Environment and Rural Affairs Monitoring & Modelling Programme (ERAMMP)

ERAMMP Report-60: ERAMMP Integrated Modelling Platform (IMP) Land Use Scenarios

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Approved by Bridget Emmett (UKCEH)
James Skates (Welsh Government)

Abbeviations Used in this Report

ABC	Agricultural Budgeting and Costing
BBS	Breeding Bird Survey
BEIS	UK Government Department for Business, Energy & Industrial Strategy
BPS	Basic Payment Scheme
BTO	British Trust for Ornithology
CARBINE	A forestry model
DA	Disadvantaged areas
DMU	Decision-Making Unit
EFT	ERAMMP Farm Type
EMEP4UK	An off-line atmospheric chemistry transport model
ERAMMP	Environment and Rural Affairs Monitoring & Modelling Programme
ESC	A forestry model
ESRC	Economic and Social Research Council
EUID	ERAMMP Unique ID
FARMSCOPER	An agricultural emissions model
FBS	Farm Business Survey
FBI	Farm Business Income
FC	Forestry Commission
FR	Forest Research
FTA	Free Trade Agreement
FTE	Full time equivalent
GHG	Green House Gas
GMEP	Glastir Monitoring and Evaluation Programme
HMT	Her Majesty's Treasury
IMP	Integrated Modelling Platform
LAM	Land Allocation Module
LFA	Less Favoured Areas
LULUCF	Land Use, Land-Use Change and Forestry
MULTIMOVE	A Package of niche models for British Vegetation
NARSES	National Ammonia Reduction Strategy Evaluation System
NFI	National Forest Inventory
NPV	Net Present Value
NRW	Natural Resources Wales
QA	Quality Assurance
RFT	Robust Farm Type
RIGOUR analysis	Repeatable, Independent, Grounded in reality, Objective, have Uncertainty managed, Robust with respect to the initial question
SAC	Special Area of Conservation
SDA	Severely disadvantaged areas
SFARMOD	Silsoe Whole Farm Model
SFS	Sustainable Farming Scheme
SRO	Senior Responsible Officer
SSSI	Site of Special Scientific Interest
TRQ	EU tariff-rate quota
UKCEH	UK Centre for Ecology and Hydrology
UKTAG	UK Technical Advisory Group
WCP	Woody Cover Product
WFD	Water Framework Directive
WG	Welsh Government
WTO	World Trade Organisation

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

1 Summary

Six scenarios consisting of changes in farm-gate prices (T1 to T6) have been applied to the ERAMMP Integrated Modelling Platform (IMP) to simulate impacts on land use change, biodiversity and ecosystem services (carbon, water quality and air quality). The scenarios were based on discussions held between stakeholders in the Evidence and Scenario sub-group (Roundtable Wales and Brexit[1]) and Welsh Government (WG) policy officials. These discussions took place in late 2020 before the arrangements for the UK leaving the EU were agreed, therefore are based on broad assumptions around the detail of the trade agreement with the EU as well as other third countries including Australia, New Zeland and USA. It is important to note that the outputs of these discussions which were used as inputs into the ERAMMP IMP may therefore not accurately reflect the outcomes achieved within the finalised trade agreements.

The T1 scenario assumes no EU trade deal and trade liberalisation, with no tariffs applied to imported products and T2 an EU trade deal with no change to the trade arrangements with third countries. These two scenarios used the changes to farm-gate prices modelled by FAPRI[2]. The assumptions used in the T3 to T6 scenarios were based on expert opinion from the stakeholder group, and include impacts on farm-gate prices which potentially could have resulted from different combinations of trade deals with New Zealand, Australia and USA. Scenarios which include "no EU deal" options (T1 and T4) are no longer relevant.

In no way whatsoever do T1, T3, T4, T5 and T6 represent a WG position; our understanding of the nature and impact of new and emerging trade deals has evolved significantly and the WG Trade Policy Team lead in this area. The objective of this work was to gain an early understanding of how changes in farm-gate prices potentially resulting from trading relationships may influence land use and subsequently effect entry into the Sustainable Farming Scheme. We note that many other factors are also likely to influence Welsh farm-gate prices, such as (but not limited to), currency exchange rates, energy prices and extreme weather events in other parts of the world.

This report provides an overview of the land use implications of all these scenarios, but focuses on the T2 scenario, which represents an EU Trade Deal. This T2 scenario is being used as the counterfactual scenario against which the costs and benefits of the land use implications of the proposed Sustainable Farming Scheme will be assessed in the Regulatory Impact Assessment for the proposed Agricultural Bill. This includes the estimated environmental outcomes of the EU Trade Deal scenario and, where the ERAMMP IMP has attached monetary valuations to these, the value of these outcomes to society. In the Cost Benefit Analysis, these monetary values will inform the overall estimated Net Present Value (NPV) of this business-as-usual counterfactual.

The IMP involves many assumptions and these need to be borne in mind when interpreting and using its outcomes. By necessity, all models are a simplification of the real situation, but can still provide very useful insights if applied for a specific purpose and with caution. The

[1] https://gov.wales/evidence-and-scenario-sub-group-roundtable-wales-and-brexit
[2] https://www.afbini.gov.uk/sites/afbini.gov.uk/files/publications/FAPRI-UK%20Brexit%20Report%20-%20FINAL%20Clean.pdf

collaborative and iterative consortium-based approach to co-designing the IMP has meant that Welsh Government and IMP teams have clear, open channels of communication for asking questions. This ensures that the modelling represents government aspirations as well as possible and the limits of the approach are well understood.

IMP outputs for the T2 scenario show that some simulated full-time farms (>1 FTE labour) come under economic pressure (7%) and are simulated to be unable to produce a sufficient Farm Business Income to be economically viable. For these farm types, no options to transition to a more alternative profitable farm type are available and they are assumed to leave full-time agriculture. A greater number of farms transition to dairying resulting in a 75% increase in the number of dairy farms. This is associated with large increases in the number of dairy cattle (73%) and reductions in sheep (-34%). A general intensification of grassland systems is simulated resulting from the farm type transitions, with a 66% increase in temporary grasslands and a 21% decrease in permanent grasslands. Overall, these changes in agriculture and land use are simulated to lead to mixed, but predominantly negative, effects on biodiversity, increases in GHG emissions and deterioration in air and water quality.

The T2 scenario predicts the least change in agriculture out of the six scenarios. T1 simulates the greatest impacts on agriculture due to significant farm-gate price reductions across dairy, beef and sheep systems, with a large number of full-time farms leaving agriculture. This leads to large increases in woodland area and generally positive effects on biodiversity and ecosystem services. T3 and T4 also simulate large impacts on agriculture. These are associated with significant farm transitions to dairy (due to increases in milk prices and significant decreases in beef and lamb prices) resulting in larger increases in GHG emissions and greater declines in air and water quality, compared to the T2 scenario. The T5 and T6 scenarios fall between these extremes, with T6 projecting the second greatest impacts on agriculture (after T1) in terms of farms under pressure. These simulated changes in agriculture are associated with net benefits for air and water quality, but net costs for GHG emissions; although these costs are lower than for scenarios T3-T5.

2 The ERAMMP Integrated Modelling Platform

The ERAMMP Integrated Modelling Platform (IMP) is a computer model that simulates the potential effects of government policies and other drivers on agriculture, land use and the natural environment in Wales. The nature of decision-making around agriculture, land use, and the environment is inherently complex due to the range of interdependencies between different drivers, sectors and the varied actors within them. The problem faced by many traditional modelling approaches is that they address these sectoral challenges independently without being able to explicitly represent the implications for other sectors. To address this challenge of sectoral interdependence, the IMP has been developed using an integrated approach that recognises that drivers or policies in one sector may have consequences or unintended effects in other sectors. In this way, the IMP explicitly accounts for biophysical and socio-economic interactions between sectors.

The IMP has been co-designed between the ERAMMP consortium and the Welsh Government. It has been specifically tailored to provide information to support the development of new policies focused on natural resource management, land use and agriculture under a range of Welsh economic and regulatory futures. The IMP allows emerging policy ideas to be explored and stress-tested in an integrated manner prior to final design and implementation.

The IMP comprises a chain of specialised, state-of-the-art models customised (as best as practicable) with Welsh data. These models cover agriculture, forestry, land use allocation, biodiversity and a range of ecosystem services (including water quality, air quality, greenhouse gas emissions/carbon sequestration) and their valuation. Eleven models have been linked together by establishing data-flows between them across the model chain (Figure 2.1). These data-flows represent the interdependencies between different sectors or impacts.

Scenario settings developed in collaboration with Welsh Government are used to parameterise all models in the chain depending on the policy question being asked of the modelling system (Figure 2.1; Box 1) (see Section 3 for a description of the scenarios developed for this study). The scenario settings are used by two forestry models, ESC and CARBINE, to estimate the productivity and carbon storage potential of forestry (Figure 2.1; Boxes 1 and 2). Information on the price of timber and the costs of establishing and managing forestry are then used to estimate the profitability of five different forest management options at the scale of a farm holding. These outputs are passed to an agricultural model which allows on-farm woodland to be considered as a potential alternative land use within a farm. The SFARMOD agricultural model uses the outputs from the forestry models and the scenario settings to estimate the profitability of various agricultural activities, taking account of biophysical and agricultural constraints (Figure 2.1, Box 4). The profitability of both the current farm type and all potential alternative farm types is estimated for each full-time farm holding in Wales.

The profitability of the different farm types is compared within the Land Allocation Module (LAM) (Figure 2.1; Box 5). Transitions from current land uses to alternatives are projected through a set of rules and thresholds. These compare the current farm type with other alternative profitable farm types. If the current full-farm type is able to produce a sufficient level of Farm Business Income (FBI), the LAM considers whether there is a more profitable alternative farm type. If there is, and the increase in profitability from the new farm type is sufficient to make transition worthwhile (given the capital investment needed to transition) the modelled farm will change land use to the more profitable farm type. If the current full-time farm type is *not* able to produce a sufficient FBI, the modelled farm will be projected to change to the most profitable viable farm type through sale. If no profitable farm type is available, the LAM will consider whether forestry is a profitable alternative instead. If so, forestry will be established, and if not, the modelled land will leave full-time agriculture and be considered to go through natural succession in the modelled outputs.

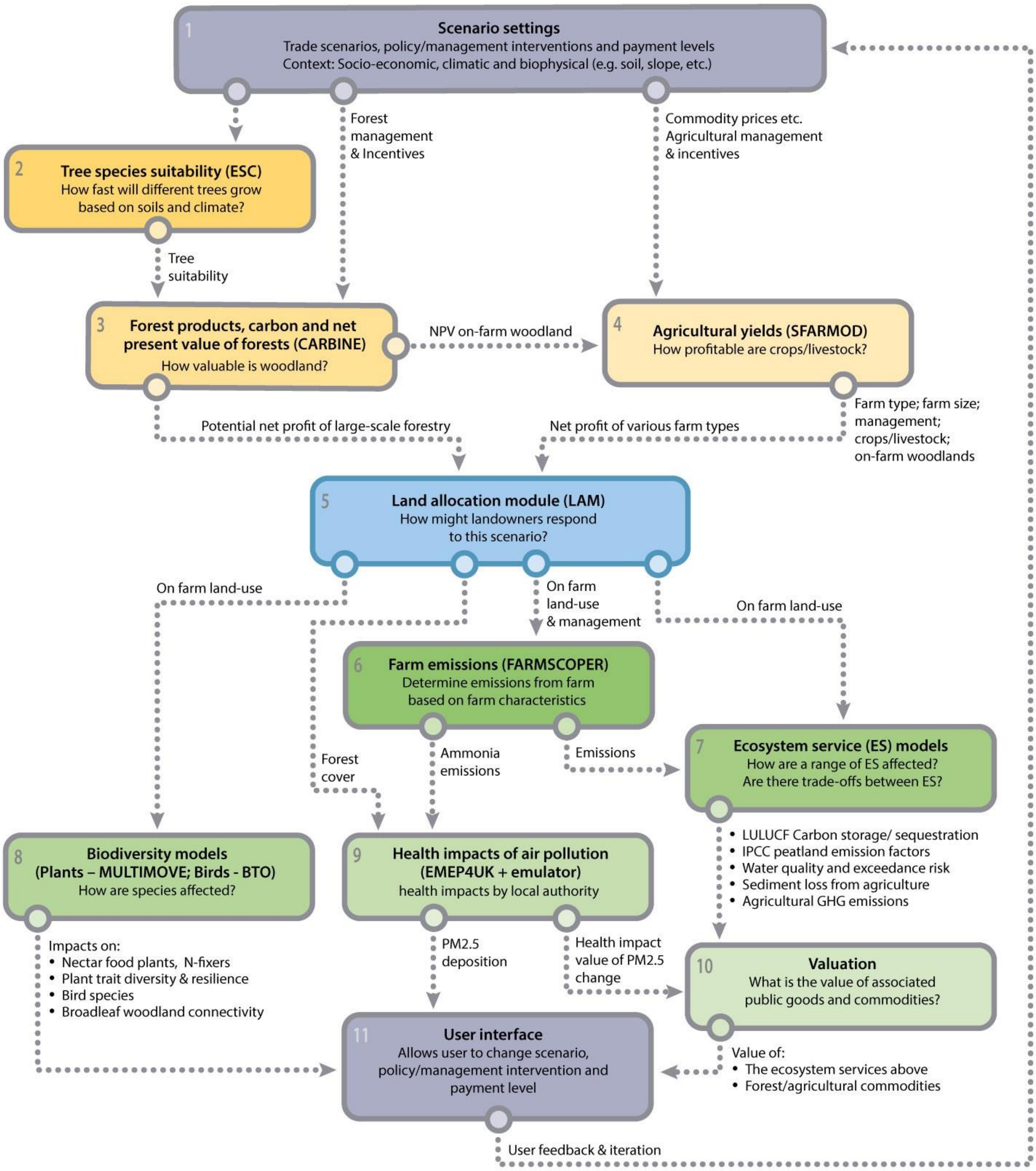


Figure 2.1: Simplified schematic displaying the component models of the IMP and the links between them. Boxes represent either inputs, component models or the user interface. Arrows represent the flow of data, with text illustrating the types of data being passed between models. Box colour differentiates between the main components of the IMP: the top of the chain, the LAM and the bottom of the chain.

Once the predicted land allocation and livestock numbers are established for each farm, the agricultural emissions model, FARMSCOPER (Figure 2.1; Box 6), determines the emissions from each modelled farm based on their characteristics (e.g. land area, fertiliser use, livestock excreta and manure, soil type). Emissions include greenhouse gasses (e.g. nitrous oxide), nutrients (e.g. phosphorus) and other pollutants (e.g. ammonia), and may be affected by user specified mitigation measures. A set of ecosystem service models (Figure 2.1; Box 7) use the information from the LAM on changes in on-farm land use and management to estimate changes in carbon sequestration due to land use, land use change and forestry (LULUCF) and changes in peatland use. This information is combined with the information from FARMSCOPER on greenhouse gas emissions from agriculture to estimate overall changes in carbon. The ecosystem service models also use information passed from FARMSCOPER to assess changes in water quality (e.g. Water framework Directive phosphorus status, drinking water nitrate status, sediment loss from agriculture).

Impacts of the changes in land use and management on biodiversity are simulated using the MULTIMOVE and BTO models (Figure 2.1; Box 8). MULTIMOVE estimates habitat suitability for a wide variety of plant species, including woodland and arable specialist plant species and positive Common Standards Monitoring (CSM) species (specialist plants of other semi-natural habitats, e.g. lowland grassland, lowland wetlands, lowland heath and upland habitats). The BTO models estimate species-specific abundance for 68 bird species associated with different habitats across Wales. In addition, the broadleaf woodland connectivity model simulates the effect of new on-farm woodland and afforestation (as passed from the LAM) on connectivity between existing woodland patches.

The EMEP4UK meta-model uses information passed from the LAM on new woodland and information passed from FARMSCOPER on ammonia emissions from farms to estimate changes in fine particulate matter (PM2.5) concentration (Figure 2.1; Box 9). Implications of these changes for human health, in terms of life years lost, are then computed.

In the final stage of the IMP integrated chain, the ecosystem services are valued using monetary values for carbon, water quality and the health impacts of air pollution (Figure 2.1; Box 10). The ecosystem service valuation follows a hierarchy of valuation methods (market prices, avoided costs, revealed preference and stated preference) using value transfer approaches and following best-practice guidelines. The monetary values are presented alongside physical values for all indicators, including biodiversity, and the effects on farm business income.

The IMP operates at various spatial resolutions depending on what scale is most appropriate for the indicator being simulated (e.g. sub-farm, farm, catchment). The finest spatial resolution that is used for simulating farm type and land use transitions is the Decision-Making Unit (DMU). A DMU is sub-farm (often field-scale) defined as a managerially homogenous cluster of soil type, rainfall, slope, altitude and land cover. The modelling outputs are generally presented graphically or as maps. Summary level data are available in addition to analysis at the sub-national level for the following indicators:

- Farm type and profitability
- Agricultural income
- Agricultural production
- Land use and livestock numbers
- Suitability of species populations for plants and birds

- Woodland habitat connectivity
- Woodland productivity and harvested wood products
- Carbon in soils, vegetation and biomass
- GHG emissions from land use, land use change and forestry, agriculture and peat
- Water quality (nitrate, phosphorus and sediment load)
- Water Framework Directive P status and drinking water N status
- Air quality (PM2.5 concentration and effects on human health)
- Monetary values across a range of ecosystem services over 5, 25 and 75 years

2.1 Model assumptions and quality assurance

The IMP has been designated as business critical by the Welsh Government. Business critical models are broadly difined as those where:

- the modelling drives essential financial and funding decisions;
- the model is essential to the achievement of business plan actions and priorities; or
- errors could engender serious financial, legal, reputational damages or penalties.

The IMP complies with the stringent quality assurance processes of the UK government Aqua Book[3], notably employing in its development, operation and application the principles of "R.I.G.O.U.R.": analysis should be **R**epeatable, **I**ndependent, **G**rounded in reality, **O**bjective, have **U**ncertainty managed and be **R**obust with respect to the initial question. Complying with the Aqua Book ensures analyses are conducted in a transparent manner with appropriate quality assurance of inputs, methodology and outputs in the context of the risks their use represents, and hence can be considered *'fit-for-purpose'.*

To address these issues, the ERAMMP IMP was developed following the principles of co-creation, taking an iterative approach that involved the modelling consortium and Welsh Government experts throughout. The principles of RIGOUR were strictly adhered to with all assumptions underlying the modelling approach agreed, transparently documented and signed-off by a Senior Responsible Officer within Welsh Government following a multi-stage iterative discussion between modellers and end users. In addition, modelling teams employed a range of appropriate methods for quality assurance, including validation, sensitivity analysis, contextualisation and interpretation, and detailing historical peer review, and produced a quality assurance document that detailed all these procedures.

The full set of assumptions and quality assurance procedures are detailed in Annexes 1 and 2. Key assumptions that should be borne in mind when interpreting the model outputs are:

[3] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/416478/aqua_book_final_web.pdf

- Changes in land use are assumed to be driven by on-farm economics and land suitability. They do not take into account off-farm / non-agricultural employment, skills or cultural and behaviour responses.
- As such, the IMP is applied only to full-time farms (> 1 FTE labour). Farms with less than 1 FTE of labour were excluded from the modeling as these smaller "micro farms" are likely to be farming for lifestyle reasons, with wages being made elsewhere. Hence, it would not be appropriate to predict their behaviour based on agricultural economic drivers.
- The simulated farm outcomes arise from the long-term change in farm profitability resulting from the long-term increases/decreases in farm-gate prices, and will occur over farm-specific timescales. However, for the purpose of the modelling, these transitions are assumed to happen in an unspecified short-term.
- The ecosystem service economic accounts presented are partial and based solely on the components explicitly mentioned. Other significant aspects (e.g. recreation) are not valued.

There are also significant assumptions within the Land Allocation Module of the IMP, which are described in detail in Annex-1. The rules and thresholds for the main transitions are:

- If a full-time farm fails to achieve an annual FBI of at least £6,000 p.a. in its current <u>and</u> any alternative modelled farming system, it is assumed that the farm is likely to leave full-time agriculture. Whether the farm transitions to part-time farming, diversifies into non-agricultural activities or leaves farming altogether is not modelled. As a simplification, the biodiversity and ecosystem service models in the IMP assume that such a farm will leave agriculture in the short-term, with the land undergoing natural regeneration or being afforested.

- If a full-time farm fails to achieve an annual FBI of at least £6,000 p.a. in its current farm type, but can achieve an annual FBI of at least £6,000 p.a. as an alternative farm type, it is assumed that the farm may change farm type (at some point in time), but it is likely to be through sale rather than through a purposeful change by the farmer.

- If a full-time farm achieves a modelled annual FBI of between £6,000-£13,000 p.a. in its current farm type (based on an upper limit of the national minimum wage), it is assumed that the farm will continue to operate as a full-time farm in its current form but is unlikely to change farm type (irrespective of the alternative farm types' FBI).

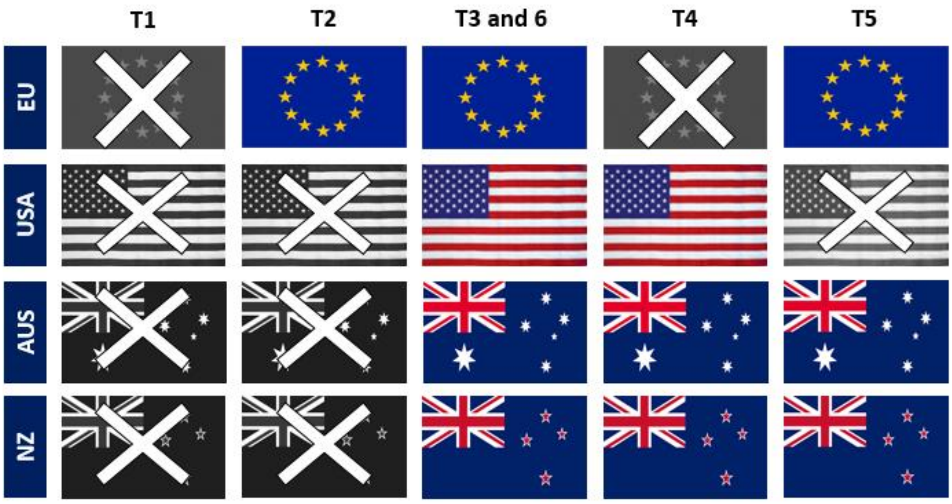
- If a full-time farm achieves a modelled annual FBI of more than £13,000 p.a. in its current farm type, then it is assumed that there are potential opportunities to change to a more profitable farm type if there is sufficient financial incentive. This incentive needs to be a minimum increase in the FBI of either £5,000 p.a. or 25% of current farm type's FBI <u>plus</u> an additional FBI increase of 10% of any additional tenants capital requirement for the specific farm type transition, whichever is greatest. There is also a constraint of a minimum dairy herd of 70 milking cows for new dairy farms.

This transparent, self-critical, iterative approach is essential to understanding how the model results should and should not be interpreted, as well as highlighting where information from others sources is needed to contextualise and support Welsh Government decision-making.

3 The scenarios

Six land use scenarios were developed in the last quarter of 2020 during six "virtual" discussion workshops held with stakeholders from the Roundtable Evidence and Scenarios sub-group. The workshops considered the evidence and possible impacts of a free-trade agreement (FTA) or no FTA with the EU, and future FTAs with third countries (focusing on USA, Australia and New Zealand). The evidence presented was drawn from information in the public domain, consisting of current trade volumes and prices, production costs and prices in third countries, their production standards and their capacity to increase their exports to the UK. The workshops also consideredas the possible outcomes of different combinations of these FTAs.

Stakeholders discussed their opinions on the expected changes in farm-gate prices for milk, beef and lamb that they considered consistent with the various combinations of trade agreements (Figure 3.1). The outputs from the workshop considered the potential implications of different trade arrangements on Welsh farming and land use, fishing, food, forestry, and rural economy and communities. Given these workshops took place before the FTAs with Australia and New Zealand were finalised, they are unlikely to accurately reflect the terms of the finalised agreements and the outputs should therefore be considered as illustrative.



	Baseline (2015)	T1	T2	T3 / T6	T4	T5
Milk (p/litre)	35	31.6	35.4	36.8/33.3	38.5	36.8
Beef (£/kg LWT)	1.85	1.02	1.80	1.48	1.39	1.57
Lamb (£/kg LWT)	1.68	1.19	1.66	1.43	1.26	1.51

Figure 3.1: Overview of the land use scenarios and their assumptions regarding FTA (indicated by the flag) vs no FTA (indicated by a cross) and farm-gate prices for baseline (2015) and each scenario.

The rationale for the the small changes in farm-gate prices if a trade deal that includes food products is achieved with the EU (T2) was that the significant impacts of high EU tariffs for Welsh products would be avoided. However, non-trade barriers would come into place resulting in additional costs from additional inspection work, bureaucracy, new infrastructure requirements and delays at ports. The possible consequences of no EU deal (T1) were considered to be disruption of established supply chains, which could cease to function if tariffs are applied to food products. This would lead to the loss of export markets for Welsh agricultural products and potential significant falls in farm-gate prices.

Stakeholders considered FTAs with Australia, New Zealand and the USA would be likely to exert significant influence on UK markets, and Welsh farm-gate prices. These three countries are strong exporters of agricultural commodities on global markets. The UK already trades such products with Australia and New Zealand with trade limited by tariffs and quotas. EU and UK trade in food products with the USA has been limited due to long standing disputes over production standards and certain animal diseases.

New FTAs with these countries could open up significant trade in agricultural products; gaining access to the UK market for these products will be a priority for them during trade negotiations. The UK has a close relationship with Australia and New Zealand and there is already a significant amount of trade with recognition of production standards. New Zealand lamb imports are unlikely to increase in the short-term because they have not filled their quota for many years and expansion of their dairy sector is reducing further growth in lamb production. This situation could quickly change if other export markets, such as China, suddenly close. In the long-term New Zealand could increase lamb exports to the UK if market conditions dictate that this is profitable.

Australia does fill its current EU tariff-rate quota (TRQ) for lamb and has the potential to expand if an FTA lifts or increases the TRQ, posing a potential threat to domestic lamb prices. Both Australia and New Zealand are exporters of beef and an increase in this trade could undermine UK beef markets (T5), although it is possible that this trade would directly compete with Republic of Ireland beef exports, currently the largest external beef supplier to the UK.

The Roundtable discussions also noted that imports to the UK from both New Zealand and Australia are currently subject to equivalence rules, which place restrictions on production standards for products destined for the UK although some products already imported do not meet UK standards. Trade deals which further lower current UK standards, produced at lower cost, would further undermine the UK price.

Stakeholders felt that trade in agricultural products with the USA would take time to develop as markets in both the UK and the USA are not yet established. There are also issues around the very different production standards used in their farming and food processing systems. The USA exports large quantities of beef, dairy product and pigmeat. Any targeted campaign to export these products onto UK markets could radically change the UK market for these products. On the positive side, the USA does offer a possible opportunity to export lamb. However, US specifications for lamb are currently very different to those in the UK. For example, the US market favours far heavier carcasses than the UK market currently supplies. At the time of these discussions, the small ruminants rule prevented carcasses from the UK entering USA markets. This is arguably a greater barrier to Welsh lamb entering the US market than tariffs.

Stakeholders felt that the biggest threats emerged in the combined impact of multiple FTAs. The combined impact of deals with both Australia and New Zealand looked likely to reduce both lamb and beef prices simultaneously, possibly to world price level (T5). This would have an enormous impact on the Welsh largely mixed grazing farming industry. This combined with a FTA with the USA would result in a trade environment that becomes very challenging for domestic producers. The scenarios with all trade deals in place (T3 and T6) shows domestic producers, Australia, USA, New Zealand and the EU all competing on UK markets.

The farm-gate prices from Figure 3.1 were applied to the ERAMMP IMP to assess impacts on land use, biodiversity and public goods. In the application of the scenarios to the IMP, it was assumed that there is no feedback between the scenario farm-gate prices and the IMP outputs. For example, the IMP runs did not take into account that simulated increases in dairy products may constrain milk price change as product supply and demand rebalance.

4 Summary of findings for each scenario

This section describes the outputs of the IMP run for each scenario. It focuses on the T2 scenario (the EU deal), which is the "business-as-usual" counterfactual scenario being used in the Cost Benefit Analysis of the land use implications of the proposed Sustainable Farming Scheme for the Agricultural Bill. Full results for all six scenarios are presented as slidepacks, available as Technical Annex 60TA1 [4].

4.1 EU deal only (T2 scenario)

Although price changes within the T2 scenario are relatively small, they represent a long-term change in the relative profitability of differing farming systems. Consequently, a significant number of farms are simulated to either (i) have opportunities to convert to a more profitable farm type because they achieve a minimum Farm Business Income (FBI) of at least £13,000 p.a. and there is a sufficient economic incentive to convert to a more profitable farm type [1488 farms], or (ii) are under economic pressure because they do not achieve a modelled FBI of at least £6,000 p.a. in their current farm type [774 farms]. Although 549 farms are simulated to leave full-time agriculture in T2 because their FBI is less than £6,000 p.a. and there are no alternative more profitable farm types, it should be borne in mind that 501 simulated farms fail to reach the £6000 p.a. threshold within the baseline IMP run.

The only farm types that are simulated to increase in numbers are dairy, mixed, and specialist beef in severly disadvantaged areas (SDA) (Figure 4.1). Conversely, reductions in the number of sheep and mixed grazing farm types are projected in disadvantaged areas (DA), SDA and non-DA/SDA. Dairy farm numbers increase in all Area Statement regions; largely at the expense of mixed grazing and specialist sheep (SDA) farm types. These simulations are based on the transition rules within the Land Allocation Model (LAM) of the IMP (see Section 2 and Annex-1). It should be noted that the IMP does not assume a time-frame over which farm type transition may occur, which will depend on farm-specific factors. However, the downstream models assume that such transitions occur in the short-term.

Simulated total or aggregate FBI from full-time farms under baseline and T2 (without and with transitions between farm types) is shown in Figure 4.2. If current full-time farms continue as currently (as would be likely in the short-term), simulated total FBI declines by about 8% under the T2 scenario, with the declines mostly being in lowland cattle and sheep farms and specialist sheep (SDA) farms. These declines are partially offset by a small increase within the current dairy farms. However, with farm businesses undergoing farm type transition, there is a potential 17% simulated increase in total FBI, despite the reduced number of full-time farms, due to significant increases in the number of dairy farms. Total simulated FBI from full-time farms increases in all Area Statement regions. The smallest increases are in Mid Wales

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[4] Harrison,.P.A., Dunford, R., Beauchamp, K., Cooper, J., Cooper, J.M., Dickie, I., Fitch, A., Gooday, R., Hollaway, M., Holman, I.P., Jones, L., Matthews, R., Mondain-Monval, T., Sandars, D., Seaton, F., Siriwardena, G.M., Smart, S.M., Thomas, A.R.C., Trembath, P., Vieno, M., Williams, A.G., West, B., Whittaker, F. (2022) *Environment and Rural Affairs Monitoring & Modelling Programme (ERAMMP)*. Technical Annex-1 Report-60TA1: ERAMMP Integrated Modelling Platform Land Use Scenarios Slidepacks. Report to Welsh Government (Contract C210/2016/2017)(UK Centre for Ecology & Hydrology Projects 06297 & 06810) www.erammp.wales/60TA1

and North West Wales due to the limited opportunities for the agricultural intensification needed for dairying.

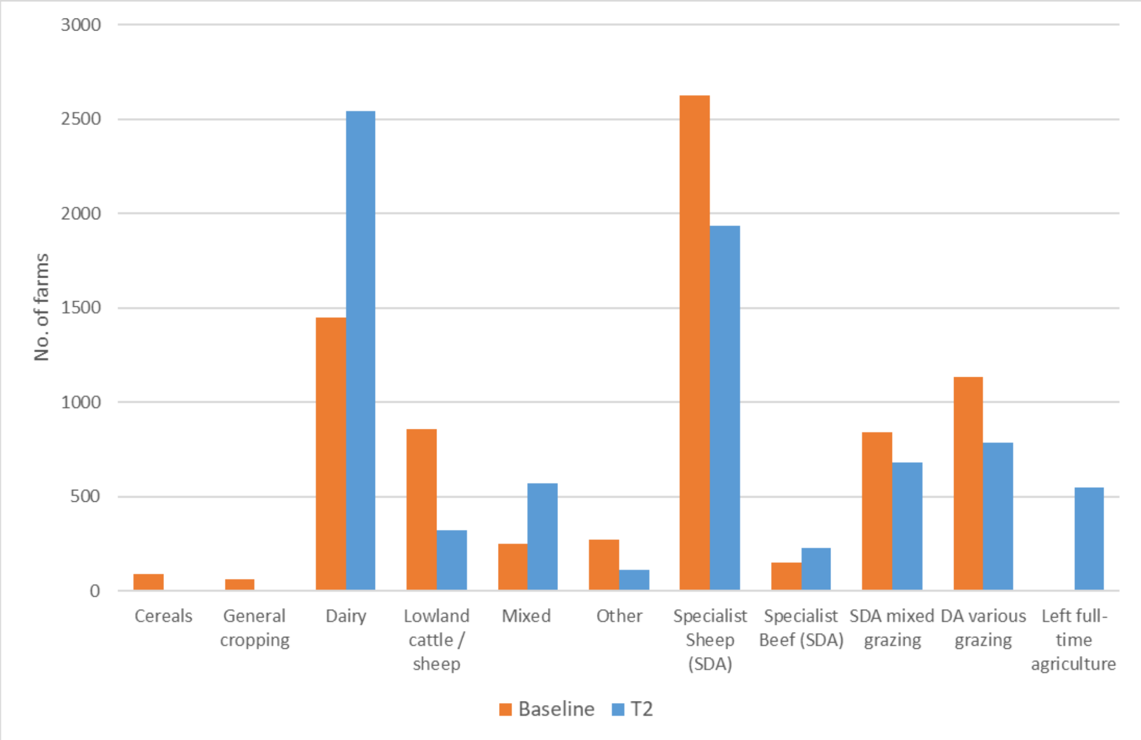


Figure 4.1: Simuated full-time farm numbers for each farm type under the baseline IMP run and the T2 scenario.

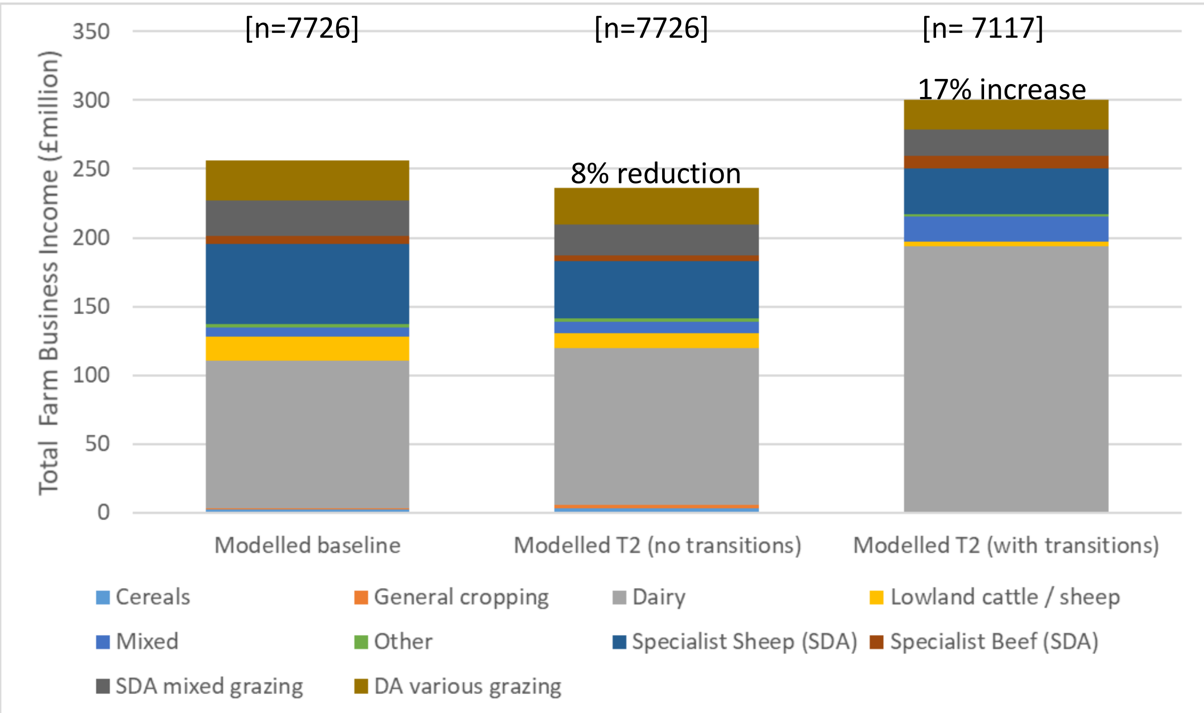


Figure 4.2: Total simulated FBI from full-time farms for the baseline IMP run and the T2 scenario.

An intensification of managed grassland systems is simulated on those farms remaining in full-time agriculture in the T2 scenario across Wales, with a 66% increase in temporary grass and a 21% decrease in permanent grass (Figure 4.3). This is associated with the large increases in dairy livestock numbers (+73%) and decreases in sheep numbers (-34%).

The simulated area of new woodland that is established through natural regeneration and afforestation on farms that are modelled to leave full-time agriculture is shown in Figure 4.4. The total area of new woodland is 6,060 ha. Afforestation is considered if land will generate a positive Net Present Value (NPV) and is suitable for tree growth (i.e. climatically-suitable, not too steep, not peat soil or in a protected area). If conditions on land that leave agriculture are not met for afforestation and land is suitable for trees, natural regeneration to unmanaged woodland is simulated. Most of the new forest simulated for the T2 scenario comes from afforestation (4,679 ha) rather than from natural regeneration (1,381 ha). If the land is not suitable for trees, natural regeneration to short vegetation is assumed.

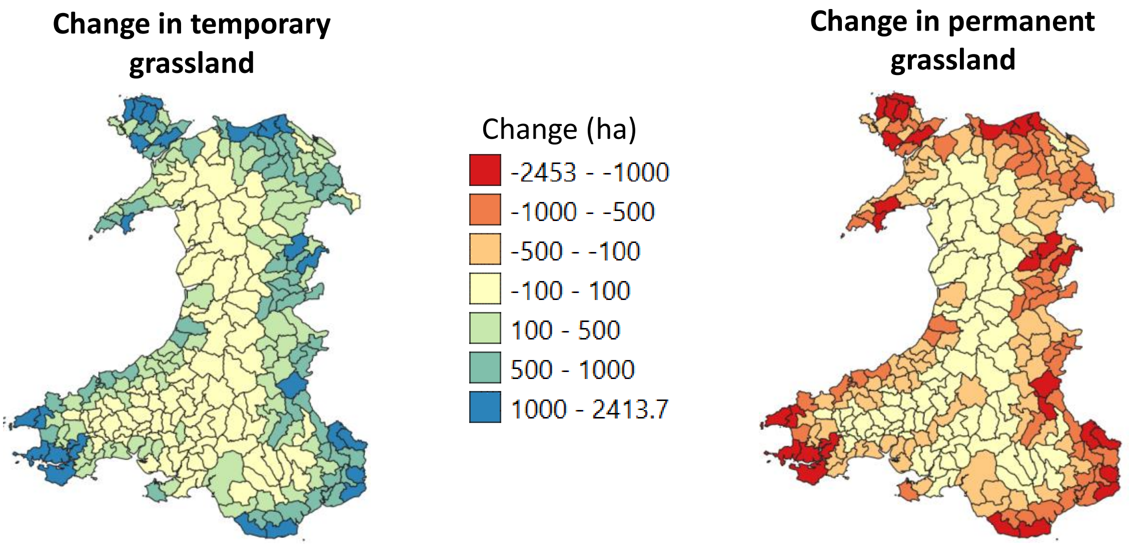


Figure 4.3: Simulated change in managed grassland for the T2 scenario.

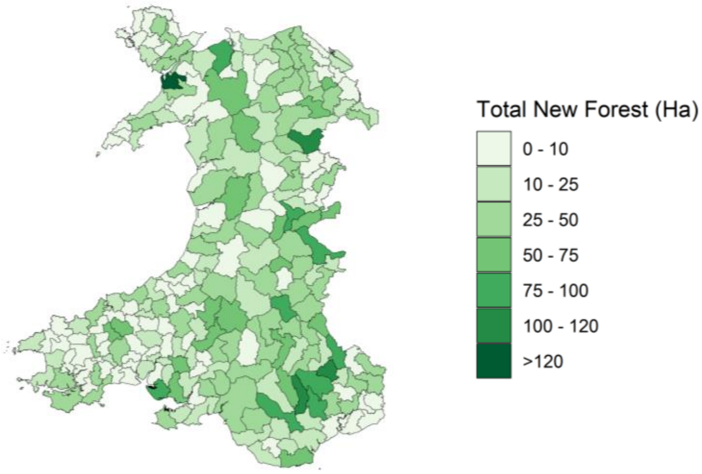


Figure 4.4: Simulated new woodland on farms leaving full-time agriculture under the T2 scenario.

These changes in land use and the intensification of grassland systems in some areas lead to variable effects on the suitability of ecological conditions for biodiversity across much of Wales. The majority of plant species are simulated to remain largely stable or decline, with 51% of plant species remaining stable, 32% declining and 17% improving. This can be broken down into either no change or decreases in suitable niche space for woodland and semi-natural habitat specialists (Figure 4.5). The small number of modelled arable specialists also largely remain stable reflecting minor change in arable land under the scenario. These patterns are similar across all regions, except for South Central Wales where no change is simulated for woodland, arable and semi-natural habitat plant specialists.

For birds, most species are simulated to maintain stable population sizes under the T2 scenario, but 19% of bird species are projected to decline, whilst 3% improve (Figure 4.5). These changes reflect the simulated changes in land use, specifically increases in the cover of maize, rotational grass and coniferous woodland. Declines are expected to be similar across Wales, although more species are in the category of “possible decline” in North East and South East Wales.

The increase in new woodland through afforestation or natural regeneration was also simulated to lead to small improvements in woodland habitat connectivity. This was greatest in South East Wales for invertebrate species with relatively low dispersal distance (500m), but some gains in connectivity are simulated for all regions for such species.

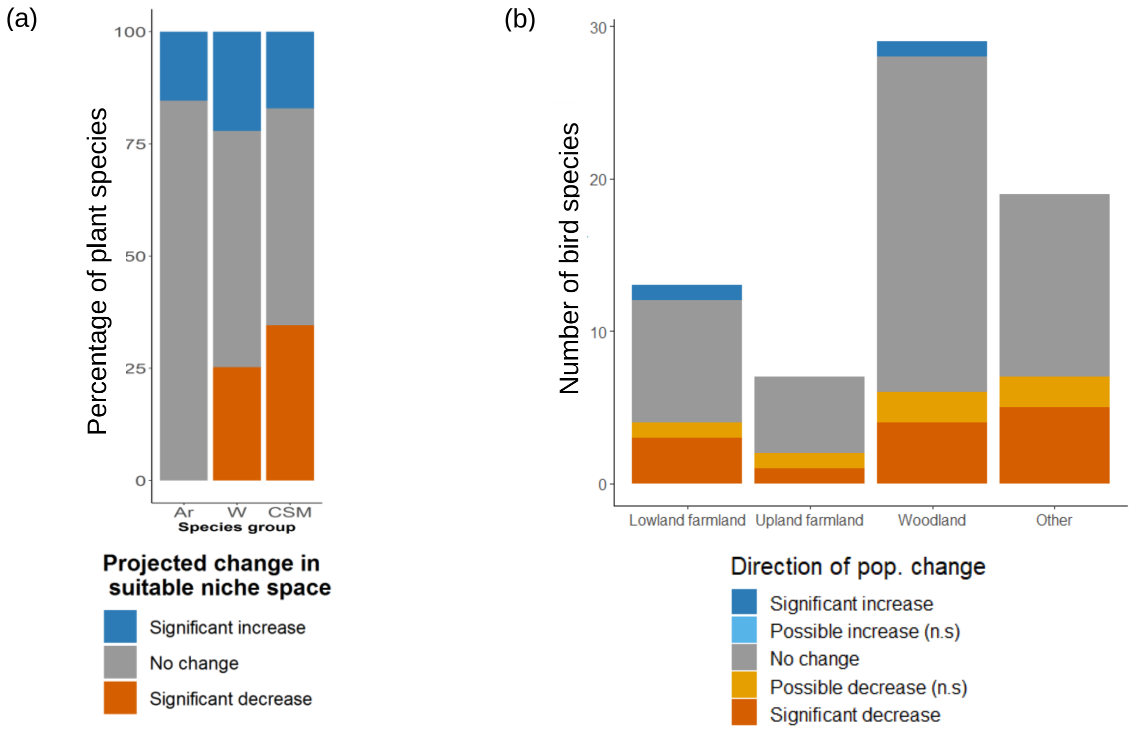


Figure 4.5: Summary of simulated national changes in biodiversity indicators for the T2 scenario: (a) change in habitat suitability for plants (Ar = Arable plant species specialists; W = Woodland plant species; CSM = semi-natural habitat (Common Standard Monitoring) specialists; and (b) change in bird populations grouped by dominant habitat type.

Three ecosystem services are modelled by the IMP: carbon sequestration/greenhouse gas (GHG) emissions, water quality and air quality. For carbon, a net decrease in carbon stocks by 2100 and increased GHG emissions are simulated for the T2 scenario, creating a net increase in atmospheric GHGs. The overall carbon budget is dominated by the modelled increases in GHG emissions associated with changes in livestock (increases in dairy cattle and decreases in sheep) and nutrient inputs (113,194 KtCO_2eq by 2100), which greatly exceeds the predicted emissions from vegetation and soils associated with agricultural land use change (9,668 KtCO_2eq by 2100; LULUCF 4 A,B,C & G).

The LULUCF categories show that carbon in cropland and grassland systems (LULUCF category 4B + 4C) is simulated to be lost in the T2 scenario due to conversions from permanent grassland into arable/grass rotation. However, small gains in carbon in cropland and grassland systems are also simulated due to land leaving full-time agriculture. Furthermore, some gains in carbon storage are simulated for forest land and harvested wood products related to agricultural land that is converted to woodland (LULUCF categories 4A and 4G).

The spatial distribution of simulated changes in LULUCF carbon stock is shown in Figure 4.6a. Carbon stocks are simulated to increase in some areas and decrease in others, whilst some have no change. Areas of decrease reflect the modelled reductions in areas of permanent grassland, and increases in improved grassland and arable-grass rotations. Areas of increase reflect new woodland (see Figure 4.4), largely due to the significant carbon storage potential of biomass and harvested wood products. Some increase may also be attributed to sequestration on land reverting to short vegetation.

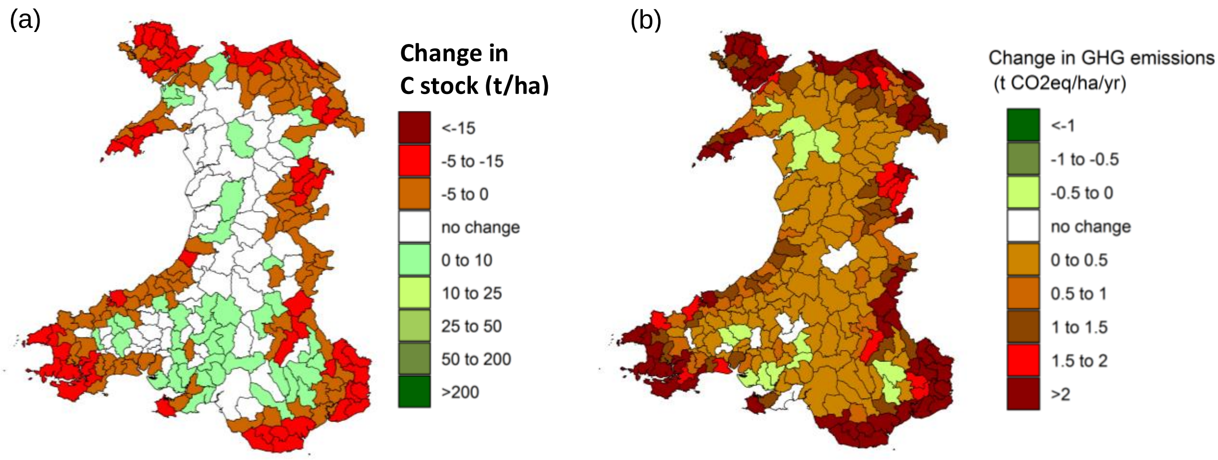


Figure 4.6: Simulated changes in (a) carbon stocks based on data for LULUCF categories 4 A, B, C and G; and (b) GHG emissions from livestock and management. Data are displayed per ha of land modelled within small agricultural areas.

The spatial distribution of simulated changes in agricultural GHG emissions is shown in Figure 4.6b. Increases and decreases reflect patterns of changes in livestock numbers/type, land use and management. Increases are seen in most areas reflecting increased intensity, with greater areas of conversion to arable/temporary grassland to support the simulated increases in dairy cattle, which are not offset by smaller decreases in sheep.

In addition, GHG emissions from wetlands are simulated to decrease slightly, reflecting land that is simulated to come out of agriculture on peat. However, this area is relatively small resulting in reduced emissions of 91 KtCO_2eq by 2100.

For water quality, the simulated changes in farm type, land use and management, and associated pollutants, result in a 26% increase in total nitrate loading and a 11% increase for total phosphorus loading for full-time farms modelled by the IMP. In contrast, a very slight decrease in sediment is simulated. Overall, these results reflect the increase in dairy cattle and increased nutrient inputs, set against a contraction of rough/permanent grass and sheep.

Simulated changes in WFD phosphorus status and drinking water nitrate status for catchments is shown in Figure 4.7. WFD phosphorus status is projected to deteriorate under the T2 scenario in several catchments, reflecting the increased agricultural intensity associated with the transition of some farms to dairy. Conversely, WFD phosphorus status is projected to improve in some catchments where land transitions to non-agricultural uses, including woodland. The pattern of status change reflects the spatial pattern of thresholds as well as the changes in loading. Drinking water nitrate status is projected to deteriorate in key areas coinciding with expansion of dairy. The spatial pattern reflects baseline concentrations in relation to the drinking water quality threshold as well as the changes in loading. For sediment loading, the spatial distribution of simulated changes shows an increase for areas where dairy expands and a decrease for the many catchments where sheep numbers decline.

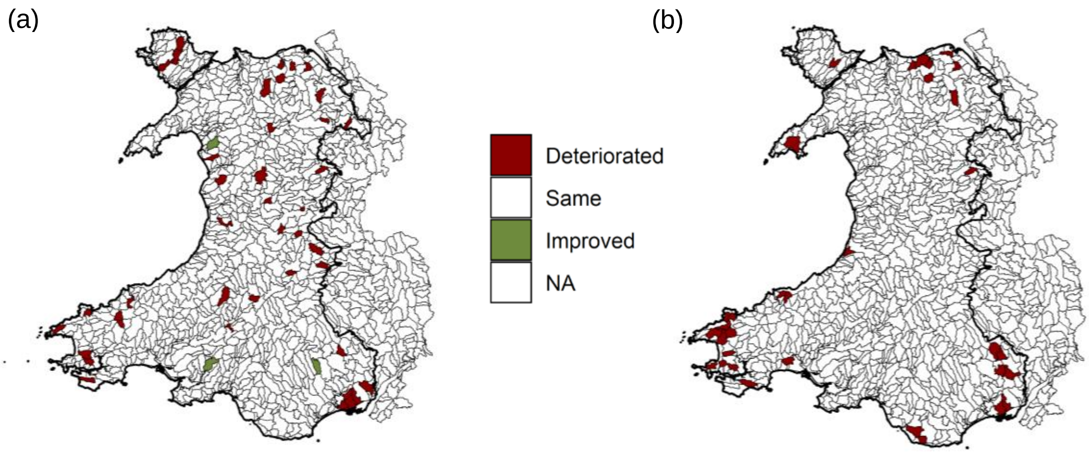


Figure 4.7: Simulated change in: (a) WFD phosphorus status; and (b) drinking water nitrate status. Note: P thresholds are UKTAG defined annual average phosphorus concentrations for WFD status based upon elevation and alkalinity, and are spatially variable. N thresholds are based on the Nitrates Directive threshold of 11.3 mg /l Nitrate (as NO3-N) for the 95th percentile concentration.

For air quality, PM2.5 concentrations are simulated to increase slightly on average for Wales (+0.04 $\mu g/m^3$). This is a result of increased ammonia emissions due to the simulated transition to, and intensification of, dairy farms combined with only small increases in woodland planting. This leads to an annual net health dis-benefit of an increase in 59.5 Life Years Lost. The spatial distribution of health outcomes are a function of change in exposure of the population. This results in the greatest dis-benefits being seen in parts of North and South Wales, with overall dis-benefits ranging from 0.002 Life Years Lost per year in Merthyr Tydfil to 6.55 in Denbighshire (Figure 4.8). The only exception is projected for Blaenau Gwent, where a minimal net positive benefit is simulated of a reduction in Life Years Lost of 0.24 per year.

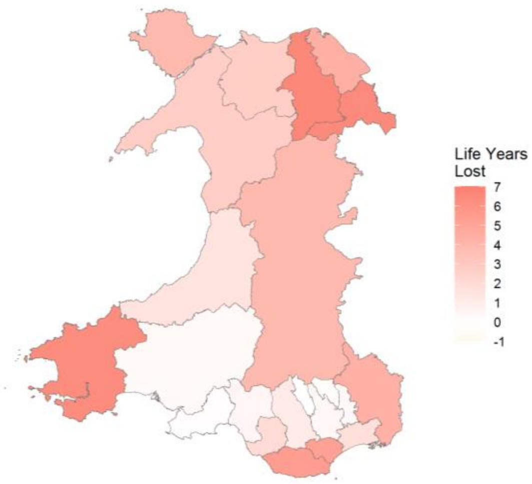


Figure 4.8: Change in Life Years Lost per year across the population due to change in PM2.5 concentration and exposure of populations in different regions of Wales.

The three ecosystem services are valued in monetary terms in the IMP as well as physical values (Table 4.1). The monetary values are broken down over time and by source for carbon/GHGs in Table 4.2. A sustained loss of value of all three ecosystem services is simulated under the T2 scenario. The greatest per ha cost comes from carbon and GHGs due to increased agricultural emissions and some LULUCF losses. Costs are simulated for all regions in both increased agricultural emissions and LULUCF losses. Smaller benefits are simulated for all services in some regions, particularly for carbon, which reflects land going to non-agricultural uses. Similarly, very small benefits are simulated for peatland GHGs in most regions, except for South West Wales, as a small area of land comes out of agriculture on peat.

Table 4.1: Summary of ecosystem service values under the T2 scenario. Note: the figures are an estimate of the value of the change in wellbeing to people over 75 years under this scenario and indicate order of magnitude of values of expected changes in the Welsh Environment.

Benefits	Physical measure	Units	Present value, 75 yrs, £	Type of value
Air Quality	Increase of 60 years	Life Years Lost each year	- £84m	Reduction in costs of health impacts from air pollution
Water Quality	65 Deteriorate, 3 Improve	Expected changes in WFD status due to changes in phosphorus per catchment	- £33m	Benefit to people from knowing of/ enjoying higher quality freshwater environments
GHGs	Increase of 117m tCO_2e	Net change in atmospheric tCO_2eq over 75 years	- £14,741m	Benefit of reducing atmospheric GHG concentrations from non-traded sources

Table 4.2: Breakdown of ecosystem service monetary values for the T2 scenario. Note: all figures are based on simplifying assumptions of change over time.

Benefits	Present value, £m			Type of value
	2025	2050	2095	

Air Quality	-£4m	-£33m	-£84m	Reduction in costs of health impacts from air pollution
Water Quality	-£5m	-£22m	-£33m	Benefit to people from knowing of/ enjoying higher quality freshwater environments
GHGs:				Benefit of reducing GHG sources:
Agriculture	-£1,681m	-£8,028m	-£12,887m	Agricultural sources (livestock and inputs)
Land use	-£698m	-£1,707m	-£1,864	Land use changes
Wetlands	£1m	£6m	£10m	Wetland sources (peatlands)
Total GHGs	-£2,377m	-£9,728m	-£14,741m	Benefit of reducing atmospheric GHG concentrations from non-traded sources

4.2 Other scenarios

The other five scenarios simulate more extreme changes in IMP outputs than the T2 scenario, as they are associated with larger long-term price changes. These are described briefly here with reference to Figures 4.9 and 4.10, but full outputs are provided in Technical Annex 60TA1 (www.erammp.wales/60TA1).

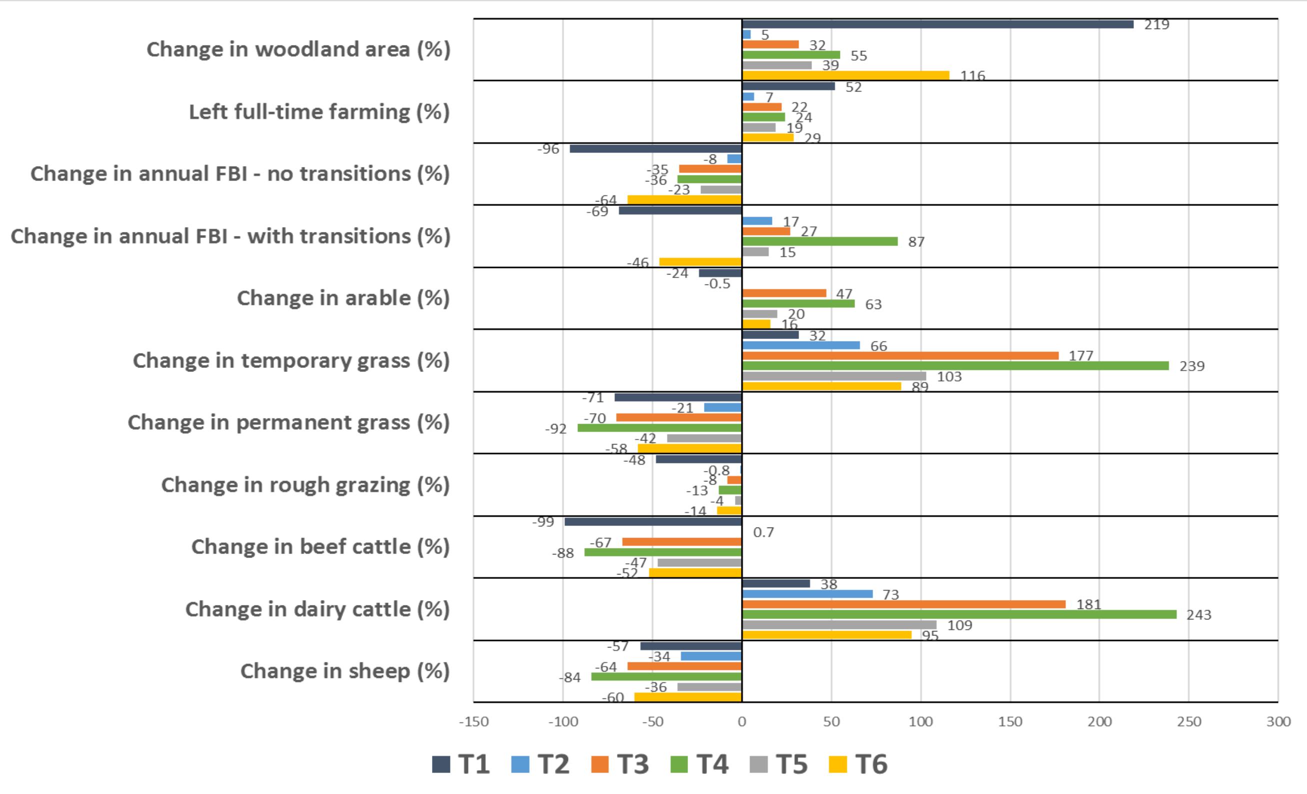


Figure 4.9: Summary of IMP outputs on agriculture and land use change for all six scenarios.

Overall, all the scenarios result in simulated increases in the area of woodland and temporary grassland, with concomitant decreases in permanent grassland and smaller decreases in rough grazing land (Figure 4.9). The T1 scenario, followed by T6, is the most extreme for increases in woodland area, whilst T5 and T3 are the least extreme (besides T2). For grassland, the T3, T4 and T5 scenarios simulate very large increases in temporary grassland

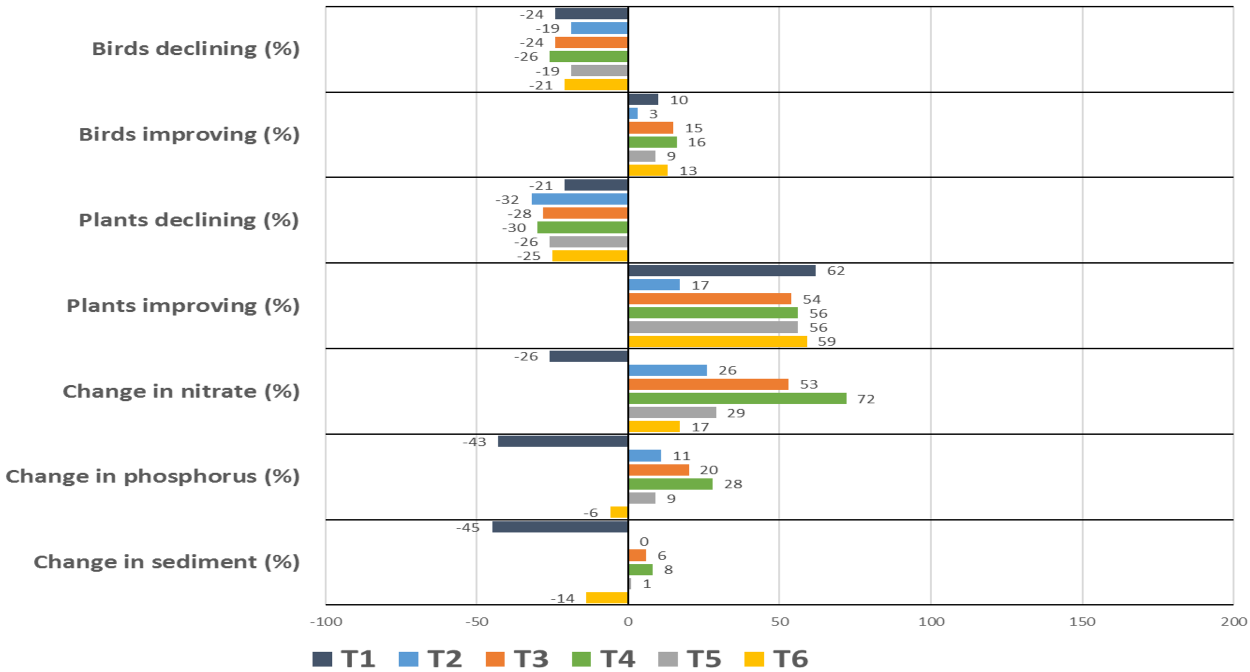
(>100%), whilst T3, T4 and T6 simulate large decreases in permanent grassland (>50%). There are generally smaller decreases in rough grazing (<15%) in all scenarios, except T1, which simulates a 48% decrease.

These land use changes are driven by the more significant lamb and beef price reductions in these scenarios, compared to T2. These price reductions are very challenging for the current full-time farms in Wales and lead to significant numbers of simulated farms leaving full-time agriculture (ranging from 19% in T5 to 52% in T1) (Figure 4.9). This releases agricultural land that is converted to woodlands through afforestation, or to woodland or short vegetation through natural regeneration of the land.

The large reductions in farm-gate prices for lamb and beef also mean that there are fewer simulated farms that can change to more profitable farm types through deliberate action rather than through sale and purchase within the T1, T3, T4 and T6 scenarios. Farm type transitions lead to increases in only dairy farms in all scenarios, with reductions in the number of sheep, beef and mixed grazing farm types in DA, SDA and non-DA/SDA. This reflects the increased relative competitiveness of dairying compared to sheep and beef farming. These farm type transitions result in simulated increases in the number of dairy cattle (from 38% under T1 to 243% under T4), and decreases in the number of sheep (from 36% under T5 to 84% under T4) and beef cattle (from 47% under T5 to 99% under T1) (Figure 4.9).

All scenarios show negative impacts on the simulated aggregate FBI for current full-time farms without farm type transitions (Figure 4.9). In all cases, simulated transition of farms (through deliberate action or sale and purchase) either leads to smaller reductions in aggregated FBI (e.g. T1 and T6, where prices decrease in all sectors, but by a smaller amount in the dairy sector) or to an increase in simulated aggregate FBI for the remaining full-time farms (e.g. T3, T4 and T5 due to the increased milk prices).

(a)



(b)

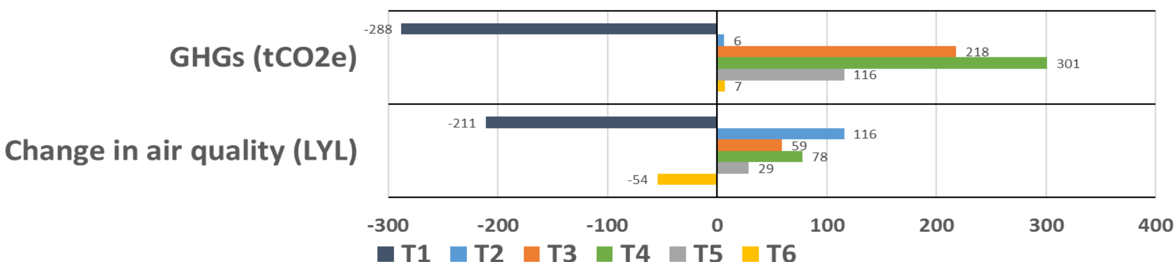


Figure 4.10: Summary of IMP outputs on biodiversity and ecosystem services for all six scenarios: (a) change in biodiversity and water quality outputs shown as percentage change from the simulated baseline; and (b) GHGs/carbon and air quality shown as absolute change from the simulated baseline.

The changes in farm types and associated land use result in mixed simulated impacts on biodiversity. All scenarios show relatively similar declines of 19-26% for bird species and 21-30% for plant species. Improvements in the suitability of habitats for species are also similar across scenarios, but are greater for plant species (54-62%) than for for bird species (9-16%). The majority of bird species populations that are predicted to significantly increase were those that specialise in woodland habitats, with T3, T4 and T6 being the most favourable scenarios. Improvements in suitable niche space for plant species are simulated across woodland, semi-natural and arable habitats, with the greatest increases occurring in the T1 and T6 scenarios. In addition, almost all new woodland is simulated to create an increase in woodland habitat connectivity. This is greatest under the T1 and T6 scenarios, which simulate the greatest increase in new woodland.

In terms of impacts on ecosystem services, the T3 and T4 scenarios predict the greatest change in GHG emissions, the highest negative impacts of air quality on health, and the highest increase in nitrate and phosphorous concentrations and sediment load – leading to the worst water quality - of the five scenarios. These changes in the T3 and T4 scenarios are associated with the large shifts to dairying. Conversely, the T1 scenario projects the greatest benefits in terms of reductions in GHG emissions, increases in carbon sequestration, and improvements in water quality and air quality. This is associated with the large number of farms that come under pressure and are simulated to leave full-time agriculture, with much of this land transitioning to woodland. The only other scenario that is not associated with losses for LULUCF carbon is T6 where final sequestration almost counterbalances the increased agricultural GHG emissions. This scenario also has simulated positive impacts on both air and water quality (sediment and phosphorous), and the lowest increase in nitrate compared to T3-T5.

Monetary valuation of the ecosystem services follows the same pattern as the physical indicators, with values in most scenarios representing a cost (i.e. a reduction in the monetary value of the service). Overall, costs are greatest for the T4 and T3 scenarios and least for the T6 scenario, which simulates benefits for water and air quality combined with a lower cost for carbon/GHGs than the other scenarios. The T1 scenario is an exception, with simulated benefits for all three ecosystem services that are particularly large for LULUCF carbon due to the large area of simulated new woodland and associated carbon sequestration.

5 Conclusions

The six scenarios of potential changes in farm-gate prices applied to the ERAMMP IMP result in large impacts on the Welsh landscape in terms of land use change, biodiversity, and ecosystem services and their monetary value. The development of the scenarios, T1 to T6, was undertaken before the terms of the UK leaving the EU were agreed, therefore discussions were based on broad assumptions around what a deal with the EU, as well as other third country trading partners would include. Stakeholders providing expert opinion tended to consider worse case scenarios and would have been influenced by the possibility of leaving the EU with no trade deal and trading under WTO rules. Their experience is that any disruption in the supply and demand of milk, beef and lamb has a large impact on farm-gate commodity price. For example, an increase in milk supply in 2015 reduced the milk price paid to farmers by over 40%.

If the UK market is opened to tarrif free trade with countries that are strong exporters of agricultural products, then stakeholders considered that it is possible to see UK farm-gate prices coming closer to prices on global markets. The scenario assumptions foused on longer term trends in farm-gate price changes and not the immediate short-term changes caused by changing supply chains. The modelling of these scenarios is therefore representative of a time when the assumed changes have reached a steady state, this time period is not defined.

The T2 scenario represents the EU trade deal, and is currently being used as the business-as-usual counterfactual against which the proposed Sustainable Farming Scheme is being assessed. Below is a summary of the main conclusions that can be drawn from these runs of the ERAMMP IMP, focusing on the T2 scenario.

EU trade deal (T2) scenario

The T2 scenario simulates the effects of relatively small changes in farm-gate prices. This results in some farms coming under economic pressure who are simulated to leave full-time agriculture; mainly sheep and mixed grazing farms. Alternatively, other farms are simulated to transition to more profitable farm types, principally to dairy, mixed or specialist beef farms. If full-time farms continue as they are currently (i.e. with no farm type transitions), total FBI is simulated to decline by about 8% under the T2 scenario, but with farm type transitions total FBI is simulated to increase by 17% due to the increased number of dairy and beef farms.

The shifts in farm type due to profitability cause a simulated intensification of agricultural land, with a substantial increase in temporary grassland, alongside a smaller decline in permanent grassland. This is associated with large increases in dairy cattle and reductions in sheep. In addition, the T2 scenario simulates a small increase in woodland that is established primarily through afforestation on land that is simulated to leave full-time agriculture.

These changes in land use and land management have some important mixed, but predominantly negative, consequences for biodiversity, GHG emissions, water quality and air quality. Overall, simulated biodiversity remains relatively stable in the T2 scenario, with 72% of bird species populations and 51% of plant species remaining stable. This is particularly true for plant species in arable land, as no species are predicted to decrease. The increases in woodland area also improve habitat connectivity for invertebrate species with low dispersal distances, particularly in South East Wales. However, the slight intensification of arable habitats and increases in coniferous woodland also result in a number of species declining, about 20% of bird species and 32% of plant species. For birds, this reflects increases in maize cover, rotational grassland and coniferous woodland; for plants this is largely due to reduced niche space in woodland and semi-natural habitats.

Small increases in carbon stock are simulated in some areas due to farms leaving full-time agriculture and corresponding increases in woodland area. However, this is not suffcient to offset the carbon losses due to decreases in permanent grassland and increases in temporary grassland and arable-grass rotations. GHG emissions from agriculture are also simulated to increase due to the greater number of dairy cattle. Overall, this results in a net decrease in carbon stocks and a net increase in atmospheric GHG emissions.

These patterns for carbon stock and GHG emissions are reflected in the simulated impacts on water quality and air quality. Total nitrate and phosphorus loads are simulated to increase because of increases in dairy cattle numbers and their associated nutrient inputs. These are therefore concentrated in catchments where dairy farming expands. Similarly, air quality is simulated to deteriorate in areas where farms convert to dairy, which leads to an overall net health dis-benefit of almost 60 Life Years Lost per year. Conversely, in areas where land transitions to non-agricultural uses such as woodland, due to farms leaving full-time agriculture and woodland expansion, measures of water and air quality are simulated to improve.

The increased agricultural emissions and LULUCF losses result in a net decrease in the value of all three ecosystem services under the T2 scenario. However, there are smaller increases in the value of carbon in some regions, and for peatland GHG emissions in isolated cases, related to land coming out of agricultural use.

Other scenarios

Simulated changes in land use in the other scenarios are more extreme than those predicted under the T2 scenario. In large part, this is due to greater reductions in lamb and beef prices, which result in a significant number of farms being simulated as leaving full-time agriculture. This is exacerbated in those scenarios where milk prices also decrease (T6 scenario), where there are less opportunities for farm type transitions. In all other scenarios, milk prices increase by between 5 and 10%, leading to substantial transitions to dairy farms (predominantly in scenarios T3 and T4). This is also associated with decreases in the numbers of sheep, beef and mixed grazing farm types.

All scenarios simulate greater increases in woodland and temporary grassland than the T2 scenario, with concomitant losses in permanent grassland and to a lesser extent in rough grazing. The largest increases in woodland are simulated in the T1 scenario. These land use changes result in negative impacts on simulated aggregate FBI for full-time farms without farm type transitions. Transitions of farms leads either to smaller reductions in FBI or increases in FBI for remaining full-time time farms, depending on the relative price of milk.

The land use changes projected in the scenarios other than T2 result in generally negative impacts on biodiversity and ecosystem services. All scenarios project overall declines in bird and plant species. However, populations of woodland bird species are simulated to significantly increase in some scenarios. This reflects the increase in available woodland habitat due to farms leaving full-time agriculture. The large numbers of farms that are simulated to transition to dairy in the T3 and T4 scenarios result in considerable negative impacts on carbon, water quality, air quality and health. This is reflected by the monetary valuation of the ecosystem services, with the T3 and T4 scenarios having the greatest associated costs. All three ecosystem services showed benefits in the T1 scenario, which are partly as a result of the large increase in woodland and the associated carbon sequestration.

Annex-1: Full List of IMP Assumptions

This Annex describes the assumptions underlying the Integrated Modelling Platform (IMP) and its constituent models/methods that have been agreed between the IMP team and a Welsh Government Expert Working Group.

This version was signed-off to cover the land use scenario work on 26/04/2021.

Abbreviations:

- DMU: Decision Making Unit – a managerially homogenous cluster of soil type, rainfall and land cover.
- FTE: Full Time Equivalent (job)
- IMP: Integrated Assessment Platform – the series of linked models being developed to explore cross-sectoral interactions and potential unintended consequences of policy interventions within ERAMMP.
- LAM: Land Allocation Module – the central module within the IMP that simulates how landowners might respond to the scenarios and policy interventions through farm and land use transitions using a set of rules and thresholds.
- LFA: Less Favoured Areas (the sum of DA + SDA).
- N, P, Z: Nitrogen, Phosphorous, Sediment (water quality indicators)
- NPV: Net present value – comparable economic indicator used by both forest and farm models to allow on-farm profit decisions to be made.
- SDA: Severely Disadvantaged Area (UK basic payment scheme designation for poor quality, often upland farmland). Likewise, DA = Disadvantaged Area.
- RFT: Robust Farm Type – broad farm categories developed by ADAS to be comparable across the UK. EFT: ERAMMP Farm Type - In ERAMMP we combine the RFTs with categorisations of LFA for Wales: Cereals, General cropping, Dairy, Lowland cattle / sheep, Mixed, Specialist Sheep (SDA), Specialist Beef (SDA), SDA mixed grazing, DA various grazing.
- WFD: Water Framework Directive (policy).

GENERAL

1. Farms under 1 FTE are excluded from the modelling and are not included in the IMP's underlying DMUs:
    a. The 1 FTE agreement is a legacy from ERAMMP Quick Start where it was agreed with WG.
    b. The logic was that at beneath 1 FTE, farmers were farming for lifestyle reasons ("micro farms") and made their wages elsewhere and that it didn't therefore make sense to try and predict their behaviour based on economic drivers.
    c. We recognise that there are alternative cut-offs (e.g. the €25,000 Standard Output) and that this would have the advantage of a direct link to the Farm Business Survey.
    d. Basing the decision on Standard Output, Standard Labour or Standard Margins is largely a matter of choice. They are all broad proxies based on weighted sums of livestock numbers and crop areas. They identify a broadly similar set of farms as "micro", although the Standard Labour has more "micro" farms than the others.

e. IMP version 1 will continue to use the 1 FTE threshold. Alternative approaches could be discussed for later versions. The following are the implications of changes to the DMUs as a result of a new approach to the cut off:
    i. SFARMOD, the LAM and the ecosystem service models and the Interface would need to reproduce all of our spatial inputs which would take significant time;
    ii. SFARMOD would run more slowly;
    iii. The ecosystem service models would need some recoding;
    iv. We would have to reprocess the ESC forestry data to the new DMUs.

2. Where the IMP modelling team and WG agree that values are particularly uncertain, sensitivity analysis will be undertaken (as specified below). The IMP team will document these results and make them available to WG.

FARMLAND

3. The agricultural model, the Silsoe Whole Farm Model (SFARMOD), uses a combination of relationships driven by soil types and annual rainfall and farm category averages to simulate farm management choices and practices. This assumes that these values are representative of the range of farm practices, land types, finances, etc. for each farm category. A farm is modelled as a set of multiple relatively homogenous blocks called DMUs. The IMP team recognise that this is a significant assumption and explicitly acknowledge the heterogeneity between and within farms that it is not possible to include with the available (particularly spatially-explicit) data.

4. The on-farm modelling is based on profit maximisation and applies a long-term (>5 year) perspective. We recognise that this is an imperfect approach, as not all (<25%) farms self-report as being driven by profit maximisation/farm output. However, this is a pragmatic assumption and there are limited alternatives that can be justified in comparison. When aggregated, profit maximisation is one of the best predictors of the collective behaviour of the population of farmers with the idiosyncrasies of individual farmers can be thought of as creating noise.

5. The baseline scenario uses activity and economic data for the harvest year 2015 to tie in with the land cover map dataset. Prices, however, reflect a longer time period to protect against peaks and troughs.

6. Typical input economic data are those used by farmers for planning, hence, ignoring spikes in costs and revenues. Data from farm planning cost books, such as John Nix Pocketbook or The Agricultural Budgeting and Costing Book (ABC), are longer term averages used to derive expected values.

7. Basic payment scheme subsidy levels in the baseline run are based on best estimates of the earlier stratified schemes that are being phased out, but were still active in 2015. Averages of the higher level schemes are also applied where the data by farm type are robust enough.
    a. Pillar 1 Basic Payment Scheme (BPS). The descriptions of the available payments were taken from the Agricultural Budgeting and Costing Book No. 83 – November 2016 historical values to reflect what was paid out in 2015. It is acknowledged that due to a legacy of bespoke payments and transition to a flat rate scheme that a range of values were paid. For the baseline modelling, we are applying:
    (i) a flat rate average 107.6 EUR (£78.70);

(ii) + 25.6 EUR (£18.72) redistributive payment on the first 54 ha.

We are not including + 52.8 EUR (£28.61) greening payments as GLASTIR is considered to be cost-neutral.

b. The payments (i) are being implemented in the SFARMOD optimization across all farmable land.
c. Payment (ii) is added during the post processing of SFARMOD outputs up to 54 ha when we aggregate the DMUs to farms.
d. Pillar 2 payments – Rural Development Programme. The Land Allocation Module (LAM) brings together farming and non-farming costs and revenues to derive overall farm profits. We assume that these grants do not affect the baseline because (1) the grants relate to the wider rural economy, (2) in the baseline we assume farm woodland is revenue neutral and managed at cost, or (3) the grants are revenue neutral and cover costs plus revenue forgone. The available schemes are:
   (i) Glastir (Entry, Advanced, Commons, Organic, Woodlands, Small Grants Scheme);
   (ii) Other grants (Sustainable Production Grant; Knowledge Transfer and Innovation and Advisory Service; Leader; Timber Business Investment Scheme; Cooperation and Supply Chain Development Scheme; Food Business Investment Scheme; Sustainable Management Scheme).

8. Baseline runs will use central estimates of subsidies, prices and costs, acknowledging that actual farm profitability ranges considerably. Some of this heterogeneity is captured by modelling the different soil types, rainfall levels, slopes and land cover within farms.

9. Baseline farm woodland generates no income, i.e. is managed at cost. It might be that it is unmanaged or managed for recreation. However, on this scale it is unlikely that timber is being harvested and, if it is, that any income covers not much more than the cost of harvest. Therefore, existing areas of farm woodland are inert in the baseline and do not form part of the optimisation or estimation of farm profitability.

10. In scenario runs, all improved grassland that can technically be cultivated is considered to be potentially able to convert to cropland. NB areas above 400m are excluded to protect hills from being ploughed.

11. Conversion of rough grazing to improved pasture is not considered. In this situation the soils are assumed to be not cultivatable / plough-able due to thin, steep, or wet soils and may also be too steep to work safely and apply fertilisers and other inputs.

12. SFARMOD can only model one set of livestock on one DMU. A DMU whose baseline Robust Farm Type contains more than one stock option (e.g. mixed lowland cattle and sheep) is assumed to be sheep for rough grazing, and cattle on improved grazing. This assumption is being sensitivity tested.

FORESTRY

13. Species selected for each forest type:
    a. Productive conifers: Sitka spruce (*Picea sitchensis*), Douglas fir (*Pseudotsuga menziesii*), Scots pine (*Pinus sylvestris*);
    b. Native broadleaves: oak (*Quercus*), beech (*Fagus*), aspen (*Populus*), birch (*Betula*);
    c. Short rotation forestry: Sitka spruce (*Picea sitchensis*), red alder (*Alnus rubra*), poplar (Populus).

14. Planting year: the models assume all new forest would be planted in year 1 (2020). This could be reviewed for later versions if needed.

15. The modelling for unmanaged forest will be less accurate that the modelling for managed forestry. FR models (ESC and CARBINE) are designed to represent managed forests. This has implications for scenarios that involve abandonment or natural regeneration as unmanaged forest doesn't achieve the same stocking density, growth rate or timber quality, and whether or not land naturally regenerates to forest will depend on additional criteria not modelled within ESC, such as deer/rabbit/cattle browsing, proximity to other forests for tree seed source, and competition vegetation types:
    a. Naturally regenerated areas are modelled as low yielding mixed species stands;
    b. This gives an approximation of the ecosystem services provided but is less accurate than planted stands.

16. The ESC suitability scores are compared to thresholds within the LAM to determine (i) where plantation forestry may be considered as an alternative land use and (ii) where natural regeneration to woody vegetation/trees is possible: 0.5 is used plantation forestry and 0.3 for natural regeneration potential. These values are in line with other published work by FR. This is an area where sensitivity analysis could be considered.

17. Woodland carbon data from CARBINE has been adjusted for the influence of rotation lengths as follows:
    a. For thin-fell conifers, assume carbon stock in vegetation, deadwood and litter after 80 years is the same as after 30 years.
    b. For managed woodland, annual change in carbon stock in vegetation, deadwood and litter (in CO2 equivalents) for each time horizon is re-calculated as:
        (i) Δ C stock 2020 to 2025 = –(44 / 12) *[($CstockT_{2025}$-$CstockT_{2020}$)/5]
        (ii) Δ C stock 2025 to 2050 = –(44 / 12) *[($CstockT_{2050}$-$CstockT_{2025}$)/25]
        (iii) Δ C stock 2050 to 2100 = –(44 / 12) *[($CstockT_{2100}$-$CstockT_{2050}$)/50]
    c. For naturally regenerated woodland, annual change in carbon stock in vegetation, deadwood and litter (in CO_2 equivalents) is set to 0 for 0-5 and 5-30 years, and is re-calculated for 30-80 years as: –(44 / 12) *[$CstockT_{80}$/80]
    d. For naturally regenerated woodland on arable land, we assumed annual soil carbon sequestration (in CO_2 equivalents) of –0.4 * 44 / 12 (we assumed no sequestration in soils from natural regeneration of grassland).

18. CARBINE calculates an estimated net present value (NPV) for an area of new woodland:
    a. The use of NPV allows the time-dependent costs and revenues associated with woodland creation, expressed in units of £/year, to be compared with the annual revenues from agricultural land use options.
    b. The NPV calculations involve calculating the sum of all costs and revenues accrued over a rotation of the new woodland, from the time it is created. Hence, if the rotation applied to the new woodland is 75 years, all costs and revenues are calculated over this period and expressed as a sum.

19. Discounting: Before the costs and revenues are added together, they are multiplied by a discount factor that applies for the year in which the cost or revenue occurs. The discount factor is calculated by assuming a discount rate. The total net cost/revenue over the rotation is then divided by a sum of discount factors over the rotation, to give the annualised discounted net cost/revenue:

a. CARBINE results are calculated for six possible discount rates of 0%, 3%, 3.5%, 5%, 6% and 10%.
b. An additional seventh result is calculated based on the Treasury Green Book methodology, in which a discount rate of 3.5% is assumed for the first 29 years, then a discount rate of 3% is assumed from 30 to 74 years, with a discount rate of 2.5% applying thereafter.
c. The discount rate from the Treasury Green Book is used in the modelling.
d. The results obtained for a specific discount factor, for use in the IMP, are selected for compatibility with IMP calculations for other land uses.
e. A discounting period equal to one rotation of the woodland type, or 200 years for non-rotational woodland systems, is assumed. The rotation period (where relevant) depends on woodland type and varies from 50 to 120 years.

20. For woodland types in which no rotation is applied (e.g. amenity forests or those managed according to continuous cover systems), a notional period of 200 years is assumed for NPV calculations.

21. Costs and revenues included in the forestry NPV calculations (where relevant for the woodland type/silvicultural system) are: (a) initial woodland establishment costs; (b) net costs or revenues from harvesting of thinnings; (c) net revenues from final felling at the end of the rotation.
    a. Establishment costs consider full costs of materials, planting, site preparation and post-planting maintenance based on Glastir costings where possible and FR expertise where not possible. They are central estimates and upper and lower sensitivity bounds have been identified for each within the QA process.
    b. Thinning costs reflect the fact that small trees harvested in early thinnings are likely to incur net costs (£17 per cubic metre standing volume) whilst later harvests (with a component of sawlog volume) are harvested at net revenue of £20 per m^3 for softwood £40 per m^3 for hardwood. These are based on estimates of net revenue obtained from standing sales of timber. The CARBINE model results can be interpreted to identify where sawlogs does or does not form part of harvested timber volume (essentially based on FC volume assortment tables).
    c. Incentive grant payments are combined with the forestry NPV within SFARMOD / the LAM depending on the payment scenario.

LAND ALLOCATION MODULE (LAM)

22. The LAM aims to assess the (uncertain) response of every ≥ 1 FTE farm across Wales to the land use scenarios. We recognise that there are many factors that influence the decisions of an individual farm business and that there is limited understanding and data that can be applied to all ≥ 1FTE farms across Wales. The LAM modelling therefore necessitates significant assumptions. It was also a key area for sensitivity testing to explore the impacts of different parameter settings.

23. Given the sampling limitations of the Farm Business Survey (FBS), we link the RFT-specific average FBS data to the specified ERAMMP farm type (as developed in Quick Start) of each ≥ 1FTE farm across Wales:
    a. ERAMMP RFTs are: Cereals, General cropping, Dairy, Lowland cattle / sheep, Mixed, Specialist Sheep (SDA), Specialist Beef (SDA), SDA mixed grazing, DA various grazing.

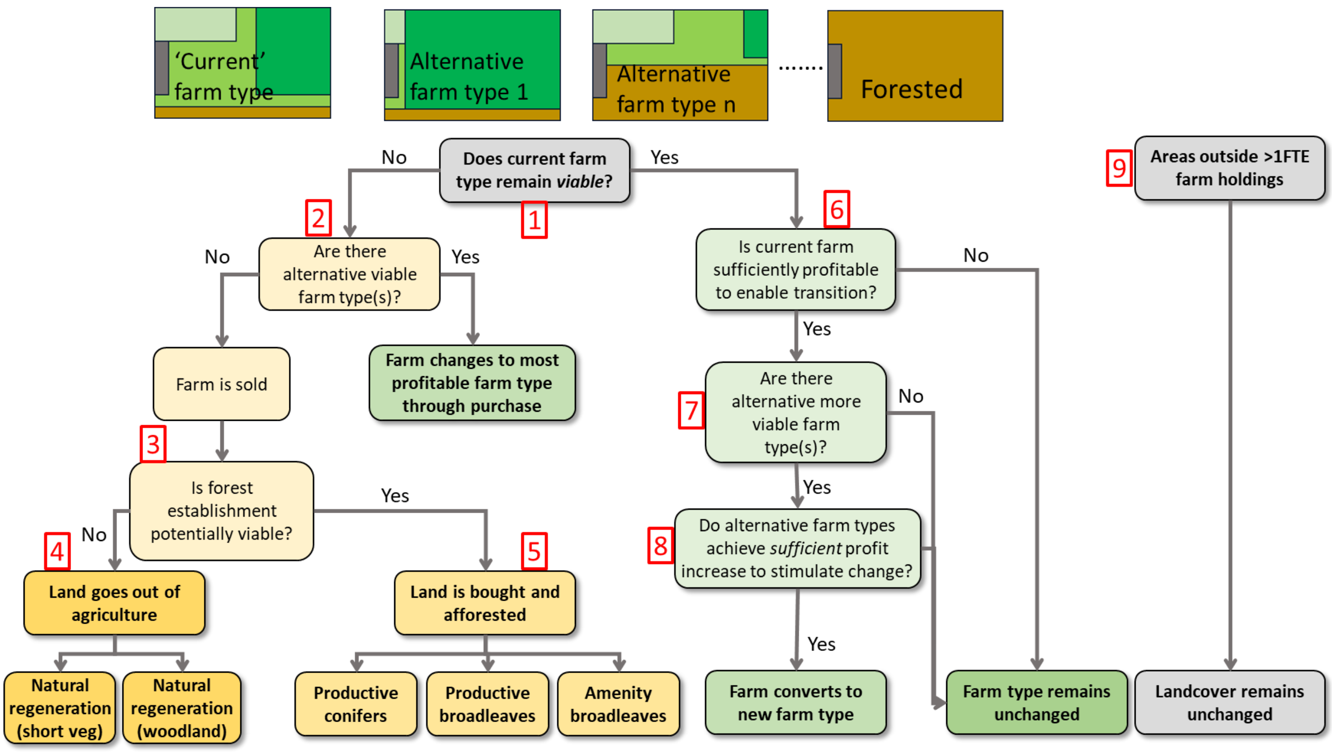
   b. These are based on ADAS' RFTs with extra detail included between SDA and DA grazing to better reflect the Welsh agricultural landscape.

24. Farm business income can be estimated from SFARMOD Farm Net Profit + Non-Agricultural Farm Income - Unaccounted costs + Unpaid labour:
   a. SFARMOD Farm Net Profit takes account of agricultural outputs, basic payments, variable costs and a subset of fixed costs. It assumes that all current agri-environment payments are cost-neutral and are thus not explicitly included.
   b. Non-agricultural income derived by the farm is estimated from the relevant RFT-type specific values from the Welsh Farm Business Survey (or appropriate regional English FBS for farm types not within the Welsh FBS). The "All sizes" values for "income from energy generation" and "miscellaneous income" for each Welsh RFT (and "Outputs from integrated Diversified Activities" and "other non-agricultural income" for English FBS) were used, expressed as £/ha. This therefore assumes that all farms of the same farm type have the same unit area non-agricultural income and thus larger farms will have larger non-agricultural income.
      i. If a farm is simulated by the LAM to change farm type (EFT), it is assumed that the level of non-agricultural income remains unchanged.
   c. Unaccounted costs can be estimated by scaling the SFARMOD fixed costs (for labour, contracting, machinery hire, fuel and repairs, and machinery depreciation) according to the ratio of the "All farms £/farm" Farm Business Survey data for farm-type specific-values of unaccounted costs (general farming costs, land expenses, buildings depreciation, rent and finance) to the Farm Business Survey values of the accounted costs (for labour, contracting, machinery hire, fuel and repairs, and machinery depreciation).

25. SFARMOD costs all labour (whether paid or unpaid, including by farmer and spouse) used for farm activities, but does not include managerial labour.
   a. We account for the value of unpaid labour by scaling the simulated farm labour FTE from SFARMOD by the ratio of unpaid labour to total labour from Farm Business Survey data using farm-type specific-values (subject to a maximum of 1.5 FTE of unpaid labour), assuming the SFARMOD labour rate of £22,000/FTE.
   b. We assume that all managerial labour is unpaid, is provided by the farmer and/or spouse, and does not significantly affect farm business income, i.e. it can be ignored from the calculation of farm business income.

26. Welsh Farm Business Survey data for 2015/16 were selected for consistency with the year used in other datasets (e.g. Land Cover Map 2015) and farm activity data used in SFARMOD.

27. The following schematic details the steps within the Land Allocation module (LAM). Assumptions related to each step (shown in the red boxes on the diagram) are described below.



28. Step 1: Does current farm type remain viable? Farm viability is based on farm business income (FBI) and we assume £6000/yr as a minimum threshold with the following justification:
    a. The ESRC Newcastle Brexit report (based on O'Donoghue et al. 2016[5]) assumes that a farm is sustainable as long as the farmer or spouse has an annual off-farm income of > £6000 (which is based on the maximum working allowance to receive full Universal Credit without help with housing costs), even if the farm is not viable;
    b. Beyond RTF-specific miscellaneous income (contracting, cottage rents, wayleaves etc) and income from energy generation (farmer- and non-farmer owned energy generation, including wind, solar, biomass, hydro, AD), there is no RTF-data on non-agricultural income from the FBS that can be applied to all farms;
    c. This threshold is a key assumption and in subsequent versions of the IMP it could be added to the user interface to explore its effect on farm/land use transitions.

29. Step 2: Are there alternative viable farm types?
    a. If the existing farm type does not meet the minimum FBI threshold, the alternative farm type with the greatest farm business income is selected, subject to the £6000 minimum FBI threshold.
    b. This assumes that the existing business cannot afford to make the transition and that transition occurs through a sale.

30. Step 3: Is afforestation viable?

[5] O'Donoghue, C., Devisme, S., Ryan, M., Conneely, R., Gillespie, P., Vrolijk, H. (2016). Farm economic sustainability in the European Union: A pilot study. Studies in Agricultural Economics, 118, 163- 171.

a. Where full-time agriculture is no longer an option, afforestation of a DMU is a potential option where tree growth conditions are suitable and:
    (i) Average slope <=22º [FR limit for efficient planting/management];
    (ii) <30% of area is within a SSSI, SAC or SPA [arbitrary threshold];
    (iii) <30% is a peat soil [arbitrary threshold].

b. The use of arbitrary thresholds (e.g. for peat / SSSIs) is a result of the fact that DMUs in their current configuration are not subset by peat/SSSI layers. As such, DMUs that overlay peat have % peat as a variable, but it is not known where that peat is within the DMU.

c. For IMP version 1 we will continue to use the existing DMUs and these thresholds, but changes to DMUs could be considered for later versions.

d. Note that of the Glastir Woodland Creation rules, only the three above are considered in the modelling.

31. Step 4: Land goes out of agriculture:
    a. Potential for natural regeneration to trees/woody vegetation if ESC forest suitability > 0.3 for any forest type. Otherwise, undergoes natural regeneration to short vegetation.
    b. Where succession to woodland is assumed, this is matched with the FR data outputs for carbon etc for re-wilding to woodland, with the qualifiers indicated in assumption 15.

32. Step 5: Is forest establishment profitable?
    a. For land that is going out of agriculture and is potentially suitable (>0.5 ESC suitability) and appropriate for afforestation, the most financially viable type of forest and forest management regime (largest positive Net Present Value) is selected.

33. Steps 6, 7 and 8: Are there sufficiently profitable alternative farm types?
    a. For a viable farm type to convert to an alternative more profitable farm type a minimum farm profit increase threshold of the greater of £5000/yr or 25% of current farm FBI is required to even consider transition.
    b. The simulated decision to convert is based on whether there is sufficient additional Farm Business Income beyond the minimum farm profit increase threshold to finance the change, with transitions requiring larger investments or being irreversible needing a larger increase in FBI.
        (i) The additional FBI is set as 10% of the investment required, reflecting the risks associated with conversion.
        (ii) The additional investment required is based on the calculated difference in tenants' capital (machinery, livestock, crops and stores) between farm types using Farm Business Survey data. Where a farm type has lower tenants capital than the existing farm, no additional investment is assumed.

34. Step 9: Land outside > 1 FTE holdings:
    a. For woodland and forest outside of > 1 FTE farm holdings, we assume that woodland/ forest type and management is constant.
    b. For land that is not within > 1 FTE farm holdings and is not currently woodland or forest, we assume that the land cover is insensitive to the trade scenario and remains constant (as per Land Cover Map):

ON-FARM AGRICULTURAL POLLUTANTS

35. The impacts of any changes in practice are expressed relative to current practice. Current implementation rates are based upon data from national stratified surveys, primarily the Defra Farm Practice Surveys and the 1st and 2nd Welsh Farm Practice Surveys.

36. Emissions of climate change gases (nitrous oxide and methane) are derived using a previous IPCC methodology (Baggott et al. 2006[6]), with the exception that indirect emissions of nitrous oxide are calculated from the modelled nitrate losses rather than using the inventory approach. There have been changes to a number of the coefficients and approaches in the current UK GHG inventory.

37. Emissions of ammonia are derived from the F national inventory for ammonia (Webb and Misselbrook 2004[7]). This has now been updated as part of the current UK agricultural ammonia and GHG inventory.

38. There are a number of fixed farm practice assumptions in the modelling work that is used to calculate the pollutant coefficient data in Farmscoper – these include fertiliser and manure application timing, soil P status and duration of livestock grazing. Assumptions are based on data from national stratified surveys, including the British Survey of Fertiliser Practice and the Defra Farm Practice Survey.

39. The full model of Farmscoper (from which the IMP coefficients are extracted) was built using 1961-90 climate data, and the results area weighted by rainfall category and the three soils represented by Farmscoper. This area weighting was undertaken for the whole of England and Wales. The data may thus not be as representative as possible of current climate in Wales. For example, the seasonality of rainfall in the 1961-90 data for the average place (in England and Wales) with 700-900mm rainfall may not be the same as it is now (using 1980-2010 data) for the average place with 700-900mm. The averaged soil properties for heavy soils under 700-900mm in the 1961-90 data might be different than with current climate data.

Aggregating farm pollutants to the landscape scale to estimate water quality

40. SFARMOD management data are linked to Farmscoper coefficients at a DMU scale to calculate baseline and change in ammonia, methane, nitrous oxide emissions, and nitrate, phosphorus and sediment loading to the watercourse.

41. For DMUs for farms <1FTE not modelled by SFARMOD, we instead apply small farm average data for nutrient inputs and livestock excreta.

42. The water quality pollutants are added up at a WFD sub-catchment scale to calculate total loading for a subcatchment. These are accumulated downstream, accounting for

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[6] Baggott SL, Brown L, Milne R, Murrells TP, Passant N, Thistlethwaite G, Watterson JD, Jackson J (2006). UK Greenhouse Gas Inventory, 1990 to 2004. Netcen, AEA Technology, Harwell, Oxfordshire. ISBN 0-9547136-8-0.

[7] Webb, J., and Misselbrook, T. H. (2004). A mass-flow model of ammonia emissions from UK livestock production. Atmospheric Environment 38, 2163-2176.

downstream links between the subcatchments.

43. The SEPARATE spreadsheet is used to account for non-agricultural loadings of N and P, and to convert these to measures of concentration to allow assessment of water quality.

44. WFD P status is assigned based on P concentration thresholds which vary with elevation and alkalinity as well as being lower in areas designated SAC. We use the same thresholds as used by NRW, with some assumptions to reflect our approach. We assess P status based on the concentration at the outflow of each WFD subcatchment, and therefore we use the most downstream threshold available. (NRW compare concentration to thresholds at monitoring points throughout the subcatchment, and then use these to assign an overall status for the WFD subcatchment).

BIODIVERSITY AND ECOSYSTEM SERVICES

Birds

45. Bird data were used from multiple years (2013-2017) to reduce impact of between-year variability and to capture data for rarer species. Species were only selected if they occurred in at least 35 1km squares to ensure development of robust models:
    a. The bird abundance and diversity estimates in this study are derived from raw BBS count data, which describe relative abundances within species and are not, strictly, comparable between species (due to variation in detectability), but are not biased for comparisons in space and time.
    b. This means that the data should not be used for comparison with data from elsewhere that were collected using different methods, but that they are robust in respect of variations due to environmental factors.

46. Changes within each scenario were purely driven by land use transitions from the upstream Land Allocation Module (LAM).

47. When summarising data for the 1km square, where 1km square boundaries intersect DMUs, it is assumed that attributes are evenly spread across the DMU.

48. To capture the coverage area of rivers & streams, river data from the Detailed River Network was used. For occasions where the width was not reported, which was regularly the case for upland streams, this width was set at 0.1m.

49. For estimating the cover of hedgerows, Woody Cover Product (WCP) data outside of National Forest Inventory data were examined. Any polygons of greater than 500 m^2, with a ratio of length: area > 0.3, were labelled as hedgerows, a value determined through visual inspection of satellite data in ArcGIS. The remaining WCP data was retained as “Other Scrub”.

50. When DMUs are designated as abandoned or subject to natural regeneration, the habitat classification for that parcel was decided through a series of rules, based upon other spatial data and selected timeslice (set at 2050 for the land use scenarios):
    a. If the ESC-CARBINE model predicted “regeneration_broadleaf” as a Management category, with a forest suitability score > 0.3, we assumed that the climax vegetation will be broadleaf woodland. To account for the time that woodland takes

to mature, these habitats were assumed to be shrub (as defined in the NFI) with less than 50 years of succession, and semi-natural grassland (a grouping of neutral and calcareous grassland) with less than 10 years of succession.

b. Where the forest suitability score was < 0.3 (occurring in less than 1% of the total sample of 1km squares), most land use in these squares consisted of either acid grassland (186/237 squares) or heather grassland (58/237). Therefore, these DMUs were assigned to have succession to acid grassland, as the closest land cover type to the likely climax vegetation that was available.

c. A maximum threshold of individual birds per species per 1km square was set at 1000 for the baseline model, based upon maximum counts from the initial survey data. Any prediction that exceeded this was flagged prior to calculating population size. An iterative procedure, described in the model technical guide, was utilised to identify whether any covariate-count outliers drove extreme predicted counts, and these were removed if they exceeded a Cook's Distance = 4.

Plants

51. In the MultiMOVE plant species modelling, it is assumed that soil changes drive correlated changes in suitability of conditions for plant species. Therefore, MultiMOVE implicitly rather than explicitly models plant-soil feedbacks. This makes things simpler, but less able to generate novel dynamic outcomes.

52. MultiMOVE models 'habitat suitability' rather than actual presence or abundance of species. This involves fewer assumptions and usefully separates intervention or climate-driven change in conditions favouring each species from the processes of dispersal and establishment required for a species to realise changes in conditions by becoming established.

53. The pool of modelled species is drawn from those observed at modelled locations plus those recorded in the wider 10km square. This ensures that changes in habitat suitability are possible as species composition turns over. This assumption is considered to be realistic because such turnover draws on nearby species populations. Even if this might depend upon managed introduction, we assume this is more achievable from local sources than distant populations.

54. Changes in habitat suitability are driven purely by land use transitions from the upstream Land Allocation Module (LAM) where these transitions are converted into associated changes in soil conditions (i.e. MultiMOVE inputs) by reference to the literature and to observations from Countryside Survey.

55. MultiMOVE only models changes at GMEP survey point locations that coincide with Decision Management Units (DMUs) modelled by SFARMOD and the LAM. This covers approximately 50% of the point locations in GMEP that have soil and vegetation data (X plot locations in 2013 to 2016).

56. Summary metrics are output that convey potential species richness of subsets of plant species that support specific ecosystem functions or services:
    a. nectar supply;
    b. forage grass richness;
    c. richness of plant that provide food for lowland farmland birds;
    d. injurious weed richness;
    e. allergenic grass richness;

f. CSM positive indicator richness.

57. MultiMOVE metrics calculated at the GMEP plot scale are averaged by land use. They are then upscaled to all farms in Wales by mapping the values to all parcels of the same land use using the IMP's land use classes:
   a. This mapping process calculates average metrics by land use type;
   b. It then maps the plot-based averages by land use to all similar land uses across Wales. This reflects a simplifying assumption that MultiMOVE metrics are a function of land use only and that changes in MultiMOVE metrics are a function of land use transitions;
   c. Incidental variation in climatic conditions between different land uses (e.g. improved grasslands could be warmer than extensive grasslands on average) is accounted for during MultiMOVE modelling;
   d. Spatial variation in MultiMOVE metrics within a given land use type are not considered.

Habitat connectivity

58. Connectivity analysis is focussed on broadleaved species. This was a pragmatic selection in the absence of a specific focal species.

59. The connectivity approach identifies DMUs that, under appropriate land use change, would increase connectivity between existing habitats. These are then flagged when the appropriate land use change is predicted by a scenario and intervention run. This approach is applied for broadleaf woodland in IMP version 1, but could potentially be expanded to new habitat types for later versions.

60. A simple tool has been developed to identify these DMUs, based on distance from existing habitat:
   a. The method requires parameterisation of:
      i. minimum patch size (0.5ha);
      ii. patch separation expected to give 50% probability of connectivity (200m).
   b. The numbers in brackets were used for the IMP prototype.
   c. For IMP version 1 they have been replaced with values from a literature review. A range of values for habitat size and travel distance have been tested, and the IMP version 1 outputs provide a sensitivity analysis type output showing the new connectivity modelled for a range of parameter combinations which may or may not be representative of species types of conservation interest.

Air quality

61. The air quality outputs are based on a meta-model approach using relationships derived from EMEP4UK outputs and health data for 2015.

62. Removal rates of PM2.5 vary with:
   a. initial pollution concentrations;
   b. the spatial location of woodland in relation to pollution concentrations;
   c. interactions among other pollutants;
   d. meteorology in the original model runs which were run at approximately 5x 6 km^2 resolution.

63. It is assumed that pollution removal due to the action of vegetation within a local authority is greater than the effects of vegetation outside of the local authority. Local authority level is used for aggregating calculations because:
    a. The health data underlying the calculations are provided at this scale;
    b. It is the most appropriate spatial scale to infer changes in pollution concentrations due to pollution removal by woodland. Benefits from a particular patch of woodland may be experienced some distance downwind (up to tens of kilometres).

64. Some spatial variation in pollution concentrations and benefitting population within a local authority is accounted for in this approach. This is achieved by calculating a population-weighted change in PM2.5 concentration for each local authority (using population aggregated to EMEP4UK grid cells of approximately 4 x 6 km resolution).

65. Proportion of woodland cover is aggregated to approximately 40 x 40 km grid as input to the calculations.

66. The meta-modelling approach takes changes derived from the scenarios as inputs. Since the scenarios do not provide information on PM2.5, the change in PM2.5 concentrations are linked to changes in ammonia emissions (derived from SFARMOD outputs linked to Farmscoper coeficients), using statistical relationships derived from the original model runs of EMEP4UK.

67. Health impacts are derived from epidemiological studies:
    a. Dose response functions for the health impacts of each pollutant are derived from statistical studies, which extract a response relationship while controlling for variation in other socio-economic and environmental factors and other pollutants;
    b. The equations are calculated using existing morbidity and mortality data for each local authority.

Carbon storage

68. LULUCF calculate change in carbon storage at devolved national level, using a Monte Carlo approach based on: (i) estimated area of land use transitions (± 30% around mean); (ii) equilibrium carbon database values for each transition (up to ± 11% of mean); and (iii) rate of change (50-300 years; the maximum and minimum rate varies with type of transition). We have adapted the LULUCF method to map carbon storage spatially at DMU level (see next assumption). However, it is not possible to calculate exact transitions between land use types at the DMU level. This is because the DMUs contain rotational land use (e.g. 80% arable, 20% grassland), which may transition to multiple land uses with afforestation (e.g. 80% forest, 20% grassland) or to a new rotation. We assume that our rotation proportions apply spatially.

69. Our adapted LULUCF method is applied as follows:
    a. Calculate change as: (((total baseline C - total scenario C)/rate of gain or loss) * proportion not woodland) + change in carbon under new woodland;
    b. For rate of gain or loss, we use the mean rate for the dominant direction of transition (gain or loss), accounting for the non-linear rate of change, but do not apply Monte Carlo for each DMU, since this would be too computationally expensive;
    c. To enable accurate economic valuation, the calculations are repeated for each year and multiplied by the carbon value for that year. The outputs are averages (or totals) of these data for the relevant time period (5, 25 and 100 years);

d. Woodland carbon has been adjusted for rotation length in post processing (see point 17. above).

VALUATION

70. There are multiple ways to value changes in ecosystem services, including:
    a. Use data that matches current economic data, but does not capture the full value of the environment;
    b. Use data that captures full environmental value, but is not strictly comparable to GDP. This is akin to the social welfare approach set out in HMT green book;
    c. IMP version 1 uses option (b) as this underpins the appraisal of policy options;
    d. A “valuation methodologies paper” (ERAMMP report 27) has been prepared to provide further details underlying this assumption (as requested at the Shrewsbury meeting in November 2019).

71. Water quality valuation:
    a. Welfare values for achieving WFD status are used. ONS use a replacement cost approach (i.e. the costs of achieving the same water quality improvement through end of pipe treatment kit), which is theoretically closer to an exchange value, but methodologically problematic.
    b. Change in load of N, P and Z is calculated from Farmscoper outputs aggregated to WFD catchments on an area basis. These are then accumulated to downstream waterbodies.
    c. The following aspects are valued:
        i. Change in P status modelled as in point 44 (above).
        ii. Change in N drinking water status relative to UKTAG2008 drinking water thresholds (95th percentile of 11.3mg/NO_3-N). N concentration calculated as in point 43 above.
        iii. Changes in sediment were not valued.

72. Carbon valuation: we use UK non-traded cost of carbon (as do ONS):
    a. We follow Green Book guidance on non-trade cost of carbon values in https://www.gov.uk/government/publications/valuation-of-energy-use-and-greenhouse-gas-emissions-for-appraisal (see Annex-2 and BEIS supplementary guidance, including scenario values).

73. Health impacts of air quality valuation: we use the avoided health costs approach, which is consistent with, but more disaggregated (and therefore more accurate than) the modelling used by the ONS for their air pollutant removal national account:
    a. We are aware of, and consistent with, guidance on methods and valuation provided in the Green Book (Annex-2) and Defra supplementary guidance. Damage costs estimates are relevant under the referenced conditions: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/770576/air-quality-damage-cost-guidance.pdf.
    b. Note there are different sets of damage costs. The CEH + eftec work for ONS followed COMEAP guidance, which Defra damage costs are based on. However, the method used for the IMP differs in that we calculate change in morbidity and mortality directly from change in pollution concentration, and use existing health data, which varies by local authority.

c. The Defra damage costs are only provided per tonne of emissions, not change in exposure (i.e. concentration), and apply a simplified correction for urban to rural settings (high, intermediate and low population density), whereas we apply a population-weighted change in concentration to calculate impacts/benefits.
d. Note that this valuation is dependent on outputs from the air pollution and health modelling, i.e. follows on from assumptions 49-54.

74. Valuation is applied for 5, 25 and 100 years, where the data are available for these timeslices (with an assumption that the scenario persists for 100 years, i.e. valuing trajectory).

A1.1 Aggregation of SFARMOD DMU outputs to the farm

This section is an addition to the signed-off assumptions document for the land use scenarios work that describes how SFARMOD outputs per Decision Making Unit (DMU) were aggregated to the farm level.

Reflecting the complexity of Welsh agricultural farming enterprises, SFARMOD simulates a broad range of farming systems across the agricultural DMUs, that range from livestock-free arable and general cropping systems to mixed forage systems (ley arable, maize and ley forage crops) supporting beef and dairy cattle to permanent grassland systems for beef, dairy or sheep to rough grazing with beef or sheep.

To aggregate appropriate DMU-level farming system solutions to each modelled full-time farm, a series of heuristics were developed that take account of a farm's ERAMMP RFT and the land cover, slope and altitude of its DMUs (Table A1.1). These heuristics reflect the changing shift in the balance between arable–forage-grass–rough grazing systems and between dairy-beef-sheep livestock types across the lowland-upland-hill gradient and between ERAMMP RFTs. They were developed based on a combination of expert judgement and calibration against June Agricultural census data in order to get appropriate crop and grassland areas and stock numbers / type.

When simulating the effects of the ERAMMP land use scenarios, SFARMOD uses these heuristics to provide the LAM with alternative ERAMMP RFT solutions for each farm, subject to some conditions:

- No baseline SDA-type ERAMMP RTFs occur where the majority of a farm's area is in a Disadvantaged Area or lowland area. Consequently, ERAMMP RFTs of "Specialist Sheep (SDA)", "Specialist Beef (SDA)" and "SDA Mixed grazing" are not provided as alternatives for farms within the currently designed Disadvantaged Area and lowland areas;

- Most ERAMMP RTFs occurred in baseline farms in which the majority of the farm area was in a Severely Disadvantaged Area. However, based on analysis of the average area-weighted altitude and slope index of baseline ERAMMP RFTs:
    - Arable and General cropping EFTs as alternative options were constrained to farms with an average area-weighted altitude <=300m and slope index of <=1;
    - Dairy, Lowland cattle and sheep, and Mixed ERAMMP EFTs were constrained as alternative options to farms with average area-weighted altitude <=400m and slope index of <=1.5

- The "Other" ERAMMP EFT was constrained as alternative options to farms with average area-weighted altitude <=400m and slope index of <=2;
- The remaining ERAMMP EFTs were unconstrained.

In addition some DMU alternatives are infeasible:

- The general cropping (i.e. with potatoes in rotation) and cereal cropping systems are not allowed in DMUs with a slope index above 0 and 1, respectively. In these cases, they default to a sheep forage ley system;
- If an expected livestock type is infeasible on rough grazing, rough grazing is not allowed to change but its stocking can change to an alternative (i.e. beef or sheep).

In this way, all agricultural DMUs have a solution for a given ERAMMP RFT when aggregated to the farm.

Table A1.1: Allocation of SFARMOD DMU cropping/forage and stocking systems to ERAMMP RFTs.

			Sfarmod DMU Cropping										
					Sfarmod DMU Stocking								
ERAMMP RFT	LCM20X5 Land Type	Over 400m altitude?[1]	Cereals None	General Cropping None	Grazing Livestock Ley Arable + Maize if suitable Beef	Grazing Livestock Ley Arable + Maize if suitable Dairy	Grazing Livestock Ley Forage Crops + Maize if suitable Beef	Grazing Livestock Ley Forage Crops +Maize if suitable Dairy	Grazing Livestock Permanent Grass Beef	Grazing Livestock Permanent Grass Dairy	Grazing Livestock Permanent Grass Sheep	Grazing Livestock Rough Grass Beef	Grazing Livestock Rough Grass Sheep
Cereals	A	No	X										
Cereals	IG	Yes									X		
Cereals	IG	No							X				
Cereals	RG	Yes											X
Cereals	RG	No											X
General cropping	A	No		X									
General cropping	IG	Yes									X		
General cropping	IG	No							X				
General cropping	RG	Yes											X
General cropping	RG	No											X
Dairy	A	No				X							
Dairy	IG	Yes								X			
Dairy	IG	No						X					
Dairy	RG	Yes											X
Dairy	RG	No											X
Lowland cattle / sheep	A	No			X								
Lowland cattle / sheep	IG	Yes									X		
Lowland cattle / sheep	IG	No									X		
Lowland cattle / sheep	RG	Yes											X
Lowland cattle / sheep	RG	No											X
Mixed	A	No		X									
Mixed	IG	Yes									X		

			Sfarmod DMU Cropping										
					Sfarmod DMU Stocking								
					Grazing Livestock	Grazing Livestock	Grazing Livestock	Grazing Livestock	Grazing Livestock	Grazing Livestock	Grazing Livestock	Grazing Livestock	Grazing Livestock
ERAMMP RFT	LCM20X5 Land Type	Over 400m altitude?[1]	Cereals	General Cropping	Ley Arable + Maize if suitable	Ley Arable + Maize if suitable	Ley Forage Crops + Maize if suitable	Ley Forage Crops +Maize if suitable	Permanent Grass	Permanent Grass	Permanent Grass	Rough Grass	Rough Grass
			None	None	Beef	Dairy	Beef	Dairy	Beef	Dairy	Sheep	Beef	Sheep
Mixed	IG	No							X				
Mixed	RG	Yes											X
Mixed	RG	No											X
Other	A	No		X									
Other	IG	Yes									X		
Other	IG	No							X				
Other	RG	Yes											X
Other	RG	No											X

			Sfarmod DMU Cropping										
					Sfarmod DMU Stocking								
					Grazing Livestock	Grazing Livestock	Grazing Livestock	Grazing Livestock	Grazing Livestock	Grazing Livestock	Grazing Livestock	Grazing Livestock	Grazing Livestock
ERAMMP RFT	LCM20X5 Land Type	Over 400m altitude?[1]	Cereals	General Cropping	Ley Arable + Maize if suitable	Ley Arable + Maize if suitable	Ley Forage Crops + Maize if suitable	Ley Forage Crops +Maize if suitable	Permanent Grass	Permanent Grass	Permanent Grass	Rough Grass	Rough Grass
			None	None	Beef	Dairy	Beef	Dairy	Beef	Dairy	Sheep	Beef	Sheep
DA various grazing	A	No		X									
DA various grazing	IG	Yes							X				
DA various grazing	IG	No							X				
DA various grazing	RG	Yes											X
DA various grazing	RG	No											X
SDA mixed grazing	A	No	X										
SDA mixed grazing	IG	Yes									X		
SDA mixed grazing	IG	No							X				
SDA mixed grazing	RG	Yes											X
SDA mixed grazing	RG	No											X
Specialist Beef (SDA)	A	No					X						
Specialist Beef (SDA)	IG	Yes							X				
Specialist Beef (SDA)	IG	No							X				

			Sfarmod DMU Cropping										
					Sfarmod DMU Stocking								
					Grazing Livestock	Grazing Livestock	Grazing Livestock	Grazing Livestock	Grazing Livestock	Grazing Livestock	Grazing Livestock	Grazing Livestock	Grazing Livestock
	LCM20X5 Land	Over 400m	Cereals	General Cropping	Ley Arable + Maize if suitable	Ley Arable + Maize if suitable	Ley Forage Crops + Maize if suitable	Ley Forage Crops +Maize if suitable	Permanent Grass	Permanent Grass	Permanent Grass	Rough Grass	Rough Grass
ERAMMP RFT	Type	altitude?[1]	None	None	Beef	Dairy	Beef	Dairy	Beef	Dairy	Sheep	Beef	Sheep
Specialist Beef (SDA)	RG	Yes										X	
Specialist Beef (SDA)	RG	No										X	
Specialist Sheep (SDA)	A	No	X										
Specialist Sheep (SDA)	IG	Yes									X		
Specialist Sheep (SDA)	IG	No									X		
Specialist Sheep (SDA)	RG	Yes											X
Specialist Sheep (SDA)	RG	No											X

Annex-2: Quality Assurance of IMP Runs

This Annex summarises Quality Assurance (QA) of the Integrated Modelling Platform (IMP). It focusses on the version of the IMP used to underpin the Land Use Scenario analysis delivered to the Welsh Government (WG) between August 2020 and March 2021.

Full details of the IMP QA can be found in the Land Use Scenario QA report in Technical Annex-2 ERAMMP Report-60TA2[8], which should be read in conjunction with Annex-1: *Full List of IMP Assumptions*. Further information to support the QA of the IMP and the interpretation of its outputs is available to the Welsh Government in the *slidepacks*, *data dictionaries* and *data cubes*.

Understanding the strengths, weaknesses, opportunities, and limits of any modelling system is vital so users of the model understand what is and is not possible to infer from the outputs. QA provides the critical reflection needed to understand these limits. The IMP is designated as *business critical* and is one source of information used to support decision-making in policy, as such, this QA is mandated by the UK Government's *Review of quality assurance of government analytical models*[9] and *Aqua Book*[10].

The Aqua book sets out the four principles of analytical QA to support the delivery of fit-for-purpose analysis:

- **Proportionality of response**: The extent of the analytical quality assurance effort should be proportionate in response to the risks associated with the intended use of the analysis.
- **Assurance throughout development**: Quality assurance considerations should be considered throughout the life cycle of the analysis and not just at the end.
- **Analysis with RIGOUR**: Quality analysis needs to be **R**epeatable, **I**ndependent, **G**rounded in reality, **O**bjective, have understood and managed **U**ncertainty, and the results should address the initial question **R**obustly.
- **Verification and validation**: Analytical quality assurance is more than checking that the analysis is error-free and satisfies its specification (verification). It must also include checks that the analysis is fit for the purpose for which it is being used (validation).

As detailed in Chapter 2 of this report and as illustrated by Figure 2.1, the IMP comprises a chain of specialised, state-of-the-art models customised with Welsh data. The models have

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[8] Harrison, P.A., Dunford R., Whittaker, F., Mondain-Monval, T., Beauchamp, K., Cooper, J., Dickie, I., Fitch, A., Gooday, R., Hollaway, M., Holman, I.P., Jones, L., Matthews, R., Sandars, D., Seaton, F., Siriwardena, G.M., Smart, S.M., Thomas, A.R.C., Trembath, P., Vieno, M., West, B., Williams, A.G. (2022). *Environment and Rural Affairs Monitoring & Modelling Programme (ERAMMP)*. ERAMMP Technical Annex Report-60TA2: ERAMMP Integrated Modelling Platform (IMP) Land Use Scenarios Quality Assurance. Report to Welsh Government (Contract C210/2016/2017)(UK Centre for Ecology & Hydrology Projects 06297 & 06810) www.erammp.wales/60TA2

[9] Review of quality assurance of government models, https://www.gov.uk/government/publications/review-of-quality-assurance-of-government-models

[10] The Aqua Book: Guidance on producing quality analysis for government https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/416478/aqua_book_final_web.pdf

been linked by establishing data flows between them, representing the interdependencies between different sectors or impacts.

Due to its designation as business critical, the complexity of the modelling chain and its use as support within policy decision-making, the IMP demands a comprehensive analytical QA response to satisfy the four Aqua Book principles. The IMP was developed within an iterative framework of design, build, test and review stages using internal (consortium) and external (including WG) expert assessment, Figure A2.1. This framework addresses both **proportionality to response** and **assurance throughout development**.

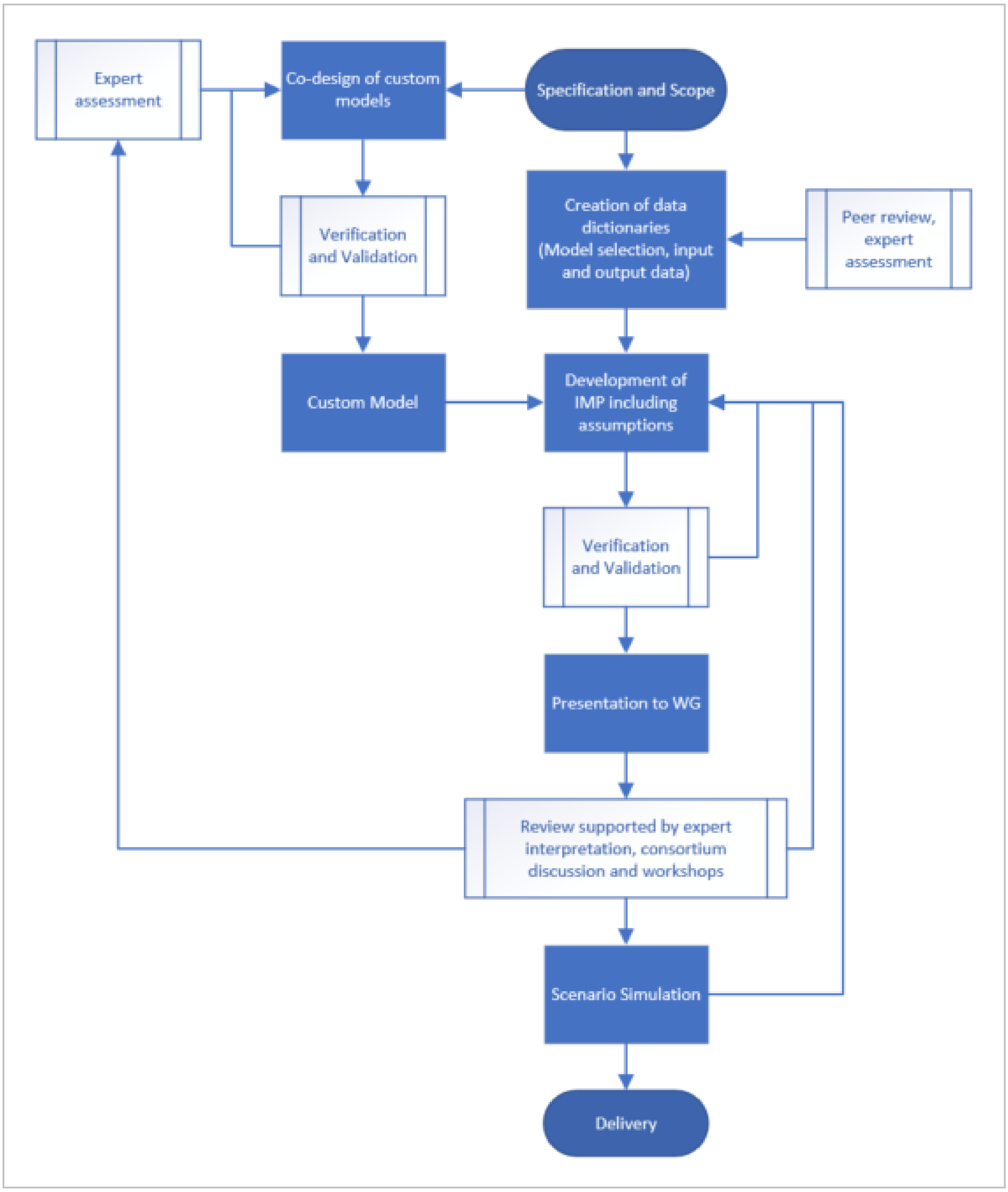

Figure A2.1: Schematic showing the design, build, test and review stages of the IMP development.

During IMP development the focus was on maintaining transparency and open communication, both of which underpin the six principles of **RIGOUR**. In turn, these encourage effective environments and processes for QA. The *IMP Land Use Scenarios QA* document addresses each principle in turn, but the following briefly sets out key activities used.

To ensure **repeatability** key parameters and assumptions were fully documented and shared with stakeholders. Published data was sourced to drive the models and modelling best practise, such as version control, was followed.

By making connections from analysis to reality, we can ensure analysis is **grounded in reality** and the context of the problem is properly grasped. The views and perceptions of both the WG and IMP consortium have been challenged through validation, sensitivity testing and expert assessment. This in turn has acted to reduce bias and encourage **independence,** particularly through the use of an iterative approach involving a range of perspectives.

Uncertainty was addressed through sensitivity analysis, validation, peer review and workshops. By addressing and communicating uncertainty and its implications, we can provide results within the context of their limitations and ensure appropriate and **robust** use.

A2.1 Model QA processes

As illustrated by Figure A2.1, the IMP comprises a series of linked models with data flows representing real-world interdependencies. For example, the combined outputs of the Land Allocation Module (LAM) (on farm land-use) and FARMSCOPER (on farm emissions) are combined to act as inputs into ecosystem service models such as water and air quality. To enable auditable and traceable data flows to ensure repeatability, records were kept of the specific datacubes acting as inputs and outputs within the modelling chain for each scenario, with each data set assigned an ERAMMP unique ID (EUID). The individual datacubes were also retained for the purpose of version control and error checking.

To assure quality throughout, each individual model has undergone QA led by an expert modelling team. The range and complexity of the models mean there is no single QA activity. Instead, QA has been delivered through a range of activities, with each adding to the overall level of QA (Table A2.1). Following modelling best practise, each team has employed the approaches most appropriate to their model, full details of which can be found in the *IMP Land Use Scenario QA* report. Briefly, these approaches include:

- **Version control:** the management of different versions of inputs, outputs and models.
- **Verification:** the process through which the model is reviewed to ensure it is error free and meets specification. Verification can include version control, code review, logic review, test review.
- **Documentation of assumptions:** the presentation of key parameters and assumptions to build understanding.
- **Expert Assessment (Consortium and External):** using expert knowledge within the consortium and externally (including a WG expert group) to assess the data, assumptions, methodology and outputs.
- **Validation:** the process through which the model is reviewed to ensure it is fit-for-purpose including comparison or contextualisation of baseline model runs with independent datasets or alternative modelling approaches.

- **Academic Peer Review:** many of the models have significant history within the academic literature (see **Error! Reference source not found.**A2.2 for key references), justifying their application within the IMP.
- **Uncertainty Analysis (Sensitivity Testing):** including sensitivity analysis of key parameters and an assessment of the implications on the results produced. This stage also reviews the relevance of pre-defined assumptions.
- **Building understanding**: presentation of baseline results to aid interpretation of other scenarios. Often including supporting expert interpretation.

Table A2.1 summarises the QA processes undertaken in each model. Each model was subject to version control, analyst self-check, internal verification, assumption documentation and internal peer review.

Table A2.1: QA processes by model

Model	Version Control	Verification	Assumption Documentation	Expert Assessment	Validation	Peer Review (PR) and Standard Approaches (SA)	Sensitivity Testing
SFARMOD agricultural model	✓	✓	✓	✓	✓	PR	×
ESC-CARBINE-NPV forestry models	✓	✓	✓	✓	✓	PR	×
Land Allocation Module	✓	✓	✓	✓	✓	×	✓
BTO bird models	✓	✓	✓	✓	✓	PR	✓
MultiMOVE plant model	✓	✓	✓	✓	✓	PR	×
Habitat Connectivity	✓	✓	✓	✓	×	×	×
FARMSCOPER emissions model	✓	✓	✓	✓	✓	PR	×
Water Quality	✓	✓	✓	✓	✓	Partial	×
Air Quality	✓	✓	✓	✓	✓	PR	×
Carbon	✓	✓	✓	✓	✓	Partial	×
Valuation	✓	✓	✓	✓	✓	SA	×

Version control:

Different versions of inputs, outputs and models were managed via strict version control through the modelling chain; this applies to all models within the ERAMMP consortium. Each model and associated datasets were assigned a unique identifier (an EUID: ERAMMP Unique Identifier). These allow cross-check and audit during both model development and scenario simulation and make it possible to trace for a given scenario the model and datacube versions that feed into the scenario slidepacks. The EUID database details where each datacube is located across the ERAMMP consortium institutions.

- The EUID database is available to the Welsh Government and can be requested by contacting the ERAMMP Project Office (www.erammp.wales/en/contact-erammp).

Verification:

Verification is the process by which modellers check and understand that their model is functioning as expected. In practice it may include checking the code for errors, setting checks to catch common errors within the code or modelling teams using their own expert judgment to assess their model's performance is within expected parameters: this step was performed by all modelling teams within the consortium. Where model outputs were passed to other modelling teams these checks were reinforced by input data sense checks of the downstream teams.

As an illustrative example, four checks were applied to ensure that the downscaling of ESC-CARBINE-NPV outputs to the DMU scale worked correctly:

1. A check was set up to ensure that the plantable area of a DMU did not exceed the total DMU area;
2. Tree suitability and yield class values were checked to be within known maximum and minimum values;
3. The geographic and climatic trends followed by the data were checked against expected patterns known from experience with the data in similar projects;
4. The Net Present Values data were checked relative to the equivalent farm economic values for output from SFARMOD.

The full QA report provides further details of the ESC-CARBINE_NPV verification.

- Verification has been carried out on all models with processes and checks tailored to each model. Key checks are detailed in the full QA report.

Assumptions documentation:

For transparency and repetition, all model assumptions are documented in the *Assumptions Document* (see Annex-1). All assumptions have been reviewed, tested, and signed-off by the WG Senior Responsible Officer (SRO). The assumptions documented reflect the final agreements of a considerable period of iteration between the consortium modelling teams and a range of experts within Welsh Government. This applies to all models within the modelling chain.

The assumptions document has been made available to WG and is provided in Annex-1.

Expert assessment:

Each model underwent expert assessment (consortium and external) to independently check model verification, validation and any implications on linked models. A full description of expert assessment is documented in the full QA report (Technical Annex-2, ERAMMP Report-60TA2).

Peer review and standard approaches:

This section covers both academic peer review and the use of agreed, standard approaches used for government reporting.

Academic peer review of models is an important step in the assessment of model's fitness-for-purpose. The majority of the models within the ERAMMP IMP chain have a significant history of application within academic literature for addressing similar questions to those they are used for in ERAMMP. A review of supporting literature for each model is provided in the QA document. A list of key references is provided in Table A2.2. In some cases, a model has been specifically developed for use in the ERAMMP IMP (Land Allocation Module, Habitat Connectivity). These models have been subject to additional checks, expert assessment and where possible, validation and sensitivity testing. In other cases, (e.g. Water Quality) the coefficients are derived from a peer-reviewed model (FARMSCOPER) and combined with the outputs of another peer-reviewed model (SFARMOD); to provide extra confidence the combined outputs are also independently evaluated (see QA doc).

The carbon accounting and ecosystem service valuation modelling components of the ERAMMP IMP use standard approaches used for government accounting. The carbon accounting follows LULUCF carbon accounting procedures, whilst the valuation of ecosystem services follows Treasury Green Book guidance on appraisal and evaluation.

- Table A2.1 highlights where peer review is complete, partial or where standard approaches have been followed. Table A2.2 summarises peer review of the individual models within the IMP; other supporting references are provided in the full QA report.

Validation:

Due to the complexity of the modelling chain, the IMP was validated by assessing the results of each model element. A baseline scenario was generated for this purpose. Representing something close to current conditions, the baseline is parameterised as a farming system with CAP Pillar 1 Basic Payments and cost-neutral Pillar 2 additional payments. Where possible, 2015 is the data year to match with the Land Cover Map 2015 used to parameterise the modelling. The full parameterisation of the IMP baseline is detailed in the assumptions document (particularly assumptions 5-12). The validation of each model varies depending on data availability, as detailed in full in the QA document.

All models were validated where possible, although the specific approach taken varies depending on the model and the available data. For example, The BTO model used cross-validation to evaluate model performance. Cross-validation is a statistical approach to evaluate predictive model performance. This technique uses the Spearman's rank correlation coefficient to assess the degree of agreement between the predicted and true values. In contrast, the Carbon modelling validated the wetland emission outputs by comparing the baseline outputs against the wetland coefficients from the emissions inventory wetland supplementary table[11].

The LAM was developed specifically for use in the IMP. As such, it underwent a comprehensive validation against three different datasets. Firstly, the Welsh Farm Business

[11] Evans, C., Artz, R., Moxley, J., Smyth, M-A., Taylor, E., Archer, N., Burden, A., Williamson, J., Donnelly, D., Thomson, A., Buys, G., Malcolm, H., Wilson, D., Renou-Wilson, F., Potts J. (2017). Implementation of an emission inventory for UK peatlands. Report to the Department for Business, Energy and Industrial Strategy, Centre for Ecology and Hydrology, Bangor.88pp.

Income (FBI) from Newcastle University's Brexit report[12] by comparing proportions of farms by FBI. Secondly, by comparing median modelled LAM FBI against farm FBI averages from the Welsh Farm Business Survey. And, thirdly by comparing the LAM baseline land cover with data from GMEP plot locations.

Full model validation was not always possible, either due to the methods employed or lack of available data. In these cases, thorough sense checks were undertaken. For example, the habitat connectivity model is a GIS toolkit used to identify areas where new habitat, as generated by the LAM, would connect two patches of unconnected habitat types. There are no appropriate datasets for comparison. Whilst the model outputs could be compared to outputs of alternative connectivity modelling tools, this would be a comparison of approaches with differing assumptions, modelling different aspects of connectivity. Hence, such a comparison would not explore uncertainty in the model as it should be interpreted. Instead, a full independent review of the code and outputs indicates that identified land does create connectivity given the model parameters.

- Further information on validation of the modelling chain is detailed in the full QA report.

Sensitivity testing:

Sensitivity testing is used to address uncertainty about key parameters. Where there is significant dependency on an uncertain assumption, effort has been made to control and communicate the implications of that uncertainty. This is particularly the case for the newly developed LAM. The LAM recognises that there are complex human and financial factors that affect changes to farm type. It is not possible to model these complex relationships, which are instead reflected by co-developed rules and FBI thresholds. Downstream models are heavily reliant on the outcome of the LAM and as such, sensitivity testing was carried out on key parameters including, the minimum simulated FBI required to continue full-time farming. This provided opportunities to challenge assumptions and understand their implications.

- LAM sensitivity analysis is detailed in the full QA report.

A2.2 Conclusion

The ERAMMP IMP is used to support policy decision-making that will have real-world impacts, so there is a need for the model outputs to have been critically evaluated and well understood by the policy teams in Welsh Government who are using them. This requires full recognition of the modelling context including the limits to modelling capability and the implications of the assumptions that underpin it.

The ERAMMP IMP has been designated as business critical, meaning that it supports the development of core elements of government policy. As such, compliance with the Aqua Book is mandated.

[12] Hubbard et al (2019). Brexit: How might UK Agriculture Thrive or Survive?. Newcastle University. https://research.ncl.ac.uk/esrcbrexitproject/outputs/Final%20Report%20Brexit%20and%20Agriculture%20March2019.pdf

To address this, the ERAMMP IMP was developed following the principles of co-creation, taking an iterative approach that involved the modelling consortium and Government experts throughout. The principles of RIGOUR were strictly adhered to with all assumptions underlying the modelling approach agreed, transparently documented and signed-off by an SRO within WG following a multi-stage iterative discussion between modellers and end users. In addition, modelling teams employed a range of appropriate methods for quality assurance, including validation, sensitivity analysis, contextualisation and interpretation, and detailing historical peer review, as detailed in the quality assurance document.

This Annex summarises QA of the ERAMMP IMP. Setting out briefly the framework within with the IMP was developed, this document outlines the key QA processes undertaken for each model. Full details of the IMP QA can be found in the Land Use Scenario QA report in Technical Annex-2, ERAMMP Report-60TA2[13], which should be read in conjunction with Annex-1: *Full List of IMP Assumptions*. Additional information to contextualise the IMP, including datacubes, data dictionaries, slidepacks and EUID database, are available to the Welsh Government and can be requested and can be requested by contacting the ERAMMP Project Office[14].

Six slidepacks containing full results from applying the ERAMMP Integrated Modelling Platform (IMP) to the six land use scenarios have been produced:

- ERAMMP_IMP_LandUseScenarios_T1_Slidepack.ppt
- ERAMMP_IMP_LandUseScenarios_T2_Slidepack.ppt
- ERAMMP_IMP_LandUseScenarios_T3_Slidepack.ppt
- ERAMMP_IMP_LandUseScenarios_T4_Slidepack.ppt
- ERAMMP_IMP_LandUseScenarios_T5_Slidepack.ppt
- ERAMMP_IMP_LandUseScenarios_T6_Slidepack.ppt

A slidepack comparing IMP results for the four land use scenarios involving an EU Free Trade Agreement has also been produced:

- ERAMMP_IMP_Cross-LandUseScenarios_T2-T3-T5-T6_Slidepack.ppt

These seven slidepacks are published as Technical Annex-1, ERAMMP Report-60TA1[15].

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[13] Harrison,.P.A. et al. (2022). *Environment and Rural Affairs Monitoring & Modelling Programme (ERAMMP)*. ERAMMP Technical Annex-2 Report-60TA2: ERAMMP Integrated Modelling Platform (IMP) Land Use Scenarios Quality Assurance. Report to Welsh Government (Contract C210/2016/2017)(UK Centre for Ecology & Hydrology Projects 06297 & 06810)
www.erammp.wales/60TA2

[14] www.erammp.wales/en/contact-erammp

[15] Harrison,.P.A. et al. (2022). *Environment and Rural Affairs Monitoring & Modelling Programme (ERAMMP)*. Technical Annex-1 Report-60TA1: ERAMMP Integrated Modelling Platform Land Use Scenarios Slidepacks. Report to Welsh Government (Contract C210/2016/2017)(UK Centre for Ecology & Hydrology Projects 06297 & 06810). www.erammp.wales/60TA1

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