70
hATL UK 2050	1 259	249	164	680	143	120	2 728	262	112
Variation (%)	67%	61%	176%	1359%	1156%	-83%	-29%	199%	59%
hECO UK 2010	658	80	63	13	0	468	5 370	53	39
hECO UK 2050	816	143	144	316	1	49	4 000	149	1 110
Variation (%)	24%	79%	128%	2349%	302%	-90%	-26%	183%	2734%
UK 2010	2 953	651	387	188	25	1 381	10 359	329	178
UK 2050 TYFA	2 823	562	617	1 421	204	401	8 598	603	1 222
Variation (%)	-4%	-14%	60%	654%	730%	-71%	-17%	83%	588%

6.4. Change in livestock units between 2010 and TYFA UK 2050

	1000 LU dairy	1000 LU cattle	1000 LU sheep and goat	1000 LU pigs	1000 LU poultry
UK 2010	1 901	5 277	4 972	1 174	1 753
UK TYFA 2050	1 644	4 072	3 295	820	1 166
Variation	-14%	-23%	-34%	-30%	-34%

6.5. Emissions reduction of TYFA UK compared to 2010 (Mt CO2eq/year) for the two scenarios computed

	Ref - 2010	TYFA UK - arable	TYFA UK - arable no afforestation
Energy consumption	7,8	7,7	7,9
Agricultural soils	16,0	7,5	7,9
Enteric fermentation	31,5	22,5	26,2
Manure management	9,3	2,6	2,9
Provision of energy	5,7	5,6	5,7
Nitrogen fabrication	5,2	0,0	0,0
Other input fabrication	0,1	0,1	0,2
Agricultural machinery	1,3	1,4	1,5

6.6. Carbon sequestration potential in TYFA-UK compared to the baseline

	Ref - 2010	TYFA UK - arable	TYFA UK - arable no afforestation
Forestry	-13,70	-17,41	-12,60
Grasslands	-5,41	-4,99	-5,95
Fallow land and green infrastructures	-0,16	-0,48	-0,48
Agroforestry		-0,46	-0,51
Land conversion (grassland vs cropland)		3,38	3,38
Organic farming carbon storage		-9,95	-9,95

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