Environment and Rural Affairs Monitoring & Modelling Programme (ERAMMP)

ERAMMP Report-72: Application of the FABLE Calculator to model pathways to sustainable land use in Wales

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Abbreviations Used in this Report

AFOLU	Agriculture, Forestry & Other Land Use
AONB	Area of Outstanding Natural Beauty
CCC	UK Climate Change Committee
CCI	Climate Change Initiative
CIAT	International Center for Tropical Agriculture
ERAMMP	Environment and Rural Affairs Monitoring & Modelling Programme
FABLE	Food, Agriculture, Biodiversity, Land use and Energy
FAOSTAT	A comprehensive digital platform of food and agriculture statistics by the Food and Agriculture Organization of the United Nations
FOLU	Food and Land Use Coalition
FTA	Free Trade Agreement
GHG	Greenhouse Gas
IIASA	International Institute for Applied Systems Analysis
LCM	Land Cover Map
LULUCF	Land Use, Land-Use Change & Forestry
PIK	Potsdam Institute for Climate Impact Research
SDSM	Sustainable Development Solutions Network
UKCEH	UK Centre for Ecology & Hydrology

Abbreviations and some of the technical terms used in this report are expanded on in the programme glossaries: https://erammp.wales/en/glossary (English) and https://erammp.cymru/geirfa (Welsh)

Contents

The full set of outputs from the FABLE-Wales Calculator for indicators related to land use change, GHG emissions, biodiversity and diets are provided as slides published separately as Technical Annex ERAMMP Report-72TA1[1].

[1] www.erammp.wales/72TA1

1 Summary

This report summarises the application of the FABLE (Food, Agriculture, Biodiversity, Land use and Energy) Calculator to model sustainable food and land use systems in Wales.

FABLE is an international model designed to simulate national level food and land use systems, which has previously been applied to the UK. For this study, we worked in partnership with Welsh Government to develop a version of the calculator specifically for Wales. We developed four different scenarios representing: (i) continuation of the current situation (Status Quo), (ii) slight improvements in line with current policy (Improvements on Current Trends), and two potential pathways to sustainability (iii) Land Sparing, based on 'sustainable intensification and release of land for nature and carbon sequestration' in line with the Climate Change Committee scenarios, and (iv) Land Sharing, using land management techniques which deliver biodiversity restoration, carbon sequestration and production simultaneously on the same land, which was more tailored to the specific land use context (large areas of rough upland grazing) and aligned with current Welsh legislation..

Both the Land Sparing and Land Sharing scenarios included an assumption of dietary change towards the Eatwell healthy diet (a more plant-based diet), as well as reductions in food waste, improvements in agricultural productivity and increased tree planting. However, while the Land Sparing scenario assumed that production would be intensified, with a shift away from extensive grazing towards greater use of improved (fertilised, re-sown) pasture, the Land Sharing scenario assumed a shift to more low-intensity extensive grazing on species-rich semi-natural grassland.

We tested the scenarios to identify pathways to sustainable land use and food systems that could deliver across multiple policy goals for greenhouse gas reduction, biodiversity conservation and healthy diets.

The results indicate that maintaining the status quo or implementing only slight improvements to current policy will not be sufficient to enable Wales to reach net-zero GHG emissions (which requires the land use sector to be a carbon sink). However, both the Land Sparing and Land Sharing scenarios were predicted to enable the land use sector to become a net carbon sink, helping to offset emissions in other sectors.

Both of these scenarios freed up land for biodiversity conservation; this was mainly semi-natural species-rich extensive grassland in the Land Sharing scenario and mainly 'Other natural land' (heath and bog) in the Land Sparing scenario. However, under the policy assumption that only 20% of new forest would be managed for biodiversity, none of the scenarios achieved the goal of creating an extra half million hectares of land for biodiversity conservation.

The analysis showed that in order to achieve this goal it would be necessary to stipulate that 86% of all new forest should be planned and managed to deliver benefits for biodiversity, i.e. it should use a diverse mix of native species (and/or natural regeneration) and be sensitively managed to maintain good ground cover and a shrub understorey layer. Planting with a mix of native broadleaved species is also estimated to deliver more carbon sequestration over the first 30 years from 2020 to 2050 compared to a regularly thinned conifer plantation.

2 Background and Context

The Welsh Government is at a significant juncture in terms of determining future policy objectives and delivery mechanisms. Having left the EU, the four countries of the UK need to chart pathways to deliver their own domestic commitments and also contribute to achieving the UK's national and international commitments.

Welsh Ministers have made commitments in law to reach net zero carbon by 2050[2]. They have also made international commitments to protect 30% of the land for nature by 2030, and domestic commitments to reverse the decline in biodiversity[3]. In terms of land use, this is described in the policy as 'creating ecologically resilient networks'.

This report summarises the first phase of a wider piece of work being undertaken by the Welsh Government. It describes how the FABLE Calculator was used to explore alternative pathways for meeting national and international commitments to tackle climate change and reverse biodiversity decline. The study explores an alternative to the high ambition pathway developed by the UK Climate Change Committee (CCC),[4] which took a land sparing approach that offered a route to net zero, but was not consistent with existing legislation in Wales. Specifically, although the CCC report states that biodiversity outcomes and ambitions need to be considered alongside climate outcomes, there are no measures designed to achieve this in their pathway. The Welsh Government therefore wanted to explore whether both of these outcomes could be delivered whilst also maintaining a vibrant agriculture sector and not offshoring emissions by simply increasing food imports.

This first phase will guide the second phase of the modelling, which will use the ERAMMP Integrated Modelling Platform[5] to explore in more detail the policy responses to the findings of Phase 1. This will include spatial analysis of the environmental, economic and social impacts of policy implementation.

2.1 FABLE Calculator

The FABLE Calculator, which forms the basis of the methodology for this work, is an open source Excel-based tool used to study the potential evolution of food and land use systems over the period 2000-2050[6]. The calculator can be used to test the impact of different policy scenarios, as well as changes in the drivers of these systems.

The FABLE calculator is driven by the demand for 76 agricultural (raw and processed) products from crop and livestock sectors, which is determined by assumptions concerning current and future diets, and population levels.

For each five-year time step over 2000-2050, the model computes the per capita demand for consumption of different products, the total demand considering food waste, imports and exports, the livestock numbers needed to meet the demand for animal produce, and the associated demand for cropland and pasture, taking into account demand for animal feed crops. It then works out the final land use change, taking account of competing demands for land for urban expansion, tree planting and protected areas. If there is insufficient land to

[2] https://www.legislation.gov.uk/wsi/2021/333/introduction/made
[3] The Nature Recovery Plan for Wales - Part 1: Our Strategy for Nature (gov.wales)
[4] CCC (2018). *Land use: Reducing emissions and preparing for climate change*. Committee on Climate Change, London, UK. https://www.theccc.org.uk/publication/land-use-reducing-emissions-and-preparing-for-climate-change/
[5] https://erammp.wales/en/imp
[6] FABLE Calculator 2020 update (iiasa.ac.at)

meet demand, crop and pasture area is scaled down to the 'feasible' area, which may result in targets for food consumption not being met.

The final 'feasible' land use change is then used to calculate GHG emissions from agriculture and land use change, as well as food security and biodiversity indicators. The calculator can be used to determine whether future policy scenarios will achieve targets for GHG reduction and biodiversity conservation while also meeting demand for food.

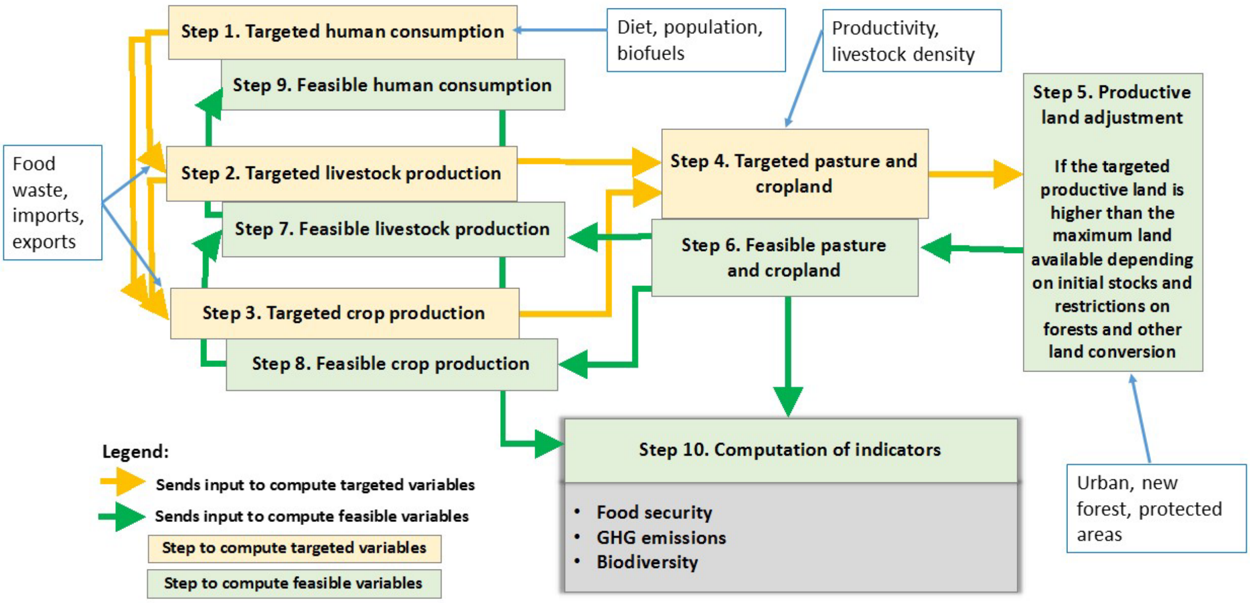

Figure 2.1: FABLE Calculator steps.

2.2 Adapting the FABLE calculator for Wales

The FABLE calculator is designed to work at the national level, supported by data from global datasets such as the FAOSTAT database[7]. We have previously applied the model for the UK land use system[8]. For this project we adapted and parameterised the model specifically for Wales.

2.2.1 Land use

For current land use, we used the UK Centre for Ecology & Hydrology (UKCEH) Land Cover Map (LCM) for Wales, which is also used for other modelling within the Welsh Government. This is more accurate than the dataset that was used for the UK version of the FABLE model (the European Space Agency Climate Change Initiative (CCI) satellite dataset), but the data is inconsistent across some time periods due to different methods and habitat classifications being used in different years.

Furthermore, the area of arable land in LCM was found to be greater than specified in the Wales Agricultural Statistics, which may be due to the inclusion of temporary grass in LCM.

[7] FABLE Calculator 2020 update (iiasa.ac.at)
[8] https://www.foodandlandusecoalition.org/wp-content/uploads/2021/01/UK_high_final.pdf

To enable the LCM data to be used within the FABLE calculator we pre-processed the data as follows:

- Scaled data to match the total area of Wales as defined in other modelling work for the Welsh Government (2,077,000 ha).
- Interpolated figures from LCM 2000, 2007 and 2015 to obtain them for required years in FABLE (2000, 2005, 2010, 2015).

2.2.2 Downscaling UK commodity balance data for Wales

The UK FABLE calculator uses FAOSTAT data on consumption, production, imports and exports of each product for the UK. These parameters were downscaled for Wales as follows:

- Consumption of food – scaled by ratio between the populations of Wales and the UK.
- Consumption of animal feed – scaled by ratio of animal numbers requiring feed (pigs, poultry, dairy cattle for part of the year).
- Production of crops, and consumption of seed – scaled by cropland area ratio.
- Production of animal products – scaled by animal numbers.
- Production of wood – scaled by forest area.
- Production of fish – scaled by data on landings in Welsh ports by UK vessels.

Using these figures, the consumption was then subtracted from the production to obtain imports or exports to and from Wales.

The exports (in tonnes) and the share of consumption that is imported (%) were kept constant after 2010, which is the default option in FABLE. However, there is also an option within FABLE to specifically model changing exports or imports for certain products, e.g. to reflect a decrease in global and/or UK demand for meat. This could be explored in future work.

2.2.3 Grassland

An important aspect of land use in Wales is the difference between intensive and extensive grassland, as there are large areas of rough grassland in Wales that are grazed extensively (i.e. at low stocking densities and with no inputs of fertilisers). However, the standard version of the FABLE model treats all grassland as a single land use type. We therefore adapted the calculator to add a new 'Extensive grassland' category, to allow for a representation of different grazing strategies within the scenarios.

We assumed current stocking densities of 2.2 FABLE livestock units per hectare on intensive grassland (equivalent to 1.4 Welsh livestock units) and 0.92 on extensive grassland(equivalent to 0.6 Welsh livestock units).[9] These were derived by fitting to the historic livestock numbers and land areas, with 25% of the herd on extensive grassland in

[9] Livestock units used in the FABLE model and quoted here are 'Tropical Livestock Units' which are different to the units used in the UK.For example, all cattle are assumed to have a TLU of 0.9 in FABLE, whereas the UK approach assigns different LUs for different types and ages of cattle, with the herd in Wales having an average LU of 0.6. Similarly all sheep are assumed to have a TLU of 0.1 in FABLE whereas the herd in Wales has an average LU of 0.06. This difference is taken into account when calibrating the stocking densities and feed requirements in the model.

the year 2000. In the Land Sparing scenario, all grazing shifts to intensive grassland by 2050, while in the Land Sharing scenario the proportion on extensive grassland increases from 25% to 50%.

2.2.4 Forest

The standard version of the FABLE model treats all forest the same, but for the Welsh scenarios we adapted the model to divide forests into semi-natural and plantation. We added user-defined parameters to specify what proportion of new and existing forest is semi-natural, and therefore supports biodiversity (for new forest this would include forest that has naturally regenerated or is created by planting a diverse mix of native species), as opposed to low diversity plantations of non-native species.

These different types of forest are assumed to have different carbon stocks and sequestration rates, as a proportion of the carbon stock within a plantation forest will be lost when it is felled and converted to short-lived products such as paper or furniture. Currently about 84% of harvested wood in the UK goes to short-lived products (panels, fencing, pallets and packaging) or wood fuel,[10] but there are ambitions to increase the proportion used for construction and other long-lived products in future.

We follow the standard FABLE approach to estimate carbon sequestration, which assumes linear sequestration rates estimated from the difference in land cover carbon stock (new land cover minus previous land covert) divided by years taken for each type of habitat to regenerate, using UK data (Table 2.1). Semi-natural forest carbon stock is calculated from the FAO Forest Carbon dataset[11] including carbon in above and below ground biomass, dead wood, litter and soil, and is consistent with recent Natural England estimates.[12] Carbon stock for plantations and regeneration rates for forest are based on the Woodland Carbon Code, taking into account typical rotation lengths (60 years) and loss of carbon stock due to biomass removal during thinning and harvesting.[13] It is assumed that new woodland is not planted on peaty soils, as that would create additional emissions not modelled here.

[10] Forest Research (2021) UK Forestry Statistics 2021. https://www.forestresearch.gov.uk/tools-and-resources/statistics/forestry-statistics/forestry-statistics-2021/. Table 2.5 indicates that 40% of UK produced softwood is used for short-lived panels, fencing, pulp or fuel and 60% is sent to sawmills, of which Table 2.17a indicates that 27% is used for construction (16% of the total) and the rest for short lived products (fencing, pallets and packaging). Table 2.6 indicates that 91% of UK produced hardwood is used for fuel.
[11] FAO (2021) Forest Carbon dataset, https://fra-data.fao.org/GBR/fra2020/carbonStock/
[12] Gregg, R., Elias, J.L., Alonso, I., Crosher, I.E., Muto, P. and Morecroft, M. D. (2021) Carbon storage and sequestration by habitat: a review of the evidence (second edition) Natural England Research Report NERR094. Natural England, York.
[13] WCC (2021) Woodland Carbon Code (WCC) Carbon Calculation Spreadsheet V2.4. Sequestration rates for typical broadleaved species in unmanaged forests tend to decline from an early peak to reach a low, steady value between 100 and 120 years after planting. This results in an estimated sequestration rate of around 3tC/ha/y, consistent with value sin Gregg et al (2021) (see footnote 11).

Table 2.1. Assumptions regarding carbon stocks and regeneration rates

Land use	% of forest carbon stock	Years to regenerate	Tonnes C/ha	Tonnes CO_2/ha
Semi-natural forest	100%	110	329	1206
Plantation	50%	60	164	603
Cropland	15%	NA	49	181
Pasture	20%	20	66	241
Other natural land	60%	125	197	724
Urban	0%	NA	0	0

2.2.5 Peatland

The standard FABLE model was also adapted to include a very basic model of peatland restoration.

All peatland is divided into 'intact' and 'degraded', which have different emission factors. There is no separate treatment of peatland used for forest, grazing, etc. Both the Land Sparing and Land Sharing scenarios assume that all peatland in Wales is fully restored by 2050.

3 Scenarios

After internal discussions within the Welsh Government with other departments, and liaising with the FABLE team on the requirements for the FABLE Calculator, four pathways towards sustainable land use and food systems for Wales were developed (Table 3.1). Scenario 1 and Scenario 2 sit within the current system, whereas scenarios 3 and 4 represent a system change.

Table 3.1: Overview of the four scenarios for Wales

Scenario	Overview
Scenario 1 – Status Quo	Continuing with no changes to current policies and no improvement in agricultural efficiency.
Scenario 2 – Improvement on current trends	Continued improvements in line with current trajectories, reflecting current trends in policy, and some agricultural efficiency gains.
Scenario 3 – Land Sparing	Using sustainable intensification techniques, the land sparing pathway sees increases in production on the best land to release land from agriculture for biodiversity restoration and carbon sequestration, and ambitious agricultural efficiency gains.
Scenario 4 – Land Sharing	Using land management techniques, the land sharing pathway delivers biodiversity restoration, carbon sequestration and production simultaneously on the same land, and significant agricultural efficiency gains (though less than the Land Sparing pathway).

The following section describes the scenarios in greater detail, and the full list of the underlying assumptions and justifications for each pathway is given in Annex-1.

3.1 Common assumptions across the four scenarios

3.1.1 Population

The Welsh population is expected to increase less than the UK population. The ONS forecasts the Welsh population[14] to grow from 3.153 million in 2019 to 3.258 million by 2050. This figure is used to calculate the demand for land for urbanisation.

3.1.2 Urbanisation

The National planning strategy, the Welsh Government's 20-year spatial plan, Future Wales[15] identifies that Wales needs 110,000 new homes by 2039. These breakdown as 16,200 in North Wales, 1,800 in Mid Wales, 25,600 in South West Wales and 66,400 in South East Wales.

The actual area of increased urbanisation needed to include the additional infrastructure associated with population growth has been estimated in previous LULUCF scenarios. For Wales the estimate is a 5% increase in urban area, from 105,773ha in 2015 to 110,000ha in 2050.

[14] https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationprojections/datasets/tablea15principalprojectionwalessummary
[15] https://gov.wales/sites/default/files/publications/2021-02/future-wales-the-national-plan-2040.pdf

Included in the increased urbanisation area is also a footprint for the current renewable ambitions in Wales associated with solar and wind delveopments. At this time, due to the physical geographical constraints of Wales there are no policy plans to increase the amount of energy derived from biofuels, contrary to the recommendations of the CCC.

3.1.3 Imports and Exports

The outcomes of leaving the EU still remain uncertain. With an EU deal, the level of uncertainty is reduced to some extent, however impacts of future FTA's remain opaque. Therefore, in the absence of better information, we assume that the share of total consumption that is imported and the quantity of total production exported remain the same up to 2050. This aspect could be explored in the future.

3.1.4 Woodland Planting Standards

It is assumed that any woodland planting would be subject to Glastir Woodland Creation constraints and sensitivities[16]. Furthermore, all planting would be compliant with UK Forestry Standards, which include:

- A minimum of 10% open ground or ground managed for the conservation and enhancement of biodiversity as a primary objective must be incorporated;
- At least 10% of the forestry unit must be "other species" to the main species planted;
- At least 5% of native broadleaved trees and shrubs must be planted;
- A minimum of 15% of the forest management unit must be managed with conservation and the enhancement of biodiversity as a major objective.

3.2 Scenario 1 – Status Quo

The Status Quo scenario corresponds to the lower boundary of feasible action, continuing with no changes to current policies. There are no constraints on agricultural expansion except for on fully protected areas, which do not include National Parks, AONBs and Heritage Coasts. There are no changes to post harvest losses or food waste reduction, and no changes in current diet. Livestock and crop productivity remain the same, peatland restoration remains in line with the current Peatland Action Plan (600 ha/year 2020-25), and there are small areas of woodland creation (300 ha/yr) in line with current rates.

3.3 Scenario 2 – Improvement on Current Trends

The Improvements on Current Trends scenario represents slight improvements to the current system, in line with current trajectories, reflecting current trends in policy. There is no agricultural expansion in protected areas, but this now includes National Parks, AONBs and Heritage Coasts. Peatland restoration is in line with the extended Peatland Action Plan, increasing slightly from the status quo (to 800 ha/year 2020-35). Crop productivity remains the same, as well as livestock productivity for beef and poultry, however dairy yield follows incremental improvements in productivity and slight increases in stocking density. The scenario includes existing trends in food waste reduction, but there is no change for post-harvest losses. There are improved afforestation targets in this scenario (of 2,000 ha/yr,

[16] https://gov.wales/sites/default/files/publications/2019-03/glastir-woodland-creation-window-7-april-2019-rules-booklet_0.pdf

rising to 4,000 ha/yr by 2030), planting 20,000 ha by 2030 and a further 80,000 ha by 2050. We assume no change in diet.

3.4 Scenario 3 – Land Sparing

The Land Sparing scenario broadly represents the UK land use strategy that was proposed by the CCC in its 2018 Land Use and Climate Change report[17], and referenced in the more recent advice report for Wales[18]. It focuses on intensification of agricultural production on the most productive land, together with dietary change and reductions in food waste, allowing land to be released for planting trees to sequester carbon.

As mentioned above, one key difference is that Welsh Government advised that there are physical constraints in biofuel production in Wales, so we did not incorporate the CCC's high biofuel production targets. Agricultural expansion is not allowed in protected areas, including National Parks, AONBs and Heritage Coasts. The scenario assumes increases in productivity for crops (+65%) and livestock, with increases for dairy achieved through improved breeding and optimising cow diet, and efficiency increases in beef production and lambing rates due to technology improvements.

There is a shift towards 100% of cattle and sheep on intensive grassland, and none on extensive grassland, with stocking densities doubling. Afforestation targets increase in this scenario, with 43,000 ha planted by 2030, rising to 180,000 ha by 2050, and all peatland (90,000 ha) is restored to a natural state by 2030. There are improved targets for food waste: 50% reduction in avoidable food waste by 2025, 60% reduction by 2030, zero avoidable food waste by 2050, and post-harvest losses are reduced by 50% by 2050.

The Welsh population is assumed to move to a healthier and more plant-based diet, based on the 'Eatwell' diet,[19] by 2050.

3.5 Scenario 4 – Land Sharing

Some of the assumptions of the Land Sparing scenario, such as the productivity improvements, could be seen as over-optimistic or unfeasible, so a fourth scenario was developed as a comparison, based on the principles of the Sustainable Management of Natural Resources policy and the Environment (Wales) Act that multiple objectives can be delivered on the same land. Using land management techniques, the land sharing pathway delivers biodiversity restoration, carbon sequestration and production simultaneously on the same land.

This scenario is characterised by no agricultural expansion on any existing semi-natural habitats (this allows the use of semi-natural grassland for extensive grazing), with aspirations to create 500,000ha of additional semi-natural habitat on agricultural land to create ecologically resilient networks .

Crop productivity increases by 39% in this scenario, with livestock productivity in line with Scenario 2 (Improvement on Current Trends) except for an additional increase in lamb

[17] https://www.theccc.org.uk/publication/land-use-reducing-emissions-and-preparing-for-climate-change/
[18] https://www.theccc.org.uk/publication/the-path-to-net-zero-and-progress-reducing-emissions-in-wales
[19] https://www.gov.uk/government/publications/the-eatwell-guide

productivity (41%). The percentage of grazing livestock using extensive (semi-natural) grassland rather than improved grassland is assumed to increase to 50% from approximately 25% currently. Afforestation and food waste targets are the same as in Scenario 3 (Land Sparing), as is peatland restoration by 2030, whereas post harvest losses are assumed to reduce by 50% by 2030.

As with the Land sparing scenario, the Welsh population moves to a healthier and more plant-based diet, based on the ‘Eatwell’ diet, by 2050.

4 Results

The following results are indications of how policy changes may impact land use change and diet to 2050. When considering the results, it is important to remember the following:

- FABLE is designed to model entire countries that have a full set of FAO statistics for the commodity balance, including production, imports and exports. For this work, assumptions had to be made to downscale these initial statistics from the UK to Wales, as described in Section 2.2.
- There are limits to what FABLE can model. For example, the calculator is not currently able to model a shift towards housing more livestock indoors.
- Although the assumptions are open to discussion, and improvements could be made to the model in future, we are confident in the overall messages. The results show the level of transformational change needed to achieve a sustainable food and land use sector.

4.1 Land use change

The Status Quo scenario represents minimal policy changes, which leads to very little changes in land use over 2020 – 2050 (Figure 4.1). The total area of cropland and grazing land increases slightly in line with population growth, alongside the slight increases in urban area and new forest that were specified in the scenario. These changes result in loss of natural land. It should also be noted that there are land constraints from 2035 onwards, meaning the demand for agricultural land is not fully met.

For the Improvements on Current Trends scenario, the increases in productivity of livestock lead to an overall decrease in grassland area. As well as this, some intensive grassland is converted to extensive grassland due to a slight decline in the herd fraction on intensive grassland between 2010 and 2050. These changes are driven by productivity increases, increases in stocking density and reductions in food waste (the diet does not change for this scenario). There are no land constraints in this scenario.

In the Land Sparing scenario, there are large decreases in both types of grassland, with extensive grassland reaching zero by 2050, as specified in the scenario definition. This decrease in grassland area is driven by movement towards a healthier diet (the EatWell Diet), optimistic zero food waste targets, optimistic productivity changes and doubling of stocking densities with all livestock on intensive pasture by 2050. This intensification of livestock grazing, whilst freeing up land for new forest (mainly plantations) and other natural land for biodiversity, will likely have implications for use of agro-chemicals. Land constraints occur only in 2030 for this scenario.

The Land Sharing scenario assumes that the percentage of herd on extensive grassland increases from 25% to 50% by 2050. This assumption leads to large increases in extensive grassland coupled with decreases in intensive grassland. All semi-natural land is protected in this scenario for biodiversity, and the area of ‘other natural land’ increases as cropland and intensive pasture is freed up due to diet change and improvements in productivity. There are also increases in new forest due to afforestation targets. Some land constraints occur from 2040 due to the high protected area and afforestation targets, although less than in the Status Quo scenario.

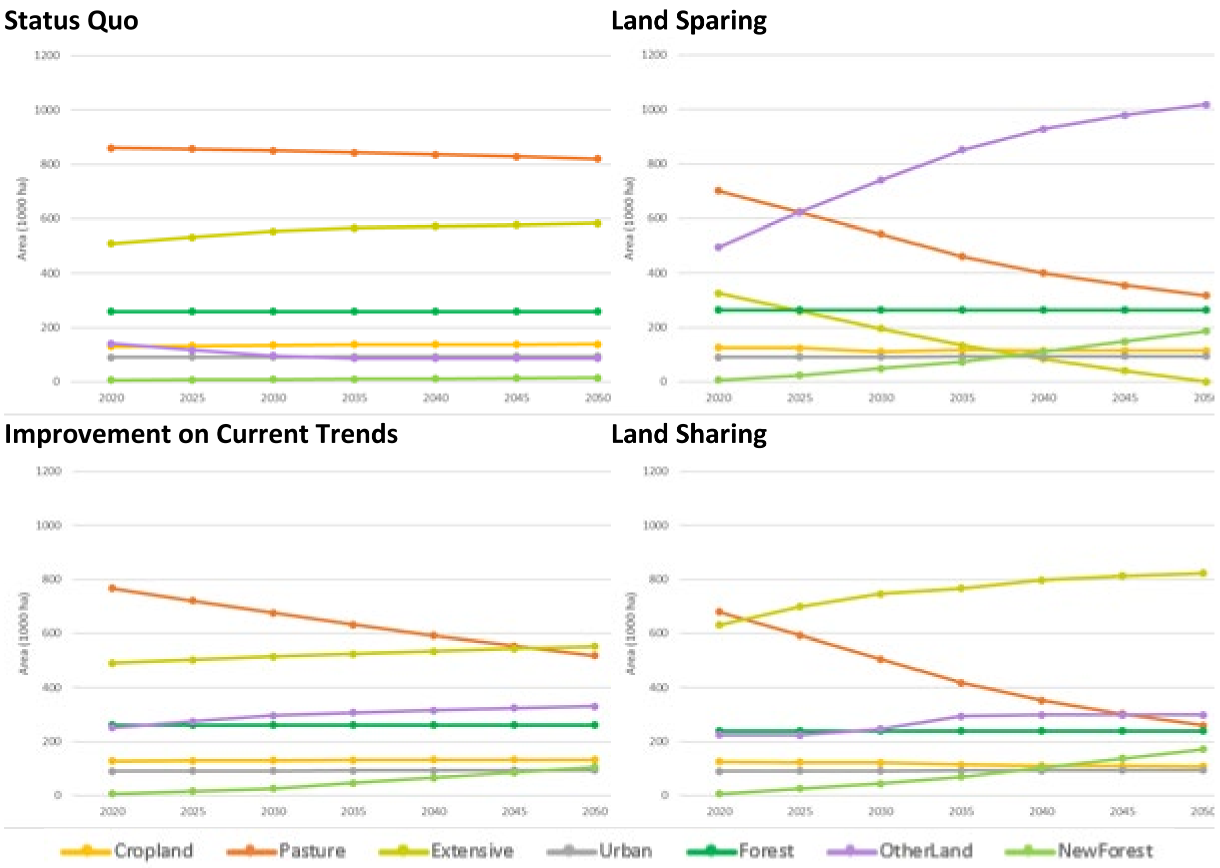

Figure 4.1: Projected land use change for the four scenarios. Note that 'Pasture' represents intensively grazed high-input ('improved') grassland and 'Extensive' represents species-rich semi-natural rough grassland.

4.2 Greenhouse gas emissions

For the Status Quo scenario, the apparent land use change emissions in the early years are mainly related to discrepancies in the historic land cover maps, which can be ignored (Figure 4.2). As these discrepancies level off (2035 onwards) the small sequestration benefit from afforestation is revealed. The emissions from livestock and cropland increase very slightly with population increases, and emissions from degraded peatland reduce very slightly due to small amounts of restoration.

For the Improvement on Current Trends scenario, emissions from livestock and cropland decrease slightly due to productivity improvements (Figure 4.2). Emissions from degraded peatland reduce slightly due to restoration, and land use change emissions shift to net sequestration due to conversion of pasture to natural land (due to productivity increases) and afforestation. Overall for this scenario, the total emissions from AFOLU (Agriculture, Forestry and Other Land Use) decreases.

The greenhouse gas emissions for livestock and cropland in the Land Sparing scenario decrease due to healthier diets, and there are decreases in emissions from degraded peatland to zero due to restoration targets. Land use change emissions shift to net sequestration due to conversion of pasture to natural land (again due to diet change, as well as productivity increases) and afforestation targets. However, it should be noted, particularly for this scenario where intensification of production is prominent, the impact of increased livestock productivity (e.g. more fertiliser use on pasture) on greenhouse gas emissions are not modelled. Total AFOLU also decreases towards 2050, more than in the Improvement to Current Trends scenario.

Similarly to the Land Sparing Scenario, the Land Sharing scenario shows decreases in emissions from livestock and cropland due to healthier diets, and emissions from degraded peatland decrease to zero due to restoration. Land use change emissions also shift to net sequestration due to conversion of pasture to extensive grassland (due to diet change and productivity increases) and afforestation. Whilst similar to Land Sparing, there is less reliance on optimistic assumptions concerning increased productivity in the Land Sharing scenario, and there is also less need for use of fertilisers on grassland, which is more in line with other sustainability goals, such as for water quality.

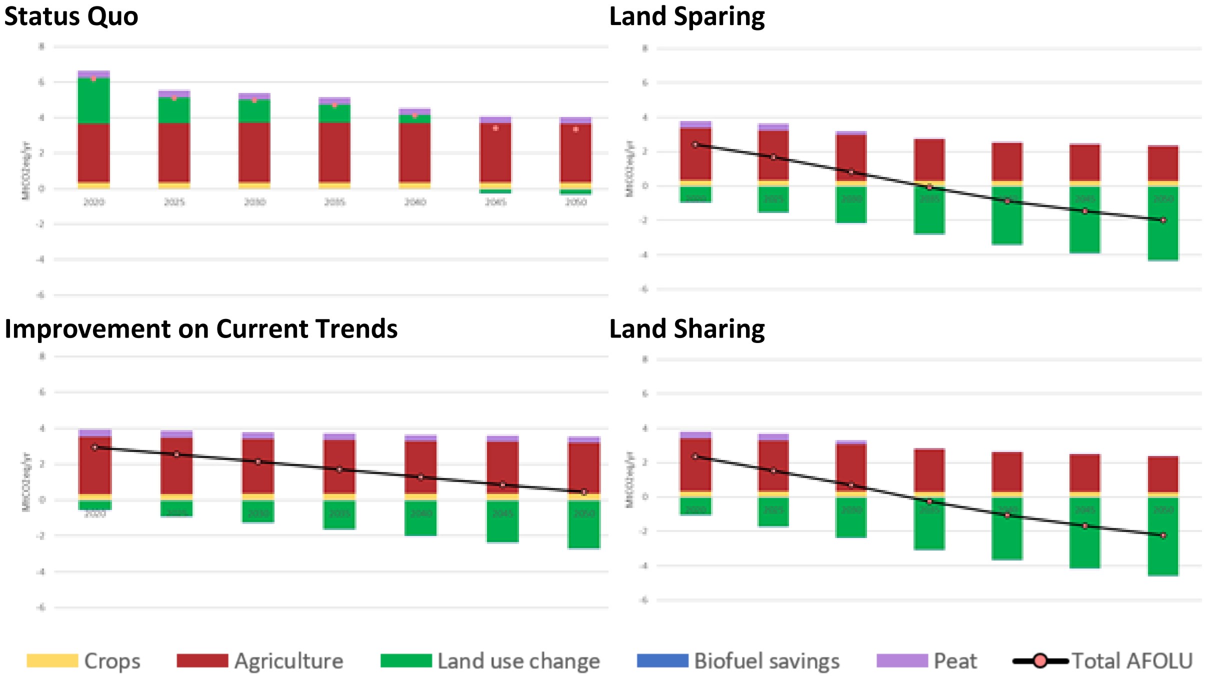

Figure 4.2: Projected greenhouse gas emissions for the four scenarios.

4.3 Land that can support biodiversity conservation

The model indicates the area of land that can support biodiversity, meaning all semi-natural land. This includes a user-defined proportion of the forest area (i.e. the proportion that is semi-natural forest composed of native species, rather than commercial plantations of non-native species), plus ‘extensive grassland’ (i.e. species-rich semi-natural grassland) and ‘other natural land’, which is mainly peat bog, heath and wetlands.

For the Status Quo scenario there is little change in the availability of other land for biodiversity, and forest area stays the same (Figure 4.3).

For the Improvements on Current Trends scenario, there are slight increases in the availability of other land, with some increase in new forest due to afforestation targets.

Figure 4.3: Projections of land that can support biodiversity conservation for the four scenarios.

In the Land Sparing and Land Sharing pathways, afforestation targets and productivity improvements lead to increases in the availability of land for biodiversity conservation. This creates an additional 317,000 ha, compared to 2010, in the Land Sparing scenario, made up predominantly of 'other natural land'. In the Land Sharing Scenario there is 394,000 ha of additional land for biodiversity, made up predominantly of extensive grassland, with the assumption that all extensive grassland is managed for biodiversity.

In these scenarios, the assumptions specify that only 40,000 ha (22%) of the 180,000 ha of new woodland would be planted specifically to deliver biodiversity outcomes. In the Improvement in Current Trends scenario, it is assumed that new woodland planting follows the existing split of about half for biodiversity and half conifer plantation. So, although less woodland is being planted, it delivers the same biodiversity benefit.

Under the initial assumptions for the Land Sparing and Land Sharing scenarios, the target of creating an additional 500,000 ha of land for ecologically resilent networks, or space for biodiversity conservation is not achieved. We therefore ran an additional test to determine how this target could be achieved for the Land Sharing scenario, and found that it could be achieved by specifying that 86% of new woodland planting should target biodiversity, which would also better align with the Land Sharing narrative (Figure 4.4).

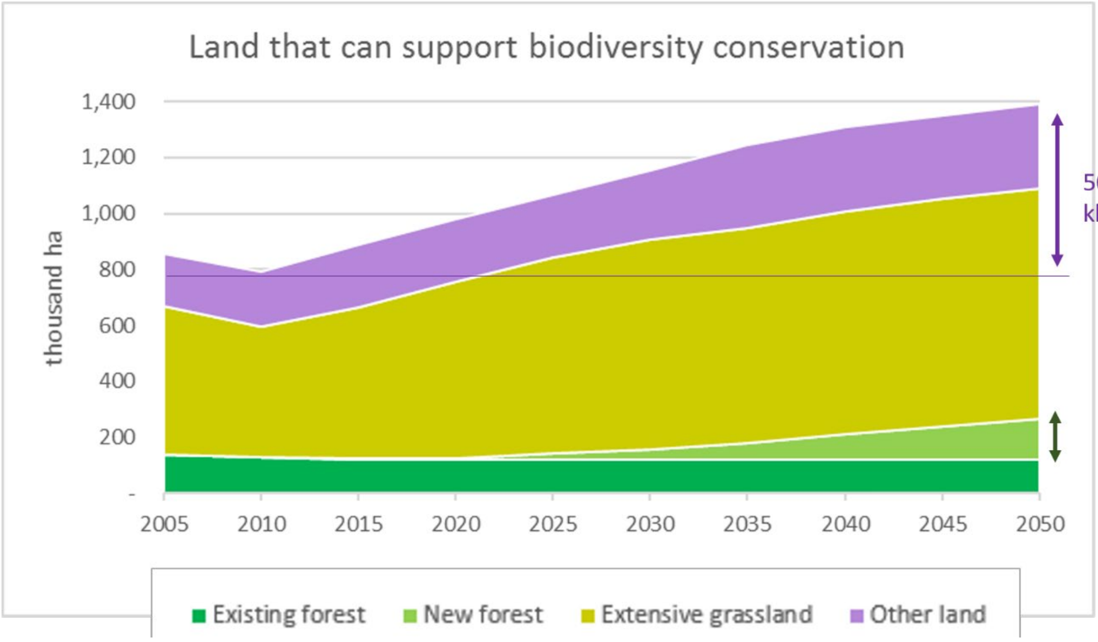

Figure 4.4: Projection of land that can support biodiversity for the Land Sharing scenario when 86% of new woodland targets biodiversity.

4.4 Diets

The Status Quo scenario includes no change to the diet scenario. Therefore, there is not much change up to 2050 (Figure 4.5a). However, land area is insufficient to produce the required amount of food from 2030 onwards. The Land Sparing and the Land Sharing scenarios (Figure 4.5b) assume that the Welsh population will move towards a healthier diet, and therefore see a reduction in average daily calorie intake per capita towards 2050.

For the Status Quo scenario, land constraints mean that there is a small gap between the target calorie consumption and the feasible consumption in later years. This means that either food consumption would have to decrease, or food imports would need to increase. There is also a smaller gap for the Land Sharing scenario but this is not noticeable on the charts.

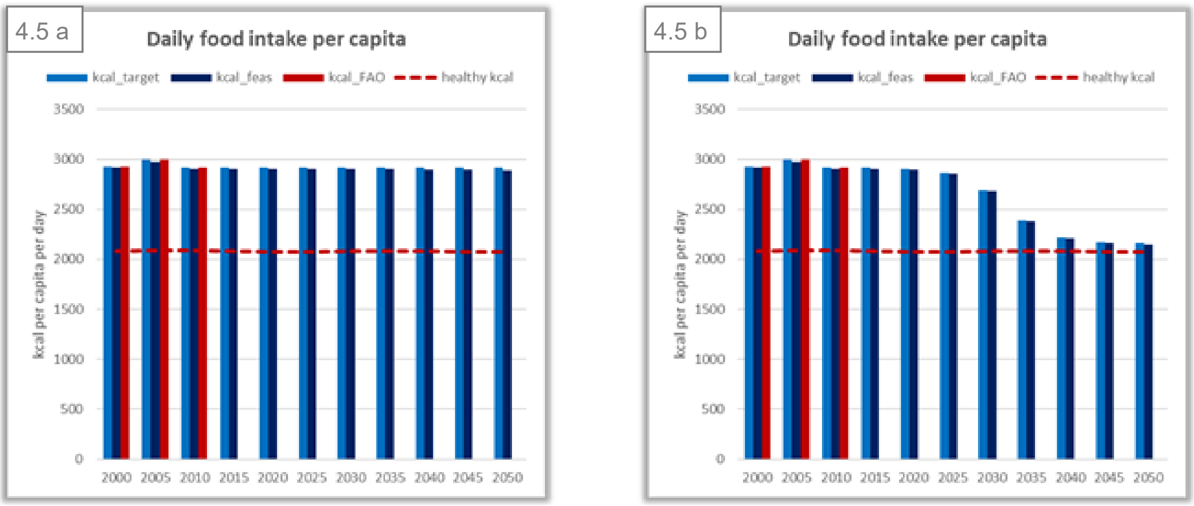

Figure 4.5: Projected daily food intake per capita for the: (a) Status Quo scenario; and (b) Land Sparing and Land Sharing scenarios.

The FABLE calculator also produces results on Feasible Food Consumption, which again for the Status Quo scenario shows no change as the assumed diet remains the same. For the Land Sparing and Land Sharing scenarios the composition of the healthier diet includes increases in cereals, fruit and vegetable consumption, and decreases in red meat, pork, poultry, sugar and fats (Figure 4.6).

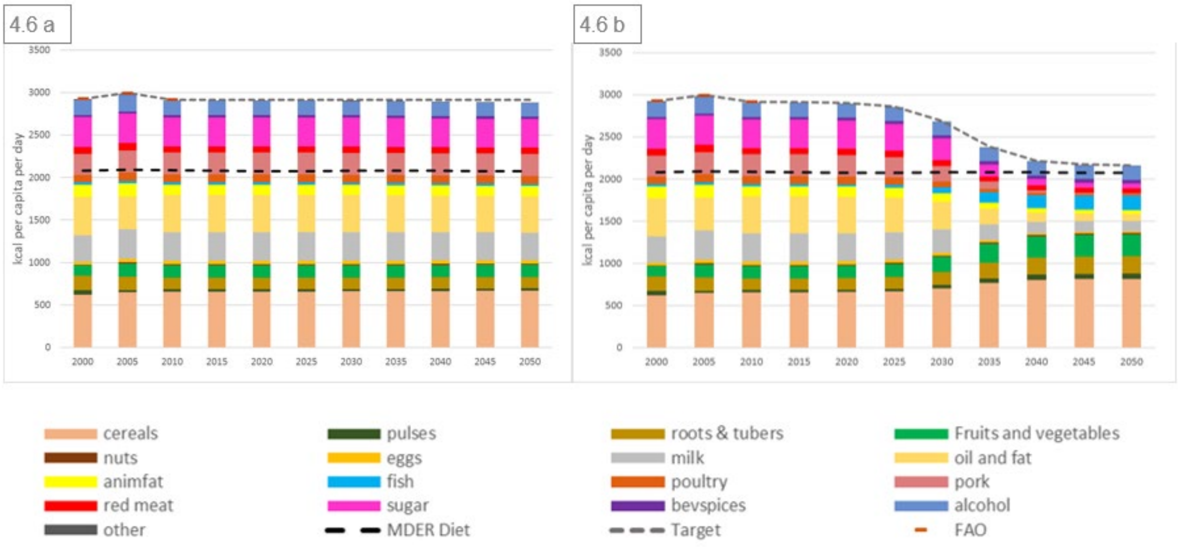

Figure 4.6: Projected feasible food consumption by class for the: (a) Status Quo scenario; and (b) Land Sparing and Land Sharing scenarios.

5 Sensitivity Analysis

5.1 Impact of productivity on land use change

In order to explore the impact of assumptions related to productivity increases in the scenarios, the livestock productivity and stocking rates for the Land Sparing and Land Sharing scenarios were changed to match the Status Quo scenario (i.e. no change). This produced drastic changes in land use, which shows the high dependence of the Land Sparing scenario on the assumptions of high productivity and stocking rate increases. Intensive pasture area remains high to 2050, with much lower increases in 'other natural land' (Figure 5.1).

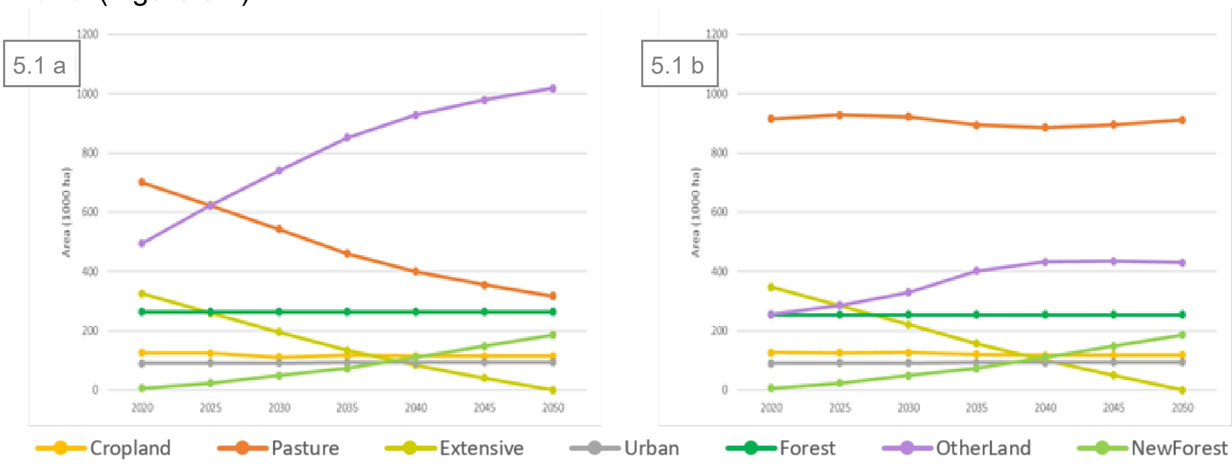

Figure 5.1: Projected land use change for the Land Sparing scenario: (a) with all assumptions; and (b) without increases in productivity and stocking rate.

The Land Sharing scenario with status quo productivity and stocking rates shows less drastic changes than Land Sparing scenario due to less reliance on increased stocking rates and productivity. There are still decreases in intensive pasture and increases in extensive grassland, but not as large. However, there is no longer an increase in other natural land (Figure 5.2).

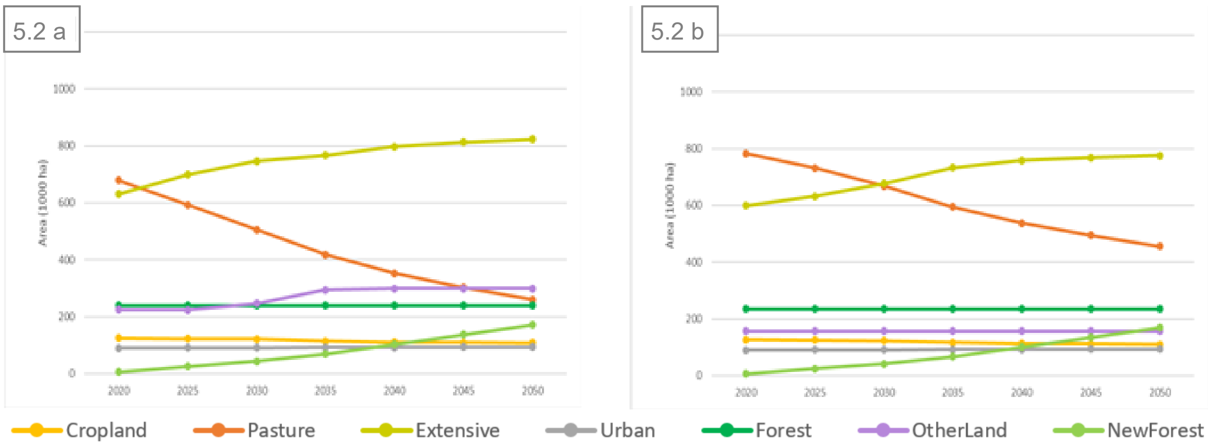

Figure 5.2: Projected land use change for the Land Sharing scenario: (a) with all assumptions; and (b) without increases in productivity and stocking rate.

5.2 Impact of diet on land use change

In order to explore the impact of diet of the projected model outputs, we first implemented the healthier Eatwell diet in the Status Quo scenario to assess how this would affect land use change.

The results show that switching to a healthier diet reduces meat demand and therefore pasture area, and allows an increase in other natural land (Figure 5.3). However, the impact is limited because most of the meat production in Wales is for export, and we currently assume no change in exports (Figure 5.4). There is therefore the potential for future work to test the impact of varying exports to simulate changing dietary preferences elsewhere in the UK and globally.

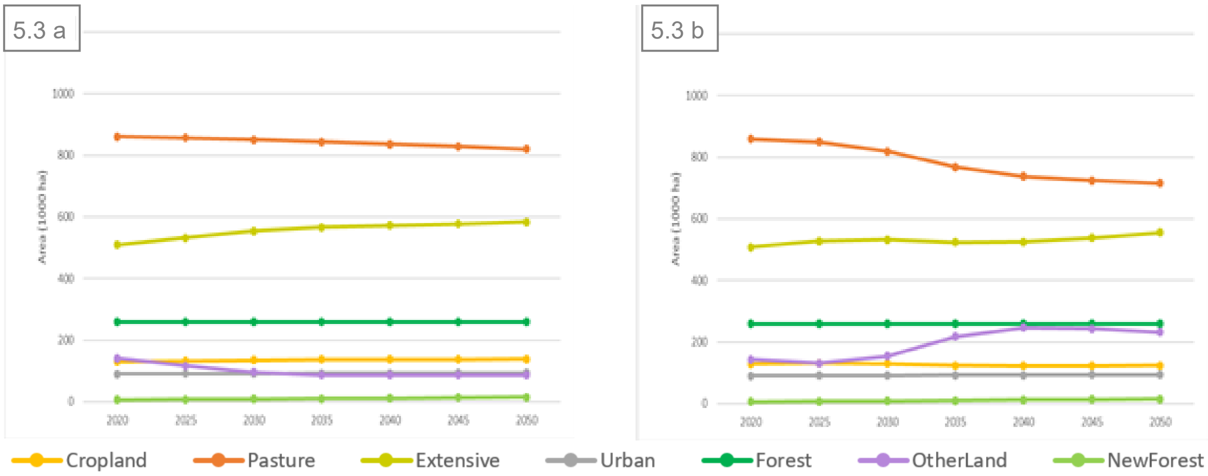

Figure 5.3: Projected land use change in the Status Quo Scenario: (a) with all assumptions; and (b) with the healthier EatWell diet.

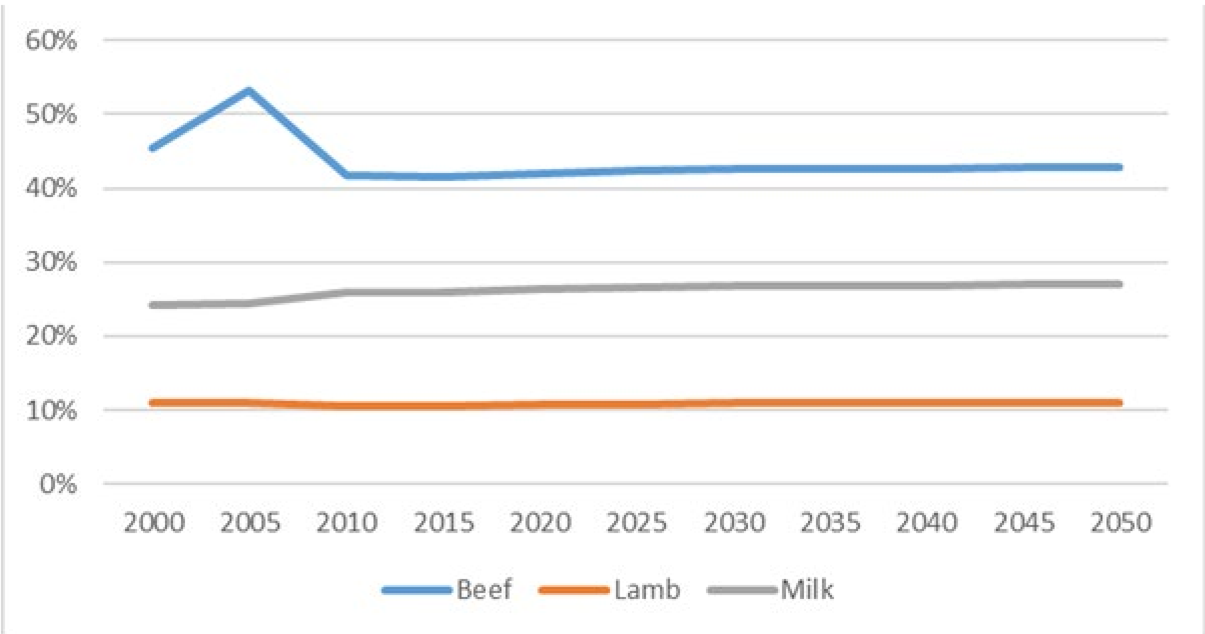

Figure 5.4: Share of production that is consumed in Wales for beef, lamb and milk. Imports and exports are similar for all scenarios, based on FAO data downscaled for the UK. Exports are fixed in tonnes at the 2010 value; share of imports is constant at the 2010 value.

6 Discussion and Conclusions

The FABLE model has been used to test scenarios for sustainable land use and food systems in Wales. The results indicate that maintaining the status quo or implementing only slight improvements to current policy will not be sufficient to enable Wales to reach net-zero greenhouse gas emissions (which requires the land use sector to be a carbon sink). However, both the Land Sparing and Land Sharing scenarios were predicted to enable the land use sector to become a net carbon sink, helping to offset emissions in other sectors.

Both of these scenarios also freed up land for ecological resilient networks, or space for nature ; this was mainly semi-natural species-rich extensive grassland in the Land Sharing scenario and mainly 'Other natural land' (heath and bog) in the Land Sparing scenario. However, under the policy assumption that only 20% of new forest would be managed for biodiversity, none of the scenarios achieved the goal of creating an extra half million hectares of land for biodiversity conservation.

The analysis showed that in order to achieve this goal it would be necessary to stipulate that 86% of all new forest should be planned and managed to deliver benefits for biodiversity, i.e. it should use a diverse mix of native species (and/or natural regeneration) and be sensitively managed to maintain good ground cover flora, open areas and a shrub understorey layer. Natural regeneration can establish a more diverse structure and composition, well adapted to local conditions and with richer genetic diversity, offering far better habitat for wildlife and more resilience to environmental change. As it typically produces a rich mosaic of open and closed canopy woodland, scrub and open areas, carbon sequestration due to tree growth may be lower per hectare than tree planting, but it could be possible to create more hectares of semi-natural woodland due to the lower costs.[20] Also, lower sequestration per hectare can be partly or completely offset by avoided loss of soil carbon from disturbance when trees are planted,[20, 21] which is especially significant in peaty soils.[22]

Another option which we did not model would be for an increase in agroforestry including silvo-arable (trees on cropland) and silvo-pasture (trees on pasture), which can increase carbon storage, provide biodiversity benefits and shelter livestock and crops from extreme weather. Although there is a lack of information and policy support for agroforestry in the

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[20] Fletcher, T. I., Scott, C. E., Hall, J., & Spracklen, D. V. (2021). The carbon sequestration potential of Scottish native woodland. *Environmental Research Communications*, *3*(4), 041003. https://doi.org/10.1088/2515-7620/abf467

[21] Warner, E., Lewis, O. T., Brown, N., Green, R., McDonnell, A., Gilbert, D., & Hector, A. (n.d.). Does restoring native forest restore ecosystem functioning? Evidence from a large-scale reforestation project in the Scottish Highlands. *Restoration Ecology*, e13530. https://onlinelibrary.wiley.com/doi/10.1111/rec.13530

[22] Friggens, N. L., Hester, A. J., Mitchell, R. J., Parker, T. C., Subke, J.-A., & Wookey, P. A. (2020). Tree planting in organic soils does not result in net carbon sequestration on decadal timescales. *Global Change Biology*, *26*(9), 5178–5188. https://onlinelibrary.wiley.com/doi/10.1111/gcb.15229

UK,[23] there are examples of successful adoption in England and Scotland.[24,25,26] Further work could be needed to assess how agroforestry could be applied in Wales, where field sizes are typically smaller, perhaps building on the approach of the farmer-led silvopasture trial in Devon.[27]

Both the Land Sparing and Land Sharing scenarios rely on challenging targets that will require transformative policy actions. These include a shift to a healthier more plant-based diet, a reduction in food waste to zero, complete restoration of all degraded peatland, and significant increases in agricultural productivity. However, the Land Sharing scenario requires lower increases in productivity compared to the Land Sparing scenario. It therefore carries a lower risk of adverse environmental impacts associated with intensifying agricultural production, such as water pollution and ecological impacts from increased use of agro-chemicals. The Welsh Government believes that Land Sharing offers a more equitable pathway, with farmers able to exercise self determination in how they reach GHG objectives, contributing to a just transition. This could be tested using the ERAMMP Integrated Modelling Platform in a second phase of this work to explore spatial implications of the pathways on a range of biodiversity and public good outcomes.

The FABLE model has demonstrated that the Land Sharing scenario provides an alternative approach to the Land Sparing model proposed in the CCC scenarios, and this approach may be more in tune with the land use context in Wales, and the Welsh Government policy targets for more sustainable and multifunctional land use.

The full set of outputs from the FABLE-Wales Calculator for indicators related to land use change, GHG emissions, biodiversity and diets are provided as slides published separately as Technical Annex ERAMMP Report-72TA1[28].

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[23] Tosh, C. and Westaway, S. (2021) Agroforestry ELM Test: Incentives and disincentives to the adoption of agroforestry by UK farmers: a semi-quantitative evidence review. Organic Research Centre.
[24] https://www.agricology.co.uk/field/farmer-profiles/stephen-briggs
[25] Jo Smith and Sally Westaway (2020) Wakelyn's agroforestry: Resilience through diversity. Organic Research Centre and Woodland Trust.
[26] https://wickedleeks.riverford.co.uk/features/climate-change-farming-net-zero/silvo-lining
[27] https://www.innovativefarmers.org/news/2021/february/18/twelve-year-field-lab-into-the-benefits-of-silvopasture-launched/
[28] www.erammp.wales/72TA1

7 Acknowledgements

The Food, Agriculture, Biodiversity, Land-Use, and Energy (FABLE) Consortium is a collaborative initiative to support the development of mid-century national food and land-use pathways consistent at the global level that could inform policies towards greater sustainability. FABLE is convened as part of the Food and Land Use Coalition (FOLU).

The Consortium brings together teams of researchers from 20 countries and international partners from the Sustainable Development Solutions Network (SDSN), the International Institute for Applied Systems Analysis (IIASA), the Alliance Bioversity-CIAT, and PIK. FABLE has published two reports in 2019 and 2020 which further describe the approach, tools, and resulting national and global pathways of the food and land-use systems (https://www.foodandlandusecoalition.org/fable/).

The UK FABLE team is led by UK Centre for Ecology & Hydrology and the University of Oxford involving Paula Harrison, Alison Smith, Nicholas Leach, Charles Godfrey, Jim Hall, Michael Obersteiner, Sarah Jones and Sarah Gall. The FABLE-Wales work described in this report has built upon the work undertaken by the UK country team.

8 Annex-1: Underlying Assumptions & Justification for the Scenario Parameters

Population Population projection – million inhabitants			
Status Quo	**Improvement on Current Trends**	**Land Sparing**	**Land Sharing**
The Population is expected to reach 3.258 million by 2050 based on ONS predictions Principal projection - Wales population in age groups - Office for National Statistics (ons.gov.uk)	As for Status Quo	As for Status Quo	As for Status Quo

LAND Constraints on agricultural expansion			
Status Quo	**Improvement on Current Trends**	**Land Sparing**	**Land Sharing**
No constraints on agricultural expansion	Constraints on agricultural expansion within National Parks	No agricultural expansion on existing habitats	No agricultural expansion on existing habitats and 500,000ha of habitat created on agricultural land
Afforestation or Reforestation Targets			
Total woodland creation in 2020/21 was around 280 ha. Assume 300 ha/y to 2050.	The current Welsh Government target is to create 2,000 ha of new woodland p.a., rising to 4,000 ha as soon as possible. Planting 20,000 ha by 2030 and a further 80,000 ha by 2050. This will lead to 106,000 ha created by 2050.	43,000 ha planted by 2030 (average of 5,000 ha/yr from 2023), rising to 180,000 hectares by 2050 (7,500 ha/yr from 2035).	40,000 ha planted by 2030 rising to 180,000 ha by 2050 (7,500 ha/yr from 2035).
Urban Expansion			
5% increase in urbanisation, from 105,773 ha to 110,000 ha	Same as Status Quo	Same as Status Quo	Same as Status Quo

BIODIVERSITY Protected areas (% of total land)			
Status Quo	**Improvement on Current Trends**	**Land Sparing**	**Land Sharing**
Existing designated sites protected for nature are maintained. This is the FABLE default but with no target to increase to e.g. 17%.	Existing designated sites protected for nature are maintained. Agriculture expansion constrained within National Parks . This is simply equivalent to including NPs within protected areas.	Same as for Improvement on Current Trends	To reverse decline in biodiversity, all semi-natural habitat (excluding woodland) are protected. This would increase protected areas for nature to 29.5%. A further 500,000 ha of habitat is created on farmland (output not input).

PRODUCTIVITY Crop productivity or the key crops in the country			
Status Quo	**Improvement on Current Trends**	**Land Sparing**	**Land Sharing**
As for the UK, in 2050, crop productivity remains the same: • 7.7 tons per ha for wheat (7.1 with climate change impacts). • 5.7 tons per ha for barley. • 43.9 tons per ha for potatoes. Based on FAOSTAT historic yields for 2010.	Same as for Status Quo	As for the UK, by 2050, crop productivity reaches: • 12.7 tons per ha for wheat (12.0 with climate change impacts). • 9.4 tons per ha for barley. • 72.4 tons per ha for potato. Based on assumption that yields for all crops increase by 65%.	As for the UK, by 2050, crop productivity reaches: • 10.7 tons per ha for wheat (10.1 with climate change impacts). • 7.9 tons per ha for barley. • 61 tons per ha for potatoes. Based on assumption that yields for all crops increase by 39% from the 2010 value, in line with the revised CCC medium projection (CCC, pers comm, 2020).
Livestock productivity for the key livestock products in the country			
Dairy Yield, Beef, Chicken to remain the same	Between 2015 and 2050, yields: • Dairy: Yield per cow 7784 l/cow in 2015. Current trend is 82 l/cow increase/yr. 35yr x 82 litre = 2870 litres, 7784 + 2870 = 10,654 l/cow in 2050 if current trend is maintained (37% increase). • Beef: Remain at 123.6 kg/head of population for cattle meat. • Poultry: Remain at 1.37 kg/head of population for chicken meat. • Lamb: 17% increase.	Between 2015 and 2050, yields: • Dairy: 50% increase for milk. • Beef: Remain at 123.6 kg/head of population for cattle meat • Poultry: Increase by 10% for chicken meat, from 1.37 to 1.51 kg/head of population. Lamb: 52% increase as sheep systems increase in efficiency.	Same as Improvement on Current Trends. Lamb: 41% increase

Pasture stocking rate			
No changes to stocking density	Change in livestock density compared to baseline: 132%	Change in livestock density compared to baseline: 202%	Change in livestock density compared to baseline: 136%
Post-harvest losses			
No changes to post-harvest losses	No changes to post-harvest losses	As for the UK, by 2050, the share of production and imports lost during storage and transportation is 0.5%. Based on assumption of a 50% reduction in losses compared to 2015, i.e. achieving the SDG 12.3 target to halve consumer and retail waste but by 2050 rather than 2030 (WRAP, 2020).	As for UK, by 2030, the share of production and imports lost during storage and transportation is 0.5%, i.e. the target is achieved earlier than the Land Sparing scenario. Based on assumption of a 50% reduction in losses compared to 2015 in line with the Courtauld 2025 Commitment (reduction of 20% across supply chain between 2015-2025) and SDG 12.3 target (halve consumer and retail waste by 2030) (WRAP, 2020).

TRADE Share of consumption which is imported for key imported products (%)			
Status Quo	**Improvement on Current Trends**	**Land Sparing**	**Land Sharing**
Exports and imports are estimated from the commodity balance after downscaling production and consumption from UK statistics and then held constant after 2010.			

FOOD Average dietary consumption (daily kcal per commodity group)			
Status Quo	**Improvement on Current Trends**	**Land Sparing**	**Land Sharing**
By 2030, the average target daily calorie consumption per capita is 2,983 kcal and is: • 168 kcal for fruit and vegetables. • 83 kcal for ruminant meat. • 119 kcal for animal fats. Based on assumption of no change in current diet as in FAOSTAT.	Welsh Dietary trends to 2050: • 108 kcal for fruit and vegetables • 168kcal for ruminant meat	Eat Well Diet - by 2030, the average target daily calorie consumption per capita is 2,739 kcal and is: • 196 kcal for fruit and vegetables. • 75 kcal for ruminant meat. • 98 kcal for animal fats. Based on meeting the Eatwell diet recommendations by 2050 (PHE, 2020; Scarborough et al., 2016).	Eat Well Diet - by 2030, the average target daily calorie consumption per capita is 2,739 kcal and is: • 196 kcal for fruit and vegetables. • 75 kcal for ruminant meat. • 98 kcal for animal fats. Based on meeting the Eatwell diet recommendations by 2050 (PHE, 2020; Scarborough et al., 2016).

Share of food consumption which is wasted (%)			
No change to food waste	Existing trends in food waste reduction - 50% reduction in food waste by 2050, 2%/yr from 2015	Wales aims to have zero avoidable food waste before 2050. By 2025: • 50% reduction in avoidable food waste By 2030: • 60% reduction in avoidable food waste By 2050: • Zero avoidable food waste (Note: All waste reduction targets are set against a 2006-07 baseline)	Wales aims to have zero avoidable food waste before 2050. By 2025: • 50% reduction in avoidable food waste By 2030: • 60% reduction in avoidable food waste By 2050: • Zero avoidable food waste (Note: All waste reduction targets are set against a 2006-07 baseline)

BIOFUELS Targets on biofuel and /or other energy use			
Status Quo	**Improvement on Current Trends**	**Land Sparing**	**Land Sharing**
No change	No change	No change	No change

CLIMATE CHANGE Crop model and climate change scenario			
Status Quo	**Improvement on Current Trends**	**Land Sparing**	**Land Sharing**
As for UK, by 2100, global GHG concentrations lead to a radiative forcing level of 6 W/m^2 (RCP 6.0). Impacts of climate change on crop yields are computed by the crop model GEPIC using climate projections from the climate model HadGEM2-E without CO_2 fertilisation effect.	As for UK, by 2100, global GHG concentrations lead to a radiative forcing level of 6 W/m^2 (RCP 6.0). Impacts of climate change on crop yields are computed by the crop model GEPIC using climate projections from the climate model HadGEM2-E without CO_2 fertilisation effect.	As for UK, by 2100, global GHG concentrations lead to a radiative forcing level of 2.6 W/m^2 (RCP 2.6). Impacts of climate change on crop yields are computed by the crop model GEPIC using climate projections from the climate model HadGEM2-E without CO_2 fertilisation effect.	As for UK, by 2100, global GHG concentrations lead to a radiative forcing level of 2.6 W/m^2 (RCP 2.6). Impacts of climate change on crop yields are computed by the crop model GEPIC using climate projections from the climate model HadGEM2-E without CO_2 fertilisation effect.

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