Woodland and trees in the farmed landscape:

Towards a diverse, resilient and vibrant agroforestry and farm woodland economy for the UK

Report for

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1 Executive summary

Tree planting is essential to achieve national climate targets and to support more resilient farming systems but talk of 'freeing up farmland' for large scale, afforestation is increasingly controversial. What might it mean for our rural communities, cultural landscapes, and food security?

Agroforestry and farm woodland (AFW) offer a viable and cost-effective way to enhance UK tree planting without reducing agricultural production and, therefore, offshoring the impacts of the UK food system (Poux et al., 2021). The integrated tree planting associated with AFW offers possibilities to enhance the provision of a range of ecosystem services, achieving co-benefits for biodiversity, water quality, landscape amenity value and animal welfare, alongside climate mitigation. Furthermore, increased agroforestry and farm woodland establishment has the potential to enhance the performance and resilience of UK food production.

The net environmental benefit from a shift to more integrated systems of agroforestry is likely to be greater than converting pasture to woodland at a whole farm scale. Furthermore, applying these more integrated land use changes at a landscape scale is likely to be a more viable option for providing a wider range of public goods than more traditional woodland conversion. If strategically incentivised, this is feasible without distorting food and rural economies. Furthermore, complete conversion of agricultural land risks carbon leakage, whilst more strategically, integrated agroforestry and farm woodland approaches retain and enhance agricultural productivity.

Strategically increasing UK agroforestry and farm woodland has the potential to enhance the performance and profitability of the agricultural economy by restructuring the landscape to one more supportive of a range of agricultural activities. Moreover, agroforestry and farm woodland can generate new markets for agroforestry and farm woodland products with positive environmental impacts. There is growing demand for locally produced products across all sectors. Marketing agroforestry and farm woodland products as ethical and environmental may help to improve the profitability of these systems. In addition, growing interest in payments for ecosystem service (PES) schemes provides a potential avenue for increased support for agroforestry and farm woodland.

In this report we set out to understand the current composition and extent of UK AFW and to understand the barriers to improved implementation. We identified key system changes that would help to improve farmer confidence in AFW implementation, as well as achieve better rewards through on-farm performance improvements and wider market opportunities.

We then set out to model the economics of different agroforestry and farm woodland systems, to better understand how public policy, natural capital markets and improved agricultural performance could support this land use change.

Insights from the model

The modelling shows that AFW options that are structured to enhance agricultural performance can be effective at enhancing farm profitability, particularly on more productive UK farm types. This is because when per hectare yield is higher, proportional performance benefits from things such as shelter can have a higher impact on total income.

The model also revealed that for lower yielding systems, such as Less Favoured Areas (LFA) grazing, woodland systems can be a more economically viable land use option if there are opportunities to monetise the carbon storage. This offers considerable scope for LFA land managers to diversify their enterprises and enhance their profitability. However, if these payments are not provided in combination with support for a wider spectrum of ecosystem services, there is a risk that they will negatively distort the land and food sectors.

When modelled, farm woodland planting was found to be the scenario most dependent on policy payments, but also the most effectively supported by current policy. In contrast, agroforestry systems with sparser tree planting and greater integration with agriculture were less well recognised and under-supported by current policy. Relatively small amounts of funding could enable these forms of agroforestry to be economically viable.

Future agroforestry and farm woodland policy development

Future policy reform, post-CAP, across the UK, offers a significant opportunity for better policy design and outcomes for AFW. Under the CAP, AFW were disincentivised because in many cases farmers lost their basic payment for land under trees, impacting both income and land value.

Whilst certain policy barriers to trees on farms across the UK are being removed, further policy intervention is still needed.

1. **Developing policies, schemes and payments focused on agroforestry and farm woodland**

There is a need to design land management and woodland creation schemes to better meet the needs of AFW, transcending institutional silos for farming and forestry.

The model indicates that public payments based on income foregone payments for development of AFW systems, combined with public and private payments for ecosystem services will be necessary to incentivise integrated and low-density agroforestry systems. This more integrated approach is likely to be an effective way to initiate widespread tree planting that provides diverse ecosystem services at the landscape level, whilst maintaining and enhancing agricultural productivity.

In fact, the model shows, that only funding the capital expenditure to develop agroforestry and farm woodland systems to land managers, is enough to make shelterbelts, and silvoarable/silvopastoral orchards economically viable and attractive land use options.

In England, Secretary of State George Eustice has committed to improve income foregone agri-environment payments to maximise farmer take-up. This will be important in overcoming barriers to the uptake of AFW.

In Scotland, the Agri-Environment Climate Scheme and Forestry Grant Scheme are providing funding to help land managers shift towards low carbon and environmentally protecting land management. Specific support is being provided for tree planting and agroforestry. Scotland's Third Land Use Strategy commits to the expansion of forest and woodland cover, acknowledging the increased role of agroforestry.

In Wales, the Sustainable Farming Scheme is set to provide payments to farmers enhancing the public goods they provide. This will include payments for AFW systems and the ecosystem services these provide.

In Northern Ireland, a Farming for Nature Package has been proposed to support increased integration of AFW within farms. This support acknowledges the potentially high benefits of silvopastoral and silvoarable systems.

To support these aims, governments across the UK need to develop explicit and consistent support for clearly defined forms of AFW. This should be supported by income foregone payments combined with public and private payments for the public goods provided. Payment support needs to focus on the establishment of new AFW systems, as well as the conservation, regeneration and public benefits provided by existing systems. AFW areas also need defining and recording in agricultural surveys. This will help to raise awareness of these system as viable and nationally relevant land use options.

2. Developing systemic and infrastructural support for agroforestry and farm woodland

There remain several systemic barriers to the practical implementation of AFW. The land-based sector is poorly equipped to manage this multifunctional land use. Economic viability is also restricted by the absence of knowledge, machinery, supply chains, and services necessary to manage AFW. Knowledge and education in the land-based sector remains siloed. This restricts land manager capability to establish profitable AFW.

Maximising take-up and benefit of AFW requires measures to increase farmer confidence. This includes extension support, innovation and development of new market in small-scale timber harvesting and processing, as well as fruit and nut production that can benefit the wider rural economy.

Local supply chains and markets are often poorly suited to AFW products such as timber and nuts. Current evidence indicates there should be an opportunity for more domestic, on farm timber production for external markets and on-farm substitution. The UK is reliant on imports for 80% of its forest product needs. With global demand set to triple over the coming decades supply is likely to become strained. Innovations in the AFW sector are going to be essential if production of timber, fruit and nuts at scale is to be viable in the UK.

There is a need to define and communicate how AFW should be effectively established across the UK. Environmental and performance benefits of these systems need to be researched and validated. Universities and agricultural and forestry advisors need to be encouraged to develop cross sectoral understanding of agriculture, forestry, and agroforestry.

3. **Developing ecosystem markets that effectively support agroforestry and farm woodland**

The governance of carbon and other natural capital markets – including through blended finance arrangements – needs to be restructured to mitigate the risks of sub-optimal tree planting scenarios and maximise co-benefits for biodiversity, animal welfare and sustainable food production. This is necessary if more integrated forms of land management such as AFW are to be incentivised through.

Our modelling has shown that the integrated policy goals delivered by AFW will not be well supported by carbon markets in isolation. Rising carbon payments risk driving up the price of land and incentivising large-scale afforestation of largely coniferous woodland. Modelling the predicted carbon payment rate of £80 per tonne by 2030 greatly increased the incomes from coniferous planting, this would distort the land-based economy.

To reduce the risk that ecosystem markets lead to this kind of distortion, blended PES schemes need developing to fund a spectrum of public goods. PES schemes, including the WCC, need to be applicable to a wider range of AFW systems. This should cover a range of planting densities, collaborative agreements, and scales. These schemes need to incentivise and enable companies across supply chains and sectors to promote and invest in AFW options that have the potential to maintain and enhance the productivity and resilience of their enterprises.

Summary

Investment in the establishment of AFW systems should occur through a combination of public support, private markets for ecosystem services and increased awareness of the performance benefits of these systems. This will be a cost-effective way to increase tree cover within the agricultural sector, whilst simultaneously enhancing agricultural performance and the resilience of UK food production.

We hope that the open-source model developed for this report will be a useful tool to support policymakers and other interested stakeholders in the generation of scenarios that can maximise AFW uptake and the associated benefits for climate, nature and sustainable food production.

2 Introduction

2.1 What is meant by agroforestry and farm woodland?

This report attempts to explore the structure and impacts of the various ways that trees are integrated into the UK's agricultural landscapes. This encompasses farm woodland, continuous areas of woodland on farms with a canopy cover of greater than 20%; and agroforestry, the deliberate integration of woody vegetation with crops and/or animals to benefit from the resulting ecological and economic interactions (den Herder et al., 2016).

These systems impart benefits to farmers, farm enterprises and to society. The report focus, however, is on the economic impact of AFW. It explores the performance benefits, markets, supply chains, and payment schemes that are established and are being developed to support an AFW economy.

2.2 Why is the integration of trees into farm enterprises important?

As awareness of the environmental externalities and increasing economic risk associated with agriculture grows, so does interest in AFW. This is because it can enhance and diversify the provision of ecosystem services (ESs) from agricultural land, thereby improving the integrated sustainability. Meta-analysis has shown that AFW can reduce flood risk and climate impacts; and benefit soil health, biodiversity, and recreation (Torralba et al., 2016).

Agriculture accounts for roughly 10% of the UK's greenhouse gas (GHG) emission and 70% of the land. It has struggled to decarbonise at the same rate as other sectors and is a major cause of biodiversity loss and water pollution. Farm woodland can play an integral role in improving these impacts. The Climate Change Committee (CCC) states that afforestation and an increase in agroforestry could reduce GHG emissions by 2.4 $MtCO^2e$ by 2030. Agroforestry alone could save 5.9 $MtCO^2e$ per year by 2050 (GOV.UK, 2022).

It has also been shown that agroforestry can increase total yields from an area by up to 40% relative to monoculture (Graves et al., 2007). This is because the integration of trees, crops and/or livestock into a system can utilise more of the productive capacity of the land, enabling more efficient resource use.

Trees on farms can also enhance the resilience of other farm enterprises. They provide shelter, fodder, and bedding for livestock; habitat for pest predators and pollinators; materials for construction; biofuel for on-farm heating and power; and can aid resource use efficiency. AFW also provides a range of less tangible and less commonly assessed services. These include recreation, education, and cultural heritage.

Whilst the benefits of AFW are widely acknowledged, UK uptake has been inconsistent and slow. Most recent farm woodland planting has taken place in Scotland, which now accounts for roughly half of all UK farm woodland. Certain forms of AFW, such as hedgerow planting have seen wide uptake and integration into farming. Others, such as arable agroforestry, are barely present.

In recent years, policy makers have tried to respond to the slow uptake of AFW by raising awareness and devising policies to support establishment. However, to date, there has not been an assessment of the impact increased AFW could have upon farm enterprises and rural economies across the UK. This report intends to contribute to this gap in the understanding of UK AFW.

2.3 Aim of this report

This report aims to review the economic impact of a sustainable agroforestry and farm woodland economy in the UK.

The report can be divided into the following tasks, each contributing to the main aim:

- A review and definition of the current types, composition, and scale of AFW in the UK.
- An assessment of the wider supply chains, enterprises, markets and market trends that intersect with and support the AFW sector.
- A review of the major policies, subsidies and payment schemes relating to AFW across the UK nations.
- Modelling the economic impacts of an increase in sustainable AFW across the UK agricultural economy.
- Identification of the major opportunities and barriers to increased UK AFW.
- Development of key recommendations for enhancing the scale of UK AFW.

The above tasks are supported by a range of relevant academic and industry literature, and a selection of case studies. These case studies are used to exemplify the structure, performance, and challenges of the AFW systems.

3 Agroforestry and farm woodland in the UK

AFW is a significant land use in the UK but remains poorly defined and rarely measured. Whilst agricultural surveys keep records of farming practices and land use across the UK, and forestry surveys do the same for woodland, there is no official database for agroforestry. Quantification is further complicated by the complexity and ambiguity around defining the different forms of agroforestry. Trees can be densely or sparsely spaced; within, around, and across fields. Not all actors agree on which of these constitutes AFW. Percentage canopy cover is a potential method of classification, but quantification is hard, and changes as trees are planted, grown, maintained, and felled.

In this report, we attempt to define the different AFW categories that should be measured. We also approximate the extent of these categories across the UK. Given the issues described above, these values are speculative, but provide the best approximation we could source.

Two reports have been especially useful for quantifying the areas of AFW across the UK. The first is the UK Forestry Statistics 2020 published by the Forestry Commission (2020). These statistics collate data from the Agricultural Census run by Defra (Department for Environment, Food and Rural Affairs) and the devolved administrations. The authors define farm woodland as farmland beneath tree stands with a canopy cover of at least 20% or having the potential to achieve this (Forestry Commission, 2020). This data covers farm woodland type, use and area. The statistics provide the area of farm woodland (1,033,000 ha), but do not provide any more detail about the composition of this woodland.

There are no national surveys in the UK quantifying agroforestry. The most complete assessment of agroforestry available for the UK was a study undertaken by den Herder et al. (2016). This study used the Land Use and Coverage Area frame Survey (LUCAS) to estimate the area of different types of agroforestry across all European countries. This survey uses classification and photographic data from 250m transects taken all across Europe to estimate the areas of land cover across the continent (https://ec.europa.eu/).

It is worth noting that neither of the two reports provide well validated or exhaustive measurement of AFW. They are based on survey data and satellite imagery. Both are prone to error. However, in the absence of any other data, they are the most accurate quantifications available and give a good indication of the relative scale and composition of UK AFW.

Den Herder et al. (2016) use the LUCAS classifications to identify land uses that combine silvicultural and agricultural practices. For this analysis we have extracted the data for the UK. This equates to a total of 0.55 million hectares of agroforestry. Whilst den Herder et al. (2016) provide a thorough breakdown of agroforestry, we have not chosen to present this data and instead present four high level agroforestry categories. This is because of the ambiguity in the definitions of agroforestry and how they are understood. Furthermore, the

European focus of the den Herder et al. (2016) study means it is unlikely to provide the necessary detail to accurately reflect these complex and poorly defined systems at the national level.

The areas of our high level AFW categories are presented in Table 1Table 1. Using this data, we estimate a total of 1.4 million ha of AFW across the UK. When aggregating the data from the den Herder et al. (2016) paper and the Forestry Commission (2020) we exclude data collected by den Herder on the extent of grazed woodland. This is because we assume this is covered under the Forestry Commissions assessment of farm woodland and its inclusion would lead to double counting. It is worth noting that the LUCAS data defines woodland as 10% canopy cover instead of the Forestry Commission's 20% requirement. Therefore, excluding the LUCAS woodland data will mean some woodland is excluded. However, we assume this area is inconsequential given the uncertainties in the data.

The remainder of this chapter explores each of these AFW categories in more detail. We assess research that explores the extent, composition and performance of the major AFW systems that comprise each of the categories. Where appropriate, we provide case studies to substantiate and exemplify aspects of the AFW systems. The assessments are used to draw together key findings related to each AFW category.

Table 1: Overview of the extent of the major types of AFW in the UK

AFW	Definition	Area (ha)
Farm woodland	An area of farm with over 20% tree canopy cover	1,033,000
Silvopastoral agroforestry	Systems that combine tree growing with the production of livestock (Grebner et al., 2021)	548,000
Silvoarable agroforestry	Systems that consist of widely spaced trees inter-cropped with annual or perennial crops (Eichhorn et al., 2006)	2,000
Hedgerows	A row of shrubs or trees enclosing or separating fields (Merriam, 2021)	71,500
Total area of agroforestry, farm woodland, and hedgerows		**1,412,000**

3.1 Farm woodland

This section provides a summary of the available data on the current area and type of forestry in the UK before focussing on farm woodlands. It also identifies the changes and trends over the last 10 years.

The main data source for the current area and type of UK forestry is contained within the Forestry Statistics report, issued annually by the Forestry Commission, and forms the basis of future reporting on forestry land use statistics. For the purposes of these statistics, woodland is defined as

> ***land beneath stands of trees with a canopy cover of at least 20% or having the potential to achieve this.***

The definition relates to land use rather than land cover, so integral open space and felled areas that are awaiting restocking are included as woodland. It should be noted that there are several agroforestry systems that can have more than 20% canopy cover – however there is no specific reference to agroforestry and there is no indication whether any agroforestry systems are included within these statistics.

The annual forestry statistics for England, Wales and Scotland are based on data from the National Forest Inventory (NFI) and adjusted for new planting. Figures for Northern Ireland are gained from the Northern Ireland Woodland Register. The NFI provides a record of the size and distribution of forests and woodland and is a continuous inventory.

3.1.1 UK woodland

The total area of woodland cover (i.e. woodlands over 0.5ha) in the UK at March 2020 is estimated to be 3.2 million ha, which equates to 13% of the total land area (Forestry Commission 2020). Of this total, there are 1.5 million ha (46%) in Scotland, 1.3 million ha (41%) in England, 0.3 million ha in Wales (9%) and 0.1 million ha (4%) in Northern Ireland.

In terms of type of woodland, broadleaved woodland accounts for approximately half (49%) of the woodland area, although this proportion varies considerably from area to area, depending on a range of site and other factors and according to country. For example, in Scotland, only 26% of woodland is broadleaved, versus 74% in England. Likewise, species composition varies across different areas and countries according to site factors such as terrain, access and location. However, what each country does have in common, is that their respective forest resources are dominated by very few species. Sitka spruce makes up around half of the conifer resource in the UK, followed by Scots pine, larches, and Norway spruce. The broadleaved resource is dominated by oak, ash, birch, beech, and sycamore. This poses potential risks, especially from pests and diseases and, in the longer term, the risks posed by climate change – see below for further comment.

The NFI report for the UK's trees outside the above-mentioned woodlands, estimates that there are 742,000 hectares of tree cover. This is split into small woodlands below 0.5 hectares, linear woods, hedges, and lone trees. The individual trees alone are estimated to contribute 97,000 hectares of canopy cover in Great Britain. These estimates are likely to include some agroforestry systems.

3.1.2 UK farm woodland

The area of farm woodland is included within the annual Forestry Statistics report and comprises nearly a third of total UK woodland area. Data on farm woodland reported is based on agricultural census data; Defra and the devolved administrations collect annual information on agricultural land use.

Unlike the forestry statistics for overall woodland cover in the UK, no data is provided on aspects such as the ownership, age, and species composition of farm woodland. However, it is likely that most of this farm woodland is privately owned as opposed to being owned by a government body such as Forestry England, or Forestry and Land Scotland. That said, we know little about the types of private owners. This limits our understanding of who drives farm woodland planting and maintenance and why. Farm woodland is expected to have a higher percentage of broadleaved species than the overall woodland area and predominantly comprise oak, ash, birch, beech, and sycamore.

The area of farm woodland in the UK has increased from 0.77 million ha in 2010 to just over one million ha in 2020. Slightly over half of all farm woodland was in Scotland, with a further 37% in England, just 11% in Wales, and 2% in Northern Ireland. The extent of the increase, however, needs to be treated with caution, as there appear to be several inconsistencies reported in the data, which reflects the way that it is collected and reported (Forestry Commission Statistics 2020). Thus, the extent of farm woodland expansion may be overstated. For example, the farm woodland area for Wales reduces from 69,000 ha in 2010 to 44,000 ha in 2011, however, the overall trend is clear. Furthermore, it is likely that much of the new woodland creation envisaged in the future will also take place on agricultural land.

3.1.3 New tree planting

Much of the tree planting over the last 20 years, particularly in England, has taken place on farms, and has been in the form of mixed broadleaved woodland. However, the amount of new planting is still significantly reduced compared to the 20 years prior to that – i.e. from 1980 to 2000 (Forestry Commission annual report, 1999-2000).

Tree planting over the last 20 years has been stimulated by the governments' woodland grant schemes. However, there are a range of motivations for farmers to plant trees on farms. Motivations can be financial, such as diversifying and increasing their income, as well as non-financial, such as improving shooting and screening land from roads. There are also disincentives and barriers, in particular the financial repercussions such as loss of agricultural income, high capital costs of establishing woodland, and the fact that the conversion of agricultural land to woodland amounts to an irreversible land use under current felling regulations. There are also issues over land tenure, land value, land taxation, availability of suitable land, lack of knowledge and skills shortages.

The uncertain future and changing situation for agriculture over the last 10-years, exacerbated by CAP reforms and Brexit, have also disincentivised tree planting on farms. Woodland grants and agri-environment payments are also in transition. This tends to result in owners having less inclination to make land uses changes such as taking land out of production to plant it with trees. Furthermore, the perceived complexity of forest grants has detracted farmers from tree planting.

On a more practical level, increasing numbers of deer, particularly in parts of England, have resulted in the need to erect costly deer fencing, reducing the economic viability of planting and grants.

3.1.4 Farm woodland economics

A range of factors influence forestry business income and the economic viability of woodland management. These include not only timber income but also financial incentives (both grants and tax treatment), as well as non-timber income, in particular sporting and, more recently, PES schemes, especially those enabling the trading of carbon units for the carbon expected to be sequestered by the new woodland.

Timber income is dictated by timber sales and management cost. Timber sales reflect the quantity and quality of timber produced, and in turn the likely markets and price. Expenses include harvesting (i.e. thinning and felling) and management costs including the preparation of management plans, felling licences and other regulations, as well as other supervision and advisory services.

From the sale of timber (i.e. the price delivered to the end user), it is necessary to deduct the costs of harvesting and haulage. Each woodland is distinct, thus only a general overview of revenue and expenditure can be given for the UK. Taking these factors into account, alongside expected markets and prices for the timber, the net income for the large managed woodlands (defined for the purposes of this study as woodlands over 10 ha) and small, less well managed woodlands have been estimated. The figures and results are presented in Table 2 and Table 3.

In estimating the net incomes several assumptions have had to be made, both with regards to the sale prices and unit costs. For example, the unit costs assume that for the large-scale woods, these can be thinned mechanically with a timber harvester, whereas the smaller woods would have to be thinned by chainsaw. Other site factors affecting unit costs include terrain, access and location which can affect the costs of labour. Average sale prices for conifer and broadleaved timber have also been estimated, based on a range of sources, including the Forestry Commission's Standing Sales Index, and Softwood Price Index, timber auction results and the author's direct experience of selling timber. Timber prices are affected by a several factors, including species, quality and quantity, and the timber market. The factors affecting the timber market and timber price trends are considered further in section 4.3.

Table 2: Expenditure versus Income (Large-scale, 10ha and managed)

Timber Operation	Unit Cost (Income) £ per tonne				
	Harvest Cost (roadside)	Haulage	Total	Sale Price	Net Income £
First thin					
Conifer	18 - 25	10 - 15	28-40	45	5 - 17
Broadleaved	18 - 25	10 - 15	28 - 40	55	15 - 27
Clear fell					
Conifer	15 - 20	10 - 15	22 - 35	75	40 - 53
Broadleaves	20 -25	10 - 15	30 - 40	100	60 - 70

Table 3: Expenditure versus Income (Small-scale, 10ha and unmanaged)

Timber Operation	Unit Cost (Income) £ per tonne				
	Harvest Cost (roadside)	Haulage	Total	Sale Price	Net Income £
First thin					
Conifer	25 - 35	10 - 15	35 - 50	45	-5 - 10
Broadleaved	25 - 35	10 - 15	35 - 50	55	5 - 20
Clear fell					
Conifer	25 - 30	10 - 15	35 - 45	60	15 - 25
Broadleaves	25 - 30	10 - 15	35 - 45	70	25 - 35

As can be seen, small adjustments to both production cost and timber sale price can have significant impacts on the overall economics of both thinning and felling operations. These impacts are summarised and explained below:

- Thinnings are usually profitable for larger woodlands, but for smaller woodlands located on difficult terrain with poor access thinnings can struggle to break-even.
- The ‘net income’ from clear felling, particularly for smaller woodlands containing poor quality timber (i.e. very limited sawlog timber), will often not cover the subsequent restocking costs.
- The ability to grow high quality timber and to have the economies of scale to reduce the costs of harvesting and other management operations is crucial.
- The existence of ‘local markets’ could significantly reduce transport distances and in turn costs. Haulage is a significant cost that reduces the net proceeds to the woodland owner and has a disproportionately large impact on the overall margin achievable for small farm woodlands with limited timber quality.
- The increase in timber prices over recent years has decreased the number of woodlands that are uneconomic to manage with obvious implications for management activity. However, smaller woodlands, particularly those with poor access and poor-quality timber still generally remain uneconomic to actively manage.

3.2 Silvopastoral systems

Table 4: Types of silvopastoral systems

Silvopastoral type	Category	Example
Grazed woodland	Longstanding grazed woodland	Cattle grazed in the New Forest
	Newly planted grazed woodland	Chickens freely ranged in newly planted woodland
Grazing with sparse trees	Grassland grazing with sparse trees	Historic parks with grazed sheep and deer
	Shrubland grazing with sparse trees	Sheep grazed in Dartmoor National Park
	Newly developed grazing with sparse trees	Recently rewilded estates
Grazed high value trees	Grazed orchards	Sheep grazed in cider apple orchards
	Grazed timber production systems	Grazed sheep amongst poplar alleys

Silvopastoral systems combine trees with livestock production (Grebner et al., 2020). These systems take various forms and occur on forest or agricultural land. Many silvopastoral systems in the UK have been maintained for centuries and depend on the preservation of traditional management practices. Others are more novel and are being developed in response to new research in conservation and awareness of environmental degradation.

Silvopastoral systems can enhance a range of ecosystems services. They can provide microclimate regulation; benefit animal welfare; enhance nutrient turnover and soil fertility; increase carbon sequestration; reduce nutrient leaching and water pollution; and provide improved and more diverse habitat (Moreno et al., 2014).

In the following sections we provide an overview of the types of silvopastoral systems and assess the various estimates of the extent of these land uses and suggest how, in future, they should be defined and measured.

3.2.1 Grazed woodland

Grazed woodland occupies 244,000 ha of the UK and is the most practiced form of agroforestry (den Herder et al., 2016). It is defined as the farming of livestock within an area designated as forest or woodland. To align with the Forestry Commission's categorisation of woodland, we propose that this should be defined as,

> ***an area with tree canopy cover of at least 20% that is grazed in a strategic and managed way.***

If managed correctly, woodland grazing can play an important role in forest conservation and regeneration. It can benefit woodland flora by increasing structural complexity, clearing vegetation to stimulate succession, and reducing competition between seedlings and other flora (Pollock et al., 2005). In fact, it has been proposed that grazing herbivores have played a crucial role in forest regeneration by preventing canopy closure and habitat simplification (Vera, 2000). Although this theory is contested, it is widely understood that correctly managed grazing pressure can benefit woodland health and biodiversity. However, overgrazing can cause habitat degradation by reducing structural complexity and species richness (Pollock et al., 2005).

Different livestock species have different grazing patterns and preferences and, hence, different impacts upon woodlands (Newman et al., 2018). Species selection and stocking density needs to be carefully managed to ensure woodlands remain healthy; traditional hardy breeds are often preferred for this kind of grazing.

It is possible to further divide grazed woodland into longstanding grazed woodland and newly planted grazed woodland.

3.2.1.1 Longstanding grazed woodland

Longstanding grazed woodland was once widespread; local people were permitted to graze livestock on wooded commons owned by landlords (Newman et al., 2018). During the enclosures much of this practice ceased, but it is still present, often maintained through common rights and practiced for its cultural and conservation value.

In the UK, cattle are the most common species grazed in woodland and are usually grazed alongside other species such as deer and sheep. A variety of cattle breeds are grazed across the UK although in Scotland, hardier breeds such as Highland cattle are favoured, presumably to cope with the harsher climate (Armstrong et al., 2003).

Traditional grazing practices have been retained in areas such as the New Forest National Park. At 57,100ha, it is the largest area of semi-natural vegetation in lowland Britain. The area exhibits traditional forms of livestock farming in which commoners graze predominantly New Forest ponies and cattle. These traditional grazing practices contribute positively to the high biodiversity value of the forest.

A distinct woodland grazing practice is the grazing of pigs through woodland. Now rare, this used to be a widespread practice and has been maintained and reinitiated in several locations across the UK and Europe. Pigs natural rooting behaviour can be used to clear areas of forest from unwanted bracken or seeds. This creates space for new species to colonise and grow. In the Wyre Forest just such a system has proven successful at enhancing new growth and the establishment of young oak trees (Woodland Trust, 2012).

3.2.1.2 Newly planted grazed woodland

Newly planted grazed woodland encapsulates a range of new silvopastoral systems, often developed to enhance ESS such as climate regulation and food provisioning. These systems are diverse, predominantly promoted and developed by forward thinking land managers and organisations. There is currently negligible data on the extent of these systems. However, given the pressing challenges of meeting UK tree planting targets across a country with 70% agricultural land cover, it will be important to explore and quantify the trends and drivers behind newly planted grazed woodland. One driver is the increasing awareness of the benefits trees can provide to livestock. This has led a growing number of farmers to use trees for shelter and fodder (Newman et al., 2018).

Fodder from trees can provide various benefits; leaves can provide fodder which can be preserved to provide a seasonal food source before pasture is ready to be grazed; and species such as willow and alder are rich in beneficial minerals and chemicals including tannins which have been shown to reduce methane production from enteric fermentation in the gut of ruminants (Kendall et al., 2021). Additionally, many agricultural animals, such as pigs (Stolba & Wood-Gush, 1989) and chickens (Bright et al., 2011), express natural behaviours in woodland areas such as foraging which can improve animal welfare.

Brownlow et al. (2005) modelled woodland pig farming systems and found that they consistently outperformed equivalent systems without woodland cover. Increased market price is also a potential benefit of these novel systems, especially as awareness about animal welfare and the environmental and public health risks of intensive farming increases.

Market incentives are becoming increasingly common and there are a growing number of cases where grazed newly planted woodland is being encouraged by actors across the supply chain. Large procurers such as Sainsburys and McDonalds are encouraging woodland farming (see Case Study 1). Awareness of the welfare and environmental issues associated with livestock farming is growing and an increasing number of consumers are shifting to more ethical diets. This is likely to encourage more supermarkets to find ways to reassure customers about product provenance. Woodland grazed and farmed products are an ideal way for supermarkets to differentiate their products from other labels such as free range whilst also enhancing their productivity and contributing to net zero targets.

Case Study 1: Woodland chickens

Background

Several companies have begun to market woodland eggs. The aims are welfare, productivity enhancement and improved environmental sustainability. The rationale is that modern chickens evolved from wild varieties that inhabited forest environments and hence tree cover encourages natural and beneficial behaviours (Bright et al., 2011).

Sainsburys launched their Woodland Free Range Eggs brand in 2004 in partnership with the Woodland Trust. To sell eggs under the label farmers must meet several requirements including providing hens with access to range area with 20% tree cover. Additionally, 1p per dozen eggs sold is donated to the Woodland Trust. This scheme has so far sold 6.1 billion eggs (https://www.about.sainsburys.co.uk) and helped plant 3.6 million native trees (https://www.about.sainsburys.co.uk/new).

McDonald's have developed a similar programme. In 2007, they worked with two of their producers, The Lakes Free Range Egg Co Ltd (Lakes) and Noble Foods Ltd, to plant trees on 5% of the total range area. This project was undertaken with FAI Farms Ltd. to investigate the impact of canopy cover upon animal welfare.

Cost benefit

David Brass at Lakes has planted 40,000 trees (15 ha of woodland) on his land. This means all Lakes Farms are planted with 20% tree cover. Brass claims that this can increase revenues of a 64,000 hen farm by £20,000 per annum and that the £2,000 per hectare planting costs are paid off in 6 months (https://www.farminguk.com/news/two-billion-eggs-sold-through-woodland-trust-scheme_36018.html). Brass believes it is the enhanced quality of the range area that supports his hens' high annual productivity of 314 eggs per hen (https://lakesfreerange.co.uk/values/sustainability/).

The research conducted by FAI with McDonald's supports this claim. It showed that the 5% tree cover increased ranging and foraging behaviours, which in turn reduced injurious feather pecking in the flock (Bright et al., 2011). This reduced mortality by 1% and increased the average quality of the eggs produced. The economic savings for a flock of 12,000 hens were calculated to be £5,148 (https://www.faifarms.com/portfolio-item/mcdonalds-tree-range-hens/).

Additional benefits

By promoting, supporting, and funding agroforestry, large companies can enhance productivity and sustainability. The Woodland Free Range Eggs brand is testament to this. The scheme has had numerous environmental benefits including mitigating the impact of more than 812,000 tonnes of carbon dioxide since it started (https://www.about.sainsburys.co.uk/news/latest-news/2019/03-10-2019-free-range-eggs). In addition, increasing the ranging behaviour of hens by planting trees may help spread the nutrient load and contamination from excretion across larger areas and enhance soil carbon sequestration. Trees also absorb ammonia, a trait that may help lower the emissions and air pollution from farms.

3.2.2 Grazed woodland economics

Many traditional woodland grazing systems now appear to be maintained for ecological and cultural reasons rather than primarily for provision of meat or dairy. Whilst the traditional breeds may sell for a premium, the low stocking densities mean this is not the primary economic reason for maintaining these land management systems. Farmers who maintain these silvopastoral practices often do so on land owned by large land holders or conservation organisations, the rights of the farmers to farm are often preserved under common rights.

An assessment of woodland cattle grazing in the UK by Armstrong et al. (2003) explored the reasons why woodland grazing changed across the different UK nations. In England, the primary reason was nature conservation, whereas in Scotland it was agricultural production. It seems that a greater percentage of grazed woodland in England is owned by NGOs and public bodies which maintain woodland grazing for ecological and cultural reasons. Whereas in Scotland larger areas of land make extensive woodland grazing more economically viable.

In the case of grazed newly planted woodland, it appears to be the animal welfare benefits that are incentivising planting. Chickens naturally seek out trees for shade and protection from predators, this increases their inclination to range (Dawkins et al., 2003). Increased ranging has been linked to reduced stress and less injurious behaviours. Birds that are ranged have been found to be healthier with higher bone breaking strength (Leyendecker et al., 2001). Tree cover has also been shown to reduce predation and mortality, increasing survival rate by as much as 4% (Bosco et al., 2014). However, there is limited and varied evidence as to these benefits, trade-offs with other potential land uses and growth rates need to be considered.

The impacts of new planted woodland upon the productivity of ruminants are uncertain. Whilst shade can reduce stress and improve growth rates in livestock such as cattle and sheep, this shade can also reduce the productivity and availability of pasture. A study in North Wales investigated the productivity of a silvopastoral sheep system over a six-year period and found that productivity remained constant even with tree cover (Teklehaimanot et al., 2002). Other studies have investigated the impact of shade upon female beef cows and found that microclimates created by tree cover can enhance welfare and increase productivity (Lemes et al., 2021).

As demonstrated in Case Study 1, large companies and brand differentiation are aiding the uptake of these practices. Brands such as the “Woodland Free Range” by Sainsbury’s, provide an economic incentive to farmers who can achieve a higher selling price from these eggs.

3.2.3 Grazing amongst sparse trees

This category covers a variety of systems composed of semi-wooded areas with open space maintained by grazing. Livestock graze on vegetation and saplings, thereby, preventing succession and closed canopy woodland from occurring.

This habitat is poorly defined and quantified. Classification and measurement of certain habitats within this category, such as Wood-pasture and Parkland, exist, but these fail to encapsulate the range of habitats that need including. We propose the need for a new classification for grazing amongst sparse trees:

> ***grazed areas predominantly covered by communities of grassland, grass-like and herbaceous plants, shrubs, or small woody plants including sparsely occurring trees with a canopy cover between 5% and 20%.***

This definition should not replace classifications such as the UK Biodiversity Action Plan (BAP) definition of Wood-Pasture and Parkland, which provides a valuable way to differentiate priority ancient habitat. 20% canopy cover is chosen as the cut-off for this habitat type to avoid overlap with the Forestry Commission’s definition of woodland (Forestry Commission, 2020).

In the rest of this section, we further divide and explore this category as: grassland grazing with sparse trees; shrubland grazing with sparse trees; and newly developed grazing with sparse trees. The first two are often longstanding systems, such as those that were once maintained as parkland for royal hunts or grazed commons. These now provide unique and complex habitats.

Newly developed grazing with sparse tree systems, on the other hand, are more novel. They are often developed and encouraged by farmers seeking a way to reduce their exposure to high costs and restrictive profit margins and stimulated by movements to rewild areas of the UK.

3.2.3.1 Grassland grazing with sparse trees

Grassland grazing with sparse trees can also be described as wood pasture or parkland. These habitats predominantly contain sparsely distributed broadleaved trees in grazed pastures and provide significant cultural, recreation, and ecological value.

The habitat is identified by den Herder et al. (2016) using the LUCAS survey as land showing signs of managed grazing predominantly covered by communities of grassland, grass-like and herbaceous plants including sparsely occurring trees with a canopy between 5% and 10% of the total area (Eurostat, 2013). They calculate the area of grassland with sparse tree cover in the UK to be approximately 240,000 hectares.

In contrast, a study by Lush (2012) calculated the area of wood pasture and parkland to be approximately 62,000 hectares with the greatest area situated in the East of England. The discrepancy is likely due to Lush’s use of the UK BAP Priority Habitat definition of wood-pasture and parkland. This definition requires the areas to include evidence of ancient management and veteran trees. Hence, more recent iterations of grassland with sparse trees will not be covered by Lush’s analysis. The failure to acknowledge this habitat is not a critique of Lush’s analysis, but due to the limitations of the definition of wood-pasture and parkland in the UK. This definition alone disregards a wide range of relevant habitats with high potential for ecological benefit.

Grassland grazing with sparse trees creates a mosaic habitat maintained by livestock and valued for scattered individual trees and the biota associated with them. The open habitat structure, scrub, ancient trees, and presence of dead or decaying wood mean these sites are rich in invertebrates, lichens, and fungi (Hartel & Plieninger, 2014). Examples of these systems are distributed across the UK and often contain veteran trees of high cultural and aesthetic value. These ancient trees can provide rare and practically irreplaceable habitat for native biodiversity.

Hartel & Plieninger (2014) state that the value of these managed, irregular systems has often been neglected. They argue that this is because they are difficult to define, sitting somewhere between pasture and woodland. Those who work in forestry have historically had a bias towards more closed canopy woodland and have neglected parkland systems. Moreover, the twin threats of agricultural intensification and agricultural abandonment have, across Europe, reduced this more extensive and diverse type of land management (Uytvanck & Verheyen, 2014).

In recent years, there has been increased effort to protect and restore parkland habitats. The habitat has been included as a priority for conservation in the UK Biodiversity Action Plan. This has led to significant restoration of neglected parks and reintroduction of grazing species (Mosquero-Losado et al., 2004).

3.2.3.2 Shrubland grazing with sparse trees

Shrubland grazing with spare trees describes land showing evidence of grazing that is dominated (>10%) by shrubs and low woody plants, including sparsely occurring trees (Eurostat, 2013; den Herder et al., 2016).

This is likely to include heathlands and moorlands predominantly, which mainly exist in hilly areas. These are usually less productive areas with high conservation value. Grazing is often practised to prevent woodland succession and maintain the structure and composition of dwarf shrub communities (Newton et al., 2009). However, the role of grazing remains controversial and negative impacts on shrub structure and species abundance have been reported (Newton et al., 2009).

Intensive grazing has been linked to environmental degradation in moorland areas like Dartmoor (Meyles et al., 2006). Livestock induced changes to vegetation and soil structure have been linked to increased downstream flood frequency. Groome and Shaw (2015), however, have connected low intensity grazing of cattle with increased species richness. Not all stated impacts were positive, though, and adverse effects from trampling were highlighted. They conclude that grazing in ecologically valuable areas needs to be judged on a case-by-case basis due to the complexity of predicting the impact of different livestock species, stocking density, and grazing patterns upon diverse floristic assemblages.

Similar issues are associated with Ffridd habitat in Wales, a once wooded habitat now maintained by grazing. This habitat exists between managed lowland and unmanaged uplands, connecting the two landscapes (RSPB, 2014). It is described as a mosaic habitat combining shrubs, trees, and grassland. This makes it valuable for biodiversity that need varied habitats throughout their lifecycles. Ffridd acts as a buffer between different land uses and enhances landscape resilience. However, as in moorland, management is complex, contested and case specific. Increased tree cover is not necessarily viewed positively as it can be associated with a reduction in habitat diversity. Grazing and burning are both viewed as beneficial and detrimental practices depending on implementation. This makes it hard to replicate this Ffridd habitat or draw conclusions about the potential it holds for enhancing AFW across the UK. However, increased investigation, quantification and protection of this valuable landscape is essential to help limit its continued degradation.

Newton et al. (2009) undertook a thorough meta-analysis of studies investigating the impact of grazing upon lowland heathland in north-west Europe and found contradictions between the opinions of conservation managers and scientific evidence. They unearthed some positive impacts on vegetation composition, but also highlighted evidence that grazing can lead to declines in the vertical structure of flora with negative impacts on species such as heathland reptiles. Evidence that grazing leads to a decline in tree abundance was also found.

Based on the evidence, it does not seem like shrubland grazing is a viable route for expansion of agroforestry practices. Whilst in certain cases it may be a suitable way to manage this heterogenous landscape, this is context dependent. In fact, grazing is more likely to decrease tree cover than increase it.

3.2.3.3 Newly developed grazing with sparse trees

Newly developed grazing with sparse trees differs from the previous two AFW systems. They are not maintained for traditional or cultural reasons, but instead offer novel systems of land use combing various habitats, species, and enterprises.

These systems are usually low intensity involving extensive grazing of traditional livestock breeds and an intent to reduce costs by enhancing specific ecosystem functions. Whilst this low intensity farming can reduce yields, the low costs and additional business opportunities such as tours, eco-tourism, and agri-environment grants can help compensate for this.

There are two key drivers for developing these sparse tree systems. The first can be described as the conservation focus. Here we see landowners deciding, to various degrees, to reduce the intensity of their management. These new systems are typified by low stocking densities; hardy traditional breeds grazed all year round; low use of inputs and, therefore, relatively low costs; and support from agri-environment payments.

The development of these systems has been encouraged by the ‘rewilding’ movement and theories around naturalistic grazing. Naturalistic grazing has been popularised by the success of the Oostvaarderplassen model in the Netherlands (Hodder & Bullock, 2009). Land reclaimed from the sea was used to let domestic livestock roam in a semi-wild manner. No feed, shelter, or veterinary care is provided, with the aim of encouraging natural behaviours. An impressive increase in species richness and abundance has resulted including an increase in many breeding bird populations.

Inspired by the success of Oostervaarderplassen, several land managers in the UK are taking a naturalistic grazing approach. The most well-known example is Knepp Castle Estate (see Case Study 2). Whilst the environmental benefits of naturalistic grazing are clear, the economic sustainability is less so. Systems such as Knepp rely heavily on agri-environment schemes, this can make them vulnerable to policy change and austerity measures.

Case Study 2: Knepp Castle Estate – East Sussex

Background

Knepp Castle Estate in East Sussex (c. 1,400 hectare) is the most well-known of a collection of Estates in the UK shifting from conventional agricultural production to a more nature driven, conservation focused approach, one often dubbed 'rewilding'. The land's relatively poor productivity, unsuitability for intensification, and consistently negative profits led the owner, Charlie Burrell, to move away from 'conventional' dairy farming. Burrell introduced a range of traditional breeds to the Estate allowing them to extensively graze seeking to emulate natural grazing patterns. The intention is to stimulate natural regeneration, and productive and diverse ecosystems. This approach can be described as a novel and unstructured form of silvopastoralism.

Cost benefit

Economically, the Estate relies on a diversity of income streams. In a 2007 feasibility assessment commissioned by the Estate, Higher Level Stewardship (HLS) payments were predicted to be £177,000 per annum. According to a more recent article written by Isabella Tree, the culling of the semi-wild herds of animals provides 75 tonnes of meat annually, bringing in around £120,000 (Tree, 2018). Eco-tourism provides an additional source of revenue to the Estate. The Estate has also estimated potential annual revenues from tourism to be £30,000. This gives an approximate total annual income of £327,000.

The extensive grazing on diverse vegetations means the animals are healthy and costs are low. The Estate's variable costs are predicted to be £30,000 and the overheads £147,000. Annual profits for the Estate, therefore, are estimated at £150,000.

Additional benefits

From an ecological standpoint, the results have been impressive. Purple emperor butterflies, cuckoos, turtle doves, and peregrine falcons are some of the biodiversity that thrives on the Estate. Knepp also provides considerable educational and recreational benefits whilst the vegetation and organic matter in the soil sequester greater levels of carbon than conventionally managed land.

The second driver to increase sparse tree cover across landscapes is the collective desire to enhance ESs. Flood protection is the most common and the collective desire to enhance this service, usually driven by local governments or NGOs, is encouraging tree planting and habitat regeneration. An NGO driven example is the Yearn Stane project (see Case Study 3). Here flood regulation, enhanced social wellbeing, public health improvement, and economic rejuvenation of the area are incentivising habitat regeneration.

Case Study 3: Yearn Stane

Background

Eadha Enterprises is a Scottish social enterprise maintaining nurseries of native aspen trees and supporting aspen woodland planting. Part of their work focuses on developing aspen agroforestry systems and validating the impacts upon farming. Aspen can enhance soil stability, provide fodder, and supply wood fuel for heating and power.

Eadha Enterprises have initiated several Scottish agroforestry projects, including the Yearn Stane restoration project that aims to restore the ecological and social resilience of a 10,000-ha area of wild moorland in Western Scotland. The area has been degraded by deforestation and drainage for agriculture. This has led to deterioration and species extinction. It has also contributed to regular and serious flooding in the lower conurbations, many of which experience high levels of economic vulnerability, unemployment, and addiction.

Yearn Stane intends to replant the area with aspen trees and other native varieties. The aim is to enhance the habitat and biodiversity of the region and in doing so enhance the water retention of the land and the capacity and quality of water bodies across the landscape. A focus of the project is community involvement. It is hoped that regenerating the landscape will enhance local well-being, education, and employment prospects.

Cost benefit

Eadha Enterprise state that aspen leaves average 17% protein and 10% fat content. Aspen wood is also digestible and fodder from the trees can replace approximately 30% of the diet of beef steers or mature sheep. Aspen agroforestry is also a potential source of biomass and can yield 1 to 1.7 tonnes per hectare annually.

These sources of income can help farmers offset the high upfront costs which average around £25 per tree. At a typical density of 400 trees per hectare this means upfront costs can be as high as £10,000 per hectare. Comparing aspen biomass to straw and assuming a value of £80 per tonne, the agroforestry could provide farmers with approximately £137 per hectare annually. Additionally, Eadha report that aspen can extend the growing season of sward, increase pasture growth by 20%. This could help reduce the expenditure of farmers on supplementary feed. The trees can also benefit livestock productivity by providing shelter.

Additional benefits

It is the social focus of Eadha Enterprise's work at the Yearn Stane project that make it particularly noteworthy. They aim to engage local communities to create value beyond the farms. Given the early stage of the project, there is no information about the impact upon these economies, but it is a useful example of how agroforestry, promoted by a tree nursery, is being used for economic regeneration. It shows how collective action, instigated by a central organisation can provide the stimulus for agroforestry at scales that would otherwise be implausible.

Whilst both these drivers can lead to similar habitat creation, they can be differentiated by the aim of the projects. Projects like Knepp are more localised and seek to enhance the resilience and natural regeneration of the area. Yearn Stane, on the other hand, focuses on benefits beyond the area where management change is taking place.

3.2.4 Grazing amongst sparse trees economics

There is negligible data available on the economic performance of grazing with sparse trees. However, it is likely that these systems operate at low stocking rates to avoid degrading the habitat. Extensive grazing systems commonly have a stocking rate around 30 to 40% lower than in conventional systems or around 1.1 livestock units per hectare (Isselstein et al., 2007). These systems are likely to rely less on artificial inputs. Hence, they will be associated with lower costs but also lower productivity per unit area than conventional pastoral grazing. Growth rate in extensively grazed systems has been found comparable to more intensively managed systems and may even improve consistency (Marriot et al., 2009).

Sparse trees and diverse habitat will also provide animals with shelter during periods of extreme weather and more diverse diets and forage. This has been shown to enhance the health and lower mortality rates of livestock. However, as with most AFW systems, these benefits will not be realised until the trees are established. Establishment times vary but are likely to take at least 5 to 10 years. For more detail on the benefits of shade upon livestock performance see Section 3.2.2 Grazed Woodland and Section 3.4.2 Shelterbelts.

Grazing can also help lower the labour costs of managing parkland and wood pasture systems. Animals graze upon shrub and young trees, thereby maintaining an open habitat suitable for sustaining the veteran trees and swards. This process would otherwise rely on mechanical and chemical inputs, both with environmental and economic costs. Some of the saved costs, however, will be offset by the costs of controlling the wide roaming herds. This either involves fencing off the area with stock proof fencing or using more innovative methods such as GPS collars that locate and herd cattle without the use of fences.

As highlighted by the Yearn Stane project (Case Study 3), regeneration of habitats with sparse trees can provide indirect benefits beyond the managed landscape. The development of biodiverse conservation areas through naturalistic grazing has the potential to stimulate tourism to the local area and communities. The associated economic benefits can help increase the availability of rural jobs (Hodder et al., 2005). Likewise, flood regulation, carbon sequestration and air quality regulation all provide valuable public goods, although valuing these services provided by a heterogenous landscape is a complex undertaking fraught with uncertainty.

3.2.5 Grazed high value trees

Grazed high value trees are differentiated from other silvopastoral systems due to the different motivation and management behind the system. In contrast to the previous examples, here it is the trees, and the products extracted from them, that are the focus of the system. In most cases, the livestock are a secondary enterprise which can enhance the productivity of the systems whilst the trees are growing. We define these systems as

> **areas grazed by livestock with a minimum of 5% canopy cover in which products harvested from the trees provide direct revenue to the land manager.**

There are two main types of grazed high value tree systems relevant to the UK. The first and most common are grazed orchards. The second are grazed timber production systems.

3.2.5.1 Grazed orchards

In the UK, the dominant form of grazed high value tree systems are grazed orchards, with grazed apple orchards being the most common. However, there is potential to establish similar systems producing fruits such as pears, cherries, plums and damsons; and nuts such as cobnuts and walnuts.

There are an estimated 24,000 hectares of orchards in the UK including around 17,000 hectares of traditional orchard. Traditional orchards are generally extensively managed and planted at low densities within permanent grassland. Of the orchards in the UK, den Herder et al. (2016) estimate that 14,200 hectares could be grazed with livestock such as sheep, cattle, pigs, and fowl. Livestock grazing not only provides an additional source of revenue for the area but has also been shown to enhance grassland diversity (Lopez-Sanchez et al., 2020).

A common example of orchard grazing involves sheep and apple orchards. Cider apple orchards are usually chosen for grazing because the aesthetics of the fruit is less important, and they are, therefore, more resilient to lower pesticide use and grazing damage. The integration of Shropshire sheep has become popular because they are believed to cause less damage to the trees. This has led to increased demand for this breed.

Poultry can also be introduced into orchards. Insects and fallen fruit provide poultry with additional feed; whilst foraging and seeking shade stimulates beneficial behaviours. In turn, this can reduce tree pest pressure (Newman et al., 2018). Species such as cattle are less common due to the higher propensity to damage trees (Lopez-Sanchez et al., 2020).

There is increasing interest in grazed orchard systems. The Bulmer Foundation commissioned work to investigate the performance of these systems and how they could enhance orchard sustainability. They have been using participatory farmer research to explore the impact of Shropshire sheep grazing upon cider production.

3.2.5.2 Grazed timber production systems

In contrast to grazed orchards, as far as we are aware, there are no examples of grazed timber production in the UK. However, there are historic examples such as those developed by the Bryant and May match making company and several experimental trials in the UK (see Case Study 4).

These systems tend to plant fast-growing timber trees such as poplar in lines separated by grass strips. A major challenge is balancing the competition between livestock and timber production. Tree planting above a certain density can limit the availability of pasture for grazing, whilst high animal stocking rates and too little tree protection can negatively impact timber production. There is also evidence that trees planted at lower densities per hectare have more knots, which lowers the suitability for timber wood production (Mäkinen and Hein, 2006).

The complexities involved in balancing the trade-offs in these mixed systems, the interdisciplinary knowledge that is required to manage timber and livestock production, and the historic lack of subsidy support have all played a role in disincentivising the uptake of grazed timber production in the UK. Moreover, the long returns on investment can be unfamiliar and unattractive to farmers, particularly those in short term tenancy agreements.

Predicting trends in the timber market over the long time periods required to take trees from planting to harvest is difficult. Especially for farmers who are usually unfamiliar with timber market dynamics. This can make investment in timber production systems financially risky.

Finally, disease, deer, squirrels and a variety of pests can severely damage timber production and protection can be expensive. When combining the costs of protection, maintenance, felling and transport, with the small scale of an individual farm, margins can become unattractively slim or negative. It is the confluence of these costs and risks that appear to have disincentivised farmers from pursuing grazed timber production. It seems that significant innovation and collective organisation would be required for farmers to access timber markets. However, given the sparsity of domestic timber supply in the UK, as well as the opportunities for in-farm substitution of expensive bought in timber, the prognosis should be positive.

3.2.6 Grazed high value trees economics

There has been some research into the economic performance of these combined systems, but most remains qualitative, poorly validated, and inconsistent. Systemic complexity and variation often make the studies hard to compare. For example, certain studies claim reduced maintenance costs for grazed orchards as livestock reduce the need to mow. However, others claim this saving is erased by herd management costs.

A grazed apple orchard trial in Northern Ireland grazed sheep at a density of 7 to 15 sheep per hectare, for 50 to 57 grazing days per year (McAdam, 2017). Agforward also modelled a similar system in the UK and proposed a stocking density of 10 sheep per hectare, grazed for 305 days per year with 60 days free from grazing to reduce contamination risk before harvesting the apples (Burgess, 2017).

The Agforward study highlighted the main economic benefit from grazing sheep within the orchard as the freeing up of land from grazing away from the orchard. This could then be put to alternative use; in the case of the model, it was used to grow hay earning £262.

Similarly, Paolotti et al. (2016) produced a lifecycle analysis to estimate the impact of orchard grazed chickens, they found that applying silvopastoral practices reduced land use by 18% compared to conventional free-range rearing.

In the Northern Ireland trial, sheep grazing reduced apple yields by between 24% and 43% (McAdam, 2017). However, this trial did not specifically select sheep breeds to minimise tree damage. In contrast, research undertake on Broome Farm as part of the Innovative Farmers programme in the UK reported no damage caused to apple yields when grazing Shropshire sheep. However, growth rates and yields were not quantified for sheep or apples.

There are trade-offs involved when growing trees and pasture in the same area, as these species compete for many of the same resources. A study by Campbell et al. (1994) found that competition from grass can reduce tree growth by between 20% and 60%. Similarly, tree growth can impede pasture production however, the combined productivity of the system is likely to be higher. Given the high costs associated with maintaining the trees: and harvesting, processing, and transporting the apples it is unclear whether these integrated systems, without public payment or support from ecosystem service payment schemes, will be more profitable than systems focused purely on sheep grazing. There is a clear need for rigorous, quantified, peer reviewed research to reduce this uncertainty.

3.3 Silvoarable systems

Silvoarable systems combine the growing of a long-term tree crop with the cultivation of a short-term crop on the same land (Eichhorn et al., 2006). There are few examples of silvoarable systems in the UK. Although den Herder et al. (2016) estimate that 2,000 hectares exist across the UK, examples remain small-scale and niche. These smaller systems are mostly trial plots, and few well established systems exist.

Traditional silvoarable systems have rapidly declined since the introduction of chemical fertilisers in the 19th century. Whilst these systems were once widespread, thinking over this period has treated tree planting and arable production as competing land uses with competing resource demands. This has led to a separation of forestry and agriculture and a bifurcation of knowledge and practice. However, there are many synergies between trees and crops that have been neglected; trees intercept rain and aid condensation; act as windbreaks; reduce evaporative water loss from crops; lift water and resources from deeper soil horizons; and reduce nutrient leaching and soil loss (Eichhorn et al., 2006). All of this can help reduce crop damage and enhance resource use efficiency.

Table 5 provides a summary of the main types of silvoarable systems. These are then explored in further detail below.

Table 5: Types of silvoarable systems

Silvoarable type	Silvoarable category	Example
Alley cropping	Fruit and nut alley cropping	Walnut trees intercropped with cereals
	Biomass and bioenergy alley cropping	Short rotation coppice willow and cereals
	Timber producing alley cropping	Alley cropped poplars and cereals

3.3.1 Alley cropping

We define alley cropping silvoarable systems as

> ***the planting of trees and agricultural crops in alternate rows. Tree rows should not exceed a width of two trees and canopy cover should be at least 5% of the area.***

It is useful to split this category into three groups. These are fruit and nut silvoarable systems, biomass and bioenergy silvoarable systems, and timber silvoarable systems. We categorise this way because the management, markets, and investments for these systems differ considerably. However, it is appreciated that there is an overlap between the systems.

3.3.1.1 Fruit and nut alley cropping

There are a few examples of fruit and nut silvoarable systems in the UK. These systems tend to involve the planting of trees in single or grouped rows within arable fields. Spaces are left between the rows to allow machinery to pass and sunlight to reach the crops.

Systems appear to work best when the land manager can establish a more direct and local route to market. Farm shops, veg box schemes, and pick your own systems allow land managers to reduce transport, processing and storage costs.

Wakelyns has one of the oldest established silvoarable systems in the UK. Between lines of trees, they grow cereals, potatoes, field vegetables and fertility building leys in rotation. A range of trees are grown; short rotation coppice (SRC) willow and hazel are grown for biomass and bioenergy; fruit trees are grown as crops; and several timber trees are grown for pollarding. Tolhurst Organics in Berkshire has established a similar alley cropping system, although planting occurred more recently. Flowers, rhubarb, and artichokes are grown in the rows between apple trees, and various species managed for biomass.

Stephen and Lynn Briggs have developed a system of silvoarable apple and mixed arable on their farm in Cambridgeshire. Lines of apple trees intersect their 52-hectare farm. Each line is separated by a 24 m arable row which allows machinery to pass. The trees are planted at a density of c.100 trees per hectare with 4,500 trees planted across the farm. Apple trees occupy 4 hectares (8%) of the area, and arable crops occupy the remaining 48 hectares (92%). Establishing the silvoarable system cost a total of £59,800 (Newman et al., 2018).

3.3.1.2 Biomass and bioenergy alley cropping

Biomass and bioenergy alley cropping often intersect with fruit and nut silvoarable systems with many systems producing both products. Silvoarable biomass and bioenergy production is mainly focused on producing at a small and local level. Many of the systems produce biomass for on-farm use, providing heat and energy using biomass boilers. Wakelyns has a system such as this, the biomass they produce from SRC willow is used to generate energy and heat for the farm buildings.

At the local level this use of biofuel can be useful to replace dependence on fossil fuels, but it is hard for singular farms to access larger markets. A group of French farmers have tried to overcome this issue by collectively processing and selling the woody biomass they produce to larger energy users (see Case Study 5). This helps small producers access economies of scale.

It is important to note that bioenergy production reduces the carbon storage of AFW systems. Carbon, stored in the biomass is quickly released back into the environment during combustion. This could be a reason why SRC is excluded from many subsidy schemes. This is a complex issue, and beyond the scope of this project but, put simply, carbon storage is highly dependent on the lifecycle of the biomass.

3.3.1.3 Timber producing alley cropping

Timber producing alley cropping systems are less common. These systems focus on the production of high-quality marketable timber. Successful systems were established in the

1950s by Bryant & May Forestry Ltd. Timber was produced for manufacturing matches alongside cereal crops for the first 8 years and then grazing up until year 20 (Eichhorn et al., 2006). These systems were discontinued when the company went out of business due to the increasing availability of cheaper imported wood. However, it is a useful example of a market driven heterogenous and integrated approach. It is also a rare example of agroforestry conceived of and maintained by the forestry sector.

The only recent examples of agroforestry timber production in the UK are experimental. Several trials have investigated the viability and impacts of growing timber species such as poplar alongside arable systems. We review the results of these trials in Case Study 4.

Case Study 4: Trials with silvoarable poplar timber production

Background

Bryant and May developed one of the few commercial timber agroforestry systems in the UK. The system integrated arable and pastoral systems between rows of poplar trees grown for veneer quality timber for match sticks. The aim of the multifunctional systems was to make full use of the land throughout the trees' lifecycles.

Trees were planted at 185 trees per hectare and the timber was harvested after 25 years. 7.9m spacing were left between the tree and 6.8m between rows. The area between the trees was cultivated to maintain clean fallow for the first season. For the next 7 to 8 years arable crops were grown in a system of alternate cropping. In every other crop bay, crops were sown during the growing season, with the neighbouring bay maintained as clean fallow. The summer crops were harvested, and the bays provided space for tending to the poplars during the winter. The fallow bays were then sown with arable crops in autumn.

This alternate growing system allowed the poplars to be pruned, accommodated the slower growing time of the shaded cereals, and reduced crop loss from disease. Subsequent research has shown that this sort of fallow cultivation is necessary to produce acceptable timber yields form poplars.

A study by Burgess et al. (2004) assessed similar trial plot systems of silvoarable poplar systems on three UK sites. They investigated how growth rates and yields were influenced by variations in crop management.

Cost benefit

The Burgess et al. (2004) study found that continuous cropping reduced the amount of harvestable timber after 7 years by 56%. However, alternate cropping, as practiced in the Bryant & May systems, helped improve the growth rate. Competition for water between the crops and the trees is the likely cause of the reduced growth rate. The tree growth also impacted crop growth which was reduced by an average of 4% for the first three years, 10% for years four and six, and 14% for year seven.

It is clear from these trials and systems that the design of silvoarable timber production systems is complex, involving trade-offs between the yields of the different elements. The replacement of cropping with livestock grazing after the 7th year seems to be advisable, as yield reduction is likely to increase at this stage.

Additional benefits

Alley cropped systems like these will provide a range of additional benefits including carbon sequestration, improved flood resilience, and shelter. Furthermore, the alternating rows can help break the spread of pests and disease across the different crops.

Due to the rarity of these systems, there is a sparsity of economic data on how they perform. However, Eichhorn et al. (2006) state that there is a pressing need for locally sourced hardwoods in Europe to meet demand and to replace dependence on tropical sources. This could provide a potentially lucrative market for agroforestry systems. Moreover, timber production can align better with silvoarable systems as there is less competition and conflict between crops and timber trees than with fruit trees. However, it is highly unlikely that farmers will have the skills, knowledge, market access, or investment capacity to access these higher value timber markets.

One option is that timber production on farms could be managed by expert foresters either through contracts or innovative cooperative and rental schemes. This is worth trialling; however, failures of the Bryant and May systems will likely have left some farmers unwilling to commit to similar arrangements.

3.3.2 Alley cropping silvoarable systems economics

The economic viability of silvoarable systems in the UK is uncertain. However, we know that the cost of labour in Northern European countries makes it difficult to run these heterogenous systems profitably. In fact, many systems across Europe operate at a loss due to high labour costs, it is subsidies that maintain these systems (Eichhorn et al., 2006).

Crop production is greater in the earlier years of a rotation and is lower closer to the tree rows due to resource competition. Crop production in Northern Europe becomes unviable once the height of the trees matches the width of the crop rows (Eichhorn et al., 2006). An experimental wheat and SRC intercropping system in Bristol found the system to be economically unviable. Whilst the system demonstrated a range of environmental benefits, commodity prices and subsidies at the time meant the system was less profitable than conventional arable systems (Nichols, 2001).

A meta-analysis of the literature exploring the impact of trees upon crop yield across Europe found that initially relative crop yields in silvoarable systems were on average 4% lower than in solely arable systems; relative yields then decreased by an average of 2.6% annually over the first 21 years (Ivezić et al., 2021). Relative crop yields also declined with increasing tree density. An increase of 100 trees per hectare lowered relative crop yield by 20%.

As demonstrated in Case Study 4, the growing of trees can have a negative impact on crop production. This is complicated by the change in impact as trees grow and competition for water and light increases. Similarly, Giannitsopoulos et al. (2020) modelled the impacts of tree growth upon crop production in an agroforestry system in the UK and showed that crop production in the agroforestry system was on average 11% lower than in the arable. Crop production ceased entirely after the first 14 years, presumably due to being outcompeted by the trees.

SRC can be used to produce woody biomass for various uses including fencing and craft, bioenergy, mulch, animal bedding, and fodder. Many of these products are used irregularly on the farm and, hence, it is difficult to calculate the economic value. Industry experts at the National Non-Food Crops Centre (NNFCC) estimate an average annual SRC yield of 8-17.5 oven dried tonnes per ha while the Forestry Commission Forest Growth-SRC model predicts average yearly yields at 9.0 tonnes and 10.3 tonnes for willow and poplar respectively. Similar results were found with an agroforestry system in Germany (Huber et al., 2014). However, lower planting will mean dramatically lower yields.

The SRC at Wakelyns yields on average 4 to 5 tonnes dry matter per ha of agroforestry annually. This dry matter is used to generate power for the farm buildings. Assigning an approximate value of £150 per tonne means the system generates up to £750 per ha per annum. When, considering the cost of labour, machinery, drying, chipping, and storing this value is likely to be negligible.

When modelling the economic performance of an arable system versus an agroforestry system Giannitsopoulos et al. (2020) showed that over a 30-year period in the UK an arable system produced an average annual net margin of €559 per hectare with grants. They compared this to an equivalent agroforestry system producing cereals and poplar timber (stocked at 1000 trees per hectare), which averaged €457 per hectare annually with grants. In other words, the agroforestry system produced 82% of the net profit of the arable system over the 30-year period.

Similar conclusions were drawn by Kaske et al (2021), who found that in a Case Study in Silsoe, England, the arable plot outperformed the equivalent silvoarable and forestry production. With grants, the agroforestry system produced 87% of the net value of the arable system. The authors speculate this is due to the annual tree maintenance costs.

Both these studies claim that agroforestry is not a competitive option without agri-environment support. However, the agroforestry systems are estimated to store between 106 and 127 tonnes of carbon dioxide per hectare over a 30-year period (Giannitsopoulos et al., 2020; Kaske et al., 2021). This means that by including a carbon payment of above €24.2 per tonne carbon dioxide equivalent the agroforestry system would become more profitable than the arable. Considering projections for carbon market values and previous values attained through auctions, this figure is entirely plausible over the coming years. However, carbon credit schemes such as the Woodland Carbon Code (WCC) do not currently provide payments for agroforestry systems as the in-field planting is too sparse to qualify.

The WCC scheme currently does not consider these types of more sparsely planted tree systems, however, as demand for offsetting increases and land available for woodland planting becomes increasing scarce, they may be considered. The cost benefit of certification and valuation may be challenging for smaller projects; however, co-operative approaches (e.g. group certification) may help to overcome this potential barrier.

3.4 Linear features

Linear features describe the planting of trees and perennial shrubs in lines, usually around the perimeters of agricultural fields. These features can enhance aesthetics, biodiversity, and a range of ecosystem services.

3.4.1 Hedgerows

Hedgerows are perhaps the most widely seen form of agroforestry in the UK. Hedgerows are defined by Merriam and Webster (2021) as

> ***rows of shrubs or trees enclosing or separating fields.***

They have numerous benefits. Functionally they help differentiate fields, enclose livestock, and shelter livestock from severe weather. Ecologically they provide shelter and food for a range of invertebrates, birds, and small mammals. They also aid several ES; they reduce soil erosion, enhance water infiltration, act as a buffer by storing run off, and store organic carbon (Holden et al., 2019).

Over the last century, huge lengths of hedgerows were removed to make way for agricultural intensification. Between the years 1984 and 1990 there was a 23% reduction in the extent of managed hedgerows across the UK (Barr & Gillespie, 2000). However, as awareness of the benefits hedgerows provide has grown and support has been provided for replanting, farmers have begun to re-establish these valuable linear habitats.

In 2007, the Countryside Survey estimated there were 477,000 km of hedgerows in the UK (Countryside Survey, 2007). Assuming an average width of at least 1.5 m, this gives a conservative total area of 71,500 hectares across England. This means hedgerows make up 0.4% of the roughly 18 million hectares of agricultural land in the UK.

Farmers generally manage hedgerows as part of good husbandry, with enhanced management supported through agri-environment schemes. Livestock farmers, particularly in the beef and sheep sector, value hedgerows for their productive use. However, Newman et al. (2018) note that if productive timber trees were to be planted every 20m across England's hedgerows this could generate 40 million cubic metres of timber, as well as significant increased carbon storage. Similar estimations are true for the use of the biomass created when trimming hedgerows. This not insignificant resource could be used as a mulch to enhance soil fertility, as fodder or bedding for livestock, or as a feedstock for bioenergy production. This helps to illustrate the productive capacity of this resource, the economic viability of the activity is, however, challenging.

There are examples, however, where actors have managed to market hedgerow resources. In France, farmers formed a co-operative to collaboratively process and sell biomass from their hedges (see Case Study 5). This allowed them to access larger markets and reduce the costs of processing their woody biomass into fuel.

Gruber and Claupein (2008) used a combination of experimental data and literature to calculate the potential productivity of hedgerows. They state that hedgerows produce a yearly mean biomass of 5 tonnes fresh matter per hectare. Taking the average farm size in

England (87 hectares) and assuming hedgerows cover 0.4% of this area, the average UK farm could produce 1.47 tonnes of fresh biomass annually from hedges. This gives approximately 0.4 tonnes of woodchips, enough to produce 5,040 MJ of energy. When aggregated across the UK this is a considerable amount, however, for an individual farmer it would generate negligible income and would be unlikely to cover even the costs of getting the biomass to market.

There are also millions of hedgerow trees scattered across the UK. These also provide a potential source of biomass, fodder, bedding, or even fruits and nuts. The economic viability of harvesting this extensively spread resource again presents a barrier for most farmers.

Case Study 5: La SCIC Mayenne Bois Énergie

Background

Mayenne Bois Énergie is a French co-operative started in 2008 that connects farmers producing woody biomass with users of wood-fired boilers. By operating as a co-operative farmers can access the means to harvest, test, process and sell the wood chippings produced from their hedgerows. Collectively farmers have increased access to market and customers can source a sustainable and reliable source of biofuel.

Cost benefit

The co-operative now has 181 members (https://www.mayenne-bois-energie.fr/qui-sommes-nous/une-cooperative-un-territoire/) and, in 2018, produced a total of 4,500 tonnes of dried woody biomass. Therefore, on average members produce 25 tonnes of biomass. At a reported €55 per tonne, this means the co-operative provides members with an average additional income of approximately €1,400. However, this presumably varies considerably, with more active members producing more.

Additional benefits

There are numerous environmental, social, and economic benefits to hedge planting. Economically, hedgerows provide shelter helping to reduce stress and mortality in livestock and wind damage to crops. The permanent root systems can also reduce soil erosion, increasing the retention and availability of nutrients. Pollinators and predators inhabiting the hedges can also enhance crop productivity and reduce loss. Hedgerows also enhance the social value of farms by improving the aesthetic of the landscape and provide habitat for valued flora and fauna to thrive. Environmentally, a km of hedgerow sequesters an average of 140 tonnes of carbon dioxide (https://afac-agroforesteries.fr/wp-content/uploads/2019/10/DP_labelhaie-VF.pdf). They also help to reduce run-off and the negative impact it can have upon water bodies.

3.4.2 Shelterbelts

Many smaller woodlands on farms have been established to provide shelter for livestock and crops. Shelterbelts have been defined by Jose & Gordon (2008) as

> ***linear arrays of trees or shrubs planted to create a variety of benefits.***

Shelterbelt trees are usually planted 2m to 5m apart and take 5 to 10 years to develop into functional shelterbelts. Structure particularly depends on the function of the shelterbelt. For example, if cows are grazed within shelterbelts, mature dairy cows require at least 3.5 square metres of space this allows sunlight to dry the ground and for it to be suitable for cows to roam (Collier et al., 2006).

By creating more hospitable microclimates, shelterbelts offer a valuable way for livestock farmers to extend their yearly grazing period (Wreford & Topp, 2020). Increasing the capacity of farmers to graze livestock outside can reduce the costs of supplementary feed during winter and free up farm building space.

Climate change will increase the frequency and intensity of flooding. Flooding can pose a significant risk to livestock, damaging feed sources, causing injury, enhancing infection risk, and mortality. Evidence from Pontbren (See Case Study 6) has shown that shelterbelts, strategically placed across a landscape, can effectively enhance water infiltration of the area and reduce runoff (Carroll et al., 2004). Hence, shelterbelts can be an effective way to reduce the exposure of agriculture to flooding.

Shelterbelts can also help to reduce soil erosion, conserve soil moisture, and improve irrigation efficiency. Additionally, they provide habitat for a range of wildlife such as many generalist birds and pollinators (Jose & Gordon, 2008). The reduced wind velocity can improve the working environment and the trees within shelterbelts can provide a source of wood fuel, timber, fodder, and bedding.

Despite the benefits, there has been limited uptake of shelterbelts over the last 20 years and beyond. Indeed, many of the constraints to the adoption of shelterbelts in farming were given in a keynote address of International Symposium on Windbreak Technology in June 1996 which bought together many of the world's experts on the topic. The identified issues are still present today.

The first set of issues relate to a shift in the economics and discourse associated with agriculture. Enlarging machinery, decreasing unit value of crops, and a drive towards farm homogenisation have made shelterbelts less attractive to farmers as they have sought economies of scale above increased resilience. Secondly, farmers have become increasingly specialised; few are knowledgeable of or appreciate the products harvestable from shelterbelts. Finally, shelterbelts have often been poorly designed. Developed shelterbelts have not been aerodynamic, have been poorly maintained, and little data has been collected on the impacts upon farm performance. This has created uncertainty about the impact of these structures upon farm performance and resilience. There is a need to enhance and co-ordinate data collection, research, and development to enhance the impact and validation of shelterbelts.

Many of the above-mentioned benefits are difficult to quantify. For example, there have been several observational studies, that have tried to assess the impacts of windbreak shelter on crop and livestock production. Whilst in most cases, shelterbelts were shown to improve plant growth and yields over a range of climate and soil regimes, particularly in vegetables, speciality crops, orchards and vineyards, the benefits are variable. The benefits that shelterbelts can provide to the surrounding agricultural fields depend on a range of factors, including soil type, temperature, wind speed, and rainfall; as well as the choice of crops and animal husbandry system; and the location and design of the shelterbelt itself.

Several studies have stated that using shelterbelts can either increase or decrease evaporation rates depending on soil and plant water status and the prevailing weather conditions. Thus, assessing the increases in agricultural production that shelterbelts (and other agroforestry systems) can provide, (both in terms of specific yield increases and area of land) in a specific context is difficult.

Notwithstanding the above, a range of policy drivers and proposals are significantly increasing interest in adopting shelterbelts.

3.4.3 Linear features economics

Linear features, and especially shelterbelts, can provide a simple and cost-effective way to reduce agricultural exposure to extreme weather events (Wreford & Topp, 2020). This function will become increasingly important as climate change is predicted to increase the frequency of extreme weather events across the UK. Studies have shown that cows in shade during more extreme weather have lower levels of thermal stress. Thermal stress can impact calf mortality, growth rate, and milk production; all of which impact the economic performance of livestock farming. Collier et al. (2006) showed that dairy cows in shade during high temperatures yielded 10% more milk.

Similar results were found by Pollard (2010), when investigating the impact of shelterbelts upon lamb mortality in New Zealand. Ewes naturally seek out dense vegetation during lambing for protection and shelter. Pollard showed that on average shelter from wind and rain reduced mortality during lambing by 10%.

There are a range of different approaches to the design and establishment of shelterbelts, which, in turn, influence the choice of species, the stocking density, the width and the siting. For example, David Lewis one of the authors of this report, is currently working with a project team that is undertaking a series of trials in Gloucestershire, to assess the performance and economics of establishing an "Optimal Shelterbelt". These optimal shelterbelts are just 5 m wide and are intended to be sited alongside existing hedgerows, to not only provide better shelter, but also to enhance the biodiversity and aesthetic of the landscape.

These shelterbelts have a significantly higher stocking density of trees, than conventional woodland creation schemes. 6,500 trees/ha are planted to create the desired porosity to provide the optimum benefit to the adjoining agricultural fields, be they used for crops or livestock. Their design has been based on extensive and long-standing research and the principles of these shelterbelts are to convert wind energy into low grade heat and humidity, through the natural tree and leaf architecture of the trees in the shelterbelt.

Various studies indicate that increases in productivity for both crop and livestock systems could be as much as 20%. However further research is needed to quantify and evidence such claims, hence the current trials. This research will also be considering the economic benefits and barriers to establishing and maintaining these shelterbelts and the likely implications for adoption. It should be recognised, however, that these shelterbelts are not currently eligible for grant funding in England. To be eligible for the English Woodland Creation Offer (EWCO), the shelterbelt would need to be in excess of 1 ha and 10 m wide. Anecdotal evidence from this project suggests there is lot of interest in the concept, but if the establishment costs cannot be covered by a grant, then this is likely to significantly limit the number of farmers who will establish similar shelterbelts.

According to the ABC Agricultural Budgeting and Costing Book 2021, hedgerow planting costs an average of £5.40 per metre. There are no known examples of the monetisation of hedgerows in the UK, although organisations such as Hedgelink have developed toolkits for biofuel harvesting and use (Hedgelink, 2022). However, based on Case Study 5 it is estimated that farmers taking an active approach to plant and valorise their hedgerows could generate incomes from biomass sales of up more than £1,200. However, it is difficult to say whether this figure accounts for management costs.

Furthermore, applying figures from Case Study 5 to the average UK farmer, would result in a figure significantly less than this. By our calculations farmers would produce under one tonne of biomass per year; the value of which would be negligible, particularly when factoring in harvesting, processing, and transporting the biomass. It is only through co-operative organisation that farmers in France manage to make the sale of biofuel an attractive activity. Without co-operation it is exceedingly unlikely that a farmer could make the biomass production from hedgerows a profitable activity.

Case Study 6: Pontbren Group

Background

Nant Pontbren is a tributary of the River Severn in Mid-Wales. 10 sheep farmers in the area started the 'Pontbren Group' in 1992 to increase tree cover across their holdings. The group's land covers approximately 1,000 hectares. Their activities mainly involve fencing off areas and planting trees. Since starting, the group have planted approximately 120,000 native broadleaf trees across 5% of their land (c.50 hectares) and regenerated 26.5 km of hedgerow (Wales Rural Observatory, 2013). This change has been achieved with no loss in agricultural productivity (Woodland Trust, 2013).

Cost benefit

The project is best known for its impact on soil water infiltration, but there are other important economic benefits. Their collaborative AFW approach has enabled them to secure external funding. Despite finding government funding schemes too inflexible, they managed to source and match fund £97,000 from the Enfys scheme. Of the total finance, £172,000 went to local contractors and £131,000 to local suppliers. This demonstrates the potential benefits of collective AFW schemes for improving rural economies.

Between the years of 2002 and 2004, most of the farmers destocked their sheep herds by 25%. During this period, a combination of subsidy support, reduced costs, improved lambing and lamb size, and greater time to focus on other activities, meant that their earnings increased by an average of £24,000 (Wales Rural Observatory, 2013).

Wood from the trees provided a replacement for straw bedding which previously had to be bought in. It also replaced the need to buy in 500 bags of compost each year for the tree nursery. However, the group did encounter difficulties storing and drying the wood chips to a moisture content suitable for bedding (20%). The farmers stated that wood chip could be a marketable product if a suitable supply chain existed. Similarly, farmers outside of the group have commented that they would happily exchange straw for woodchip if they could guarantee a regular supply of the product for a similar price.

Additional benefits

6 to 7 years after planting, soil infiltration rate at Pontbren was up to 60 times higher than in neighbouring pasture. The exact benefit to downstream flood regulation is difficult to quantify and is contested. However, it is likely that projects such as Pontbren can help slow movement of water into downstream catchments and, in certain cases, help reduce flood risk. There is an economic incentive for local governments, water utility companies and even insurance companies to support the kind of AFW approaches demonstrated at Pontbren.

The trees planted at Pontbren sequester 219 tonnes of carbon dioxide a year. Although the group has not received payment for this service, this is increasingly something that private and public organisations are funding. Enrolment in an offsetting scheme, if a suitable one was to be developed, could provide additional income for farmer groups such as those at Pontbren. Biodiversity has also benefited from the tree planting and at Pontbren there have been reported sightings of many rare and endangered species (Woodland Trust, 2013).

4 Agroforestry and farm woodland markets

UK AFW largely relies upon local markets for the sale of firewood, thinnings and orchard fruit. Production of these goods is usually small scale, decentralised and often inconsistent, preventing AFW systems from supplying to larger markets. As this report has highlighted, projects are trying to use collective action through organisations such as farmer co-operatives to increase market access.

Recent trends in timber prices, public environmental awareness, payments for public goods, and Corporate Social Responsibility (CSR) / Environmental Social Governance (ESG) provide new opportunities for AFW, potentially enhancing the market for these goods. However, markets for AFW products remain largely undeveloped, and are therefore unreliable. In the following section we provide a high-level market assessment of the key markets that could increase the demand for UK AFW production.

For each of the potential markets, where possible, we explore trends in the UK demand for the product; the main consumers; the ratio of domestic to imported supply and the difference in cost; and the nature of the supply chain. Finally, we attempt to draw conclusions about the potential of AFW to supply each of the markets.

4.1 Fruit

4.1.1 UK fruit consumption

Globalised supply changes have shifted UK fruit and vegetable consumption over the past 30 years. People now consume a wider diversity of exotic varieties, whilst consumption of traditional fruits such as pears has waned (Scheelbeek et al., 2020). At the same time, there is a need to increase fruit and vegetable consumption in the UK, just 30% of adults and 18% of children consume the recommended quantities. A pattern linked to increased risk of non-communicative disease and premature mortality.

Apples and, to a lesser extent, pears, are now the only domestically produced fruit varieties that contribute significantly to UK consumption. Apple consumption has remained high over the last half a century, accounting for 6.1% of UK fruit and vegetable consumption (Scheelbeek et al., 2020). This does not seem to vary significantly across different income or age groups, although, more generally, higher income groups consume a greater diversity of fruit and vegetables and adults under 25 and over 65 tend to consume less.

4.1.2 UK fruit production

Domestic production of fruit has not substantially changed over the past 10 years, fluctuating at around 4 million tonnes. In recent years warmer winters and frequent rains have proved problematic for growers leading to a dip in production. The value of fruit has steadily increased though, from below £0.6 billion in 2010, to over £1 billion in 2020 (Defra, 2021). Bramley apples have seen a big price rise in recent years due to low stocks (Defra, 2021).

There has been increasing production of cider orchards in the UK, with over 8,000 acres planted in the last decade. This contrasts with dessert apples which have seen a steady decline. However, recent years have seen a decline in the apple market, particularly for cider apples, at times leaving farmers struggling to sell their fruit.

4.1.3 UK fruit imports

Fruit supply has become steadily more dependent on imports. Domestic supply, as a proportion of total supply, halved from 1987 to 2013 (Scheelbeek et al., 2020). The value of imported fruits, at £3.9 billion, is four times that of domestic supply. In 2012, the UK imported 476,525 tonnes of apples, predominantly from France and South Africa. In contrast, only 192 thousand tonnes were produced in the UK (Freshfruitportal, 2019).

An increasing percentage of the UK fruit supply is produced in countries that are vulnerable to climate change (Scheelbeek et al., 2020). This is threatening the cost and security of the UK fruit supply. This could have negative repercussions for the diets of lower socio-economic groups. One method for reducing this risk is to increase local fruit production. Increased production of fruits such as apples, that are suited to the British climate, is a possible way to enhance food security. Increasing awareness of this risk, as well as pressure on supermarkets to decrease the carbon miles of their produce, could stimulate the market for fruit from UK orchards. This could increase support for agroforestry.

4.1.4 UK fruit supply chain

40% of the UK fruit supply comes from Europe (Aikins, 2020). Supply chains vary but have several standard phases. The growing phase involves preparation of the land and application of organic or synthetic fertilisers. During the next phase, the produce is transported from the farm to a storage unit where it is processed and then taken to a port. The fruit is then transported to the UK either by sea, road, air, or rail. Once it arrives in the UK, it enters the sales and distribution phase. Here, it is transported from the port to the wholesaler's warehouse where it is stored before being moved to the retailing shop.

Along this supply chain transportation and sales and distribution have the greatest influence on GHG emissions (Aikins, 2020). Efficient local supply chains could, therefore, reduce supply chain emissions. Increased drive for carbon and environmental labelling, and consumer awareness about climate change is likely to increase the demand for local, low carbon products. This could increase the market for local products. Furthermore, any future carbon taxation is likely to increase the cost of imported products. All these factors could expand the market for UK AFW produced fruits such as apples and pears.

Despite the benefits of shorter supply chains, it is worth noting that if fruit production in the UK is substantially less efficient, the proportional carbon footprint from the growing phase and localised transport may be higher. In this case local production may not be the option with the lowest climate impact. Ensuring lifecycle analysis and marketing can communicate all the benefits of AFW production will be necessary to stimulate a UK AFW fruit market.

4.1.5 Predicted trends in UK fruit production

Labour is a significant barrier to increased fruit production in the UK. Harvesting is highly dependent on seasonal foreign workers. The UK's exit from the EU, the COVID-19 pandemic, and improved socio-economic conditions in the home countries of seasonal workers have left farms vulnerable to labour shortages. The future flow of seasonal, migrant workers is uncertain, this could disincentivise farmers from investing in labour dependent systems such as orchards. Technical innovations, particularly in automation, may help ease this problem, but this is unlikely to happen at scale in the near term, or to be accessible to less intensive growers.

4.2 Nuts

Nuts are currently not produced at any significant scale in the UK; the vast majority are imported (Cowell & Parkinson, 2003). Demand is predicted to increase as plant-based diets become increasingly popular, and people seek alternative ways to access proteins and important fats such as omega 3. The popularity of nut milks as a dairy replacement will also stimulate demand. There are two main edible nuts that can be grown in the UK hazelnuts (or cobnuts) and walnuts. However, production is minimal. Less than 20 hectares of walnut trees were planted from 2000 to 2010 and only 250 acres of cobnuts exist in the UK, many of which are not harvested.

4.2.1 UK hazelnut market

The UK market for dried hazelnut kernels is worth £15m per year. According to Newman's (2000) estimations, profitable production from mechanised orchards and silvoarable systems is viable in the UK. Production at a scale necessary to substitute UK imports would require approximately 7,000 hectares and would be worth at least £15m per year. Hazel trees also provide materials for coppice products, but the market is small, generating less than £2 million per year (Newman, 2000). There is also a large market for dried hazelnut kernels in Europe. A reasonable segment of which could be targeted with a further 30,000 hectares of orchards and could generate £65m per year. Viable production at scale, however, is yet to be evidenced.

4.2.2 UK walnut market

In 2018, the UK market for walnuts was £5.7 million and has been increasing by 8% annually, import quantity was 21,500 tonnes (FAO, 2018). Per capita consumption averages 0.26g daily and is increasing. According to an analysis by McNeil and Felgate (2012), cost is the factor that determines the scale of UK imports. Consumers seem to target low cost, lower quality produce. This is likely to limit the market for UK produced walnuts that will come with a higher price tag than the intensively produced imported varieties.

4.2.3 Predicted trends in UK nut production

It appears to be price that is the greatest barrier for UK nut production. High labour costs and small-scale production make it difficult for domestic growers to compete with imported produce. Furthermore, growing conditions in continental Europe are said to be superior to the UK (McNeil, 2012). A further challenge to UK nut production is that the UK market almost entirely purchases shelled nuts (McNeil, 2012). Hence, the absence of any significant nut processing facilities in the UK is a considerable barrier to expansion of domestic production.

That said, increased awareness of carbon miles, plant-based diets, investment in mechanisation, and environmental payments could stimulate UK production, however, this is highly uncertain. Domestic nut production it seems, for the near term will be dominated by innovative farmers seeking to explore untapped domestic markets. Given the uncertainty of production, external investment appears necessary to validate and expand UK nut production. NGOs, supermarkets, research centres and the public sector could play a role in testing the potential of AFW nut systems through controlled trials, market research, and investment in harvesting and processing technology.

4.3 Timber

The UK currently imports over 80% of its timber requirements. In 2020, timber production from UK woodlands was reported to be 10.4 million m^3, whereas UK consumption was 54.8 million m^3 (Forestry Commission, 2021). Volumes are expressed in wood raw material equivalent (WRME), under bark. WRME volumes represent the amount of wood that would have been required to make the products consumed, which include sawn wood, as well as a range of wood-based panel products, paper and paperboard.

Over the last 5 years, timber sales in real terms, have steadily increased, although this was disrupted in 2020/2021 by the COVID-19 pandemic. Similarly, the output of the construction industry has been rising since 2012, indicating an expanding market for timber for construction. Moreover, increasing the use of timber in construction is a priority for the UK government. In contrast to the construction timber markets, consumption of paper and paperboard, mainly derived from small roundwood, has steadily declined since 2010. This is presumably due to increasing use of information technology in the workplace and education. However, this decline has been offset by the increase in the biomass and wood fuel market.

Timber prices have also increased significantly over the last 5 years; especially over the last 12 months. For example, by September 2021 the Coniferous Standing Sales Index, (conifer timber sold as it stands) showed an increase of nearly 50% (in nominal terms), compared with the previous year, achieving a price of £40 per m^3. The main driver for that increase was the significant increase in the price of sawlogs due to increasing demand from the construction sector. Indeed, the Softwood Price Index showed an increase of just over 60% over that same period, with the greatest price increases coming from spruce logs. (This index relates to just sawlogs, rather than all grades of timber and the point of sale is at roadside, rather than being sold standing). By contrast, the Small Roundwood Price Index (i.e. timber generally not of sufficient size or quality for the sawlog market) remained relatively stable.

Whilst these price indexes are just based on UK government owned woodlands, similar trends are reported by private sector companies such as Tilhill Forestry. The hardwood market has also improved. Firewood prices have risen along with good quality sawlog material, such as oak. The UK's production and consumption of hardwood is much less than for softwood and the Forestry Commission do not publish any formal indexes as they do for softwood, so it is difficult to quantify the exact percentage increases. However, journal article reports and anecdotal evidence, including personal involvement all confirm that significant increases in the hardwood timber prices have also occurred.

Whilst it is impossible to predict with any certainty what will happen to timber prices over the next 10 years, there are encouraging signs that the longer-term prospects also look reasonable. Gresham House predict that global timber consumption is set to almost triple by 2050 (Gresham House, 2020). Increasing demand is likely to drive up timber prices which, in turn, are likely to make woodland management operations such as thinning and felling more economic. This is likely to increase the uptake of woodland planting and management, as has been experienced over the last 10 years.

The principal markets for timber are from the timber-processing sector. This sector is built around four main forest-product sectors: sawmilling, paper and board, wood-based panels and other wood including fencing and garden furniture. Timber for biomass markets is also an increasingly important market, particularly for small roundwood from conifers. The prices paid by these processing industries will depend on the diameter, quality, and species of the roundwood, which in turn will influence the product that it can be converted to. There are essential differences between the coniferous and broadleaved timber markets which influences the markets for the different timber, the size and specifications required, and the prices paid. These are thus individually reviewed to provide an explanation and basis for the timber markets and in turn the prices being achieved.

4.3.1 Coniferous timber

Timber production in the UK is predominantly from coniferous species. In 2020, according to the Forestry Statistics, published by the Forestry Commission in 2021, the production of softwood timber from UK woodlands was estimated to be 10 million tonnes versus just 0.8 million tonnes of hardwood timber.

Small diameter roundwood timber (i.e. timber with a diameter of between 7 – 14cm) is generally sold to the pulp chipboard and wood fuel/biomass markets. Prices for pulp, chipboard and biomass have increased significantly over the last 10 years. Whilst a range of prices are quoted, depending on the quantities of timber sold, method of sale etc, journal reports and personal experience of selling timber over the last 12 months indicated that prices delivered to the timber processors are approximately £40 – £50 per tonne for pulp, chipboard, and biomass.

The larger roundwood timber (i.e. timber with a diameter of no less than 14cm) is sold as fencing bars and sawlogs. Prices for these products have also increased significantly over the last 10 years, with prices of £50 to £60/m^3 being offered for both fencing bars and over £75 to £125 for sawlogs. There are of course variations amongst species – Douglas fir and spruce may achieve more than £100/m^3, whereas prices will often be lower for other species. These indicative prices also ignore niche markets and the potential for added value

– however, there are limited examples of woodland owners tapping into these opportunities, let alone farmers.

4.3.2 Broadleaved timber

Timber production from broadleaved species accounted for 0.8 million tonnes in 2020, less than 10% of the UK overall timber production. This production has, however, been increasing - there was an increase of 60% since 2011, whereas, over the same period, coniferous production, has remained virtually stable. Notwithstanding that increase in production, there is still scope to increase timber production from broadleaved woodlands, by undertaking both thinning and felling operations. Many broadleaved woodlands, particularly smaller woodlands, remain undermanaged or unmanaged. There are opportunities for farmers and landowners to derive incomes from these woodlands whilst simultaneously enhancing their biodiversity and amenity value.

The specifications for small roundwood timber for broadleaved timber is open to debate but is reported to include timber with a diameter of between 7 to 25cm (Hart, 1991; Lewis, 2003). The main market for this timber is now firewood. Firewood represents an important local and national market. Prices have increased considerably over the last 10 years, with delivered prices to customers of £150 to £200 per tonne. However, there are significant time and financial costs involved in converting timber to firewood and its subsequent delivery. 'Roadside' prices for firewood, vary with location, but are usually £40 to £50 per tonne, so approximately £10 to £15 per tonne more than small round wood prices for conifer timber.

The larger roundwood (i.e. timber with a diameter of no less than 25cm) is sold as fencing bars and sawlogs. Prices for this category of timber vary considerably – markets and prices are very dependent on quality and species. Good quality oak, for example, may achieve over £300 per tonne whereas beech may achieve £60 to £80 per cubic metre, and poplar may achieve £40 to £50 per tonne.

4.3.3 Timber pricing

The main timber markets, and the delivered prices are set out in

Table 6. The main variation in prices received is for the larger roundwood. A wide range of prices is achieved for hardwood timber. The prices ignore local/niche markets.

Table 6: The main timber markets and an indication of delivered prices

Conifers	Delivered Price £/tonne	Broadleaves	Delivered Price £/tonne
Small roundwood (7 - 14cm dia.)			
Pulp/chipboard/ biomass	40 - 50	Firewood	40 - 50/t (roadside)
		Biomass	Firewood value more lucrative than biomass, so very little sold for biomass
Larger roundwood (14 cm + dia.)			
Fencing	50 - 60/m^3	Fencing	60 - 100/m^3
Sawlog	75 - 125/m^3	Sawlog	40 - 300/m^3

The above prices have been derived from a range of sources, including relevant timber journals, published Forestry Commission sales and anecdotal evidence and personal experience of selling timber. Unlike many other commodities, there is no single published source of information that sets out current prices. This is just one of the many challenges for farmers who have no experience in selling timber.

What the above indicative timber prices illustrate, is that there is a significant difference between the value of good quality sawlog timber versus smaller and lower quality timber. This differential in prices becomes more marked with broadleaved species, particularly for high value timber species such as oak and walnut. This differential becomes still more significant when the net prices are compared – i.e. after the deduction of the felling and transport costs.

Thus, for those landowners seeking to derive an income from timber, it will be important to try to grow high quality trees, meaning straight, free of defects and with a large diameter. However, growing trees of high quality takes skill and expertise and regular management over its rotation length. To date much of the timber contained within farm woodlands tends to be of limited quality – there are a range of reasons for that, including limited time, resources, knowledge, and expertise. These qualities also tend to be needed when trying to develop niche markets.

Knowledge of timber markets, the buyers and method of sale will impact the attainable prices. For those with less experience and market knowledge, they will tend to use an adviser and/or sell by negotiation/private treaty to a timber merchant. Sale by tender or auction and/or direct to the end user provides an opportunity to optimise prices, but requires knowledge of timber markets and buyers, as well as a potentially more time consuming and costly way of selling the timber.

4.3.4 Timber income for farm woodlands

The growth rates and, therefore, timber production achievable from a woodland will be influenced by a range of factors, including the choice of species, the site conditions, and the management regime. Lowland sites in the UK planted with conifers typically produce an annual average of 12 to 24m^3 timber per hectare over the rotation as a whole and would accordingly be assessed as falling in yield class 12 to 24. Under conventional management systems, thinning begins at 15 to 25 years after planting and is repeated every 5 to 7 years until the wood is clear felled between 40 to 60 years. Approximately 40 to 45% of total production will be from thinnings if the woodland is thinned in accordance with the above thinning cycles.

Broadleaves typically produce an average of 4 to 12m^3 timber hectare per year over the whole rotation. Under conventional management systems, thinning begins 20 to 30 years after planting and is repeated every 8 to 10 years, until the wood is clear felled between 80 to 120 years after planting, although far fewer broadleaved woodlands are managed through a clear fell system

For upland sites, conifers typically produce an annual average of 4 to 14m^3 timber per hectare over the whole rotation. Broadleaves planted in the uplands are more likely to be planted for amenity, than timber production, and so timber production from such plantings is not discussed.

For the first 20 years of the life of a woodland, there is unlikely to be any opportunities to generate income from timber sales. Thereafter, there is scope to generate income from the sale of timber until the trees in the woodland are felled. There are a range of factors that will impact the quantity and quality of the timber produced from thinning the woodland as well as the amount of timber that is harvested if/when the woodland is felled.

4.3.5 Predicted trends in UK agroforestry and farm woodland timber production

Market growth in the forestry sector is likely to increase over the coming years as the UK government has announced ambitious plans for increasing woodland planting. 30,000 hectares of woodland creation per year are targeted by 2025 to help meet 'Net Zero' commitments. Given that current planting rates are at about 13,000 hectares per year, there needs to be an acceleration of woodland creation. This need could drive schemes for planting and integrating woodland into farms across the UK. Furthermore, aims to improve habitat quality, biodiversity and water regulation are likely to provide specific incentives for

AFW. However, the economic viability of timber harvesting, sale, and transport from these AFW systems is uncertain.

Over the next three decades tree planting and, hence, timber and woody biomass production will increase. However, it is less certain how this will integrate with agriculture. Narrowly focused carbon markets and planting schemes could incentivise landowners to shift away from agriculture entirely. On the other hand, uncertainty around maintenance, profit and impact on land could drive farmers away from woodland planting. Clear but flexible schemes will be required to support the optimised use of agroforestry timber production and to quantify, communicate and reward the range of benefits it can provide.

Furthermore, lack of skills, knowledge, and market access impose significant barriers for farmers looking to access higher value timber markets such as walnut and oak. Collaboration between farmers and foresters could help to bridge the skills gap. Innovative agreements in which foresters manage and sell AFW trees across farmers' land could enhance the market for AFW timber. However, the management and transport costs associated with managing this kind of low-density timber production will be substantially higher than in more conventional systems. Whether these collaborative agreements could become economically viable is worth investigating, combining them with agri-environment and PES schemes could help make them attractive to both parties.

4.4 Biomass

4.4.1 UK bioenergy consumption

Biomass for bioenergy is a huge source of power and heat in the UK, albeit dominated by a single energy generator (Drax). Wood energy in the UK is produced from a range of wood products, including roundwood, sawmill products, wood pellets and recovered wood. In 2019, the UK consumed 9.2 million tonnes of wood pellets making them the largest source of bioenergy in the country. In fact, 60% of all biomass consumed in the UK takes the form of wood pellets for electricity generation. The remaining 40% of biomass is used for activities such as heating.

Renewable energy in 2019, provided more than a third of the UK's total energy consumption (BEIS, 2020). Biomass provided 40% of this consumption. The UK has one of the highest levels of biomass energy generation and importation in Europe, along with the fastest rate of growth (Brack, 2017). Drax power station is the largest user of biomass energy in the UK accounting for more than half of total EU imports of wood pellets (Brack, 2017).

Major UK Biomass energy producers promote their use of Sustainable Biomass Program (SBP) certified pellets as evidence of sustainability, however, in SBP's own reports over 50% of their certified production still comes from primary feedstock bringing into question the sustainability of sourcing (Sustainable Biomass Program, 2021). Felling for bioenergy production leads to a carbon debt and combustion of biomass for energy now produces 15m tonnes of carbon dioxide annually, only 5m tonnes below that of fossil fuels (Office National Statistics, 2019). This is exacerbated by the emissions of harvesting, processing, storing, and transporting the fuel (Ricardo Energy & Environment, 2018).

Although the climate impacts of woody biofuel vary considerably depending on the harvesting, collecting, processing and transport; in most circumstance, its use will release higher levels of emissions than coal (Brack, 2017). UK policy generalises biomass as carbon-neutral, which many argue needs to be reassessed and adjusted. The environmental impact of biomass needs to be considered in any subsidisation of AFW to ensure environmentally degrading practices are not supported.

The UK is by far the biggest importer of woody biofuel in Europe importing a total of 8.9 million tonnes of wood pellets in 2019 (Forest Research, 2020). 80% of these imports were sourced from North America. In comparison, only 0.3 million tonnes were produced in the UK (Forest Research, 2020). There has been an increase in the amount of recovered wood used for biofuel in the UK and an estimated 2.4 million tonnes was produced and used in 2019 (Forest Research, 2020).

4.4.2 UK biomass market

There are two separate markets for biomass, one for small-scale use and one for large-scale electricity generation or combined heat and power (CHP). Smaller scale markets tend to have higher prices and average from £9.50 - £11.60 per GJ. Larger scale energy generation averages £5 - £7 per GJ (Ricardo Energy & Environment, 2018). Wood pellets have a calorific value of 17 GJ per tonne (Forest Research, 2021) this means they have an approximate average value of £102 per tonne for larger scale energy generation and £180 per tonne for smaller scale production.

SRC is the biomass production technique most associated with AFW. In 2019, less than 33,000 tonnes of biomass were produced from SRC (Defra, 2020), with SRC accounting for 2,233 hectares of land. Of this total, approximately 28,000 tonnes of SRC woodchips were used in UK power stations in 2018/19. This provides less than 0.5% of the UK consumption.

Smaller scale energy and heat generation also supports a market for woody biomass in the UK. This has been stimulated by the Renewable Heat Incentive (RHI), which provides financial support for the purchase of biomass boilers and other technologies. By 2020, the scheme was estimated to have supported installation of 14,000 industrial units and 112,000 in the commercial and public sector. Installations that have a generation capacity of 57TWh or 210,000 TJ of energy.

4.5 Ethically and environmentally labelled products

Demand for sustainable products has increased since the birth of the environmental movement in the 1960s (Ghvanidze et al., 2016). Increasing awareness of environmental damage has been stoked by high profile reports such as those from the IPCC. Consumers are increasingly aware of the impact from their consumption and are actively seeking ways to lessen it.

The UK has the fourth largest market for organic food in Europe and it is growing at an increasing rate. In 2021, the market grew faster than it has done in 15 years. An increase of 12.6% brings the value to £2.79 billion (Soil Association, 2021).

Most UK sales of organic foods occur through supermarkets, but demand for food box schemes is increasing at a consistently faster rate. These schemes deliver fresh, organic, and predominantly local food direct to consumers. Box schemes increased in value by more than a third in 2021 to £500 million (Soil Association, 2021). Lower carbon miles, increased transparency and lower environmental impact are drivers of this consumption (Aikins & Ramanathan, 2020). Consumers want an alternative to the globalised agri-food sector where even organic produce is often imported.

As consumer awareness of environmental impact grows, so does the demand for more transparent environmental labelling. In 2009, a survey found that 72% of EU citizen supported the mandatory use of carbon footprint labelling in the future. However, in the UK, the quantity and complexity of labelling has led to limited success to date. Many organisations are calling for consistent format for labelling to be established which could help increase consumption of sustainable and local produce.

Supply of sustainably certified timber is also growing, a report in 2008 for the Forestry Commission found that sales of certified timber increased across all major timber products. In 2008, 83.6% of all UK timber production and imports were sustainably certified (Moore, 2008). Demand for sustainably certified timber has also increased rapidly, with specific requests for these products increasing from 10% of sales in 2005 to around a third in 2008.

Most woodlands within private ownership, and particularly AFW are, however, not yet certified. If much of the timber being derived from the woodlands is only of firewood value, then certification is unlikely to have any impact on the prices that the woodland owner would receive. One must also consider whether any potential premium for timber from certified sources is sufficient to cover costs of achieving certification for small scale farm woodland production. Innovative group certification schemes have been developed to tackle this issue. These schemes support smaller land managers wishing to achieve certification.

All these separate markets demonstrate a clear shift in consumer preference. They want to know that their consumption is sustainable. This trend provides a potential market for UK AFW products, which can be sold as local, low carbon, nature friendly and supporting of improved animal welfare.

Clear branding and labelling will be necessary to take advantage of this market opportunity. Something that is difficult for smaller producers and supply chains to undertake. Collaboration and coordination will help AFW producers raise awareness of the benefits associated with their products. Local supply chains such as box schemes also provide a consistent market for select AFW farmers to sell into. These supply chains could be an opportunity to expand the market for UK fruit and nuts.

4.6 Ecosystem markets

Recognition of the need to provide public and private support for the supply of ecosystem services is growing. Many ecosystem services fall outside of conventional markets and suppliers are rarely compensated for the public goods they provide. Narrowly focused, profit driven production has outcompeted production techniques that deliver a wider range of ESs. Ecosystem markets seek to change this by providing producers with payments for more diverse ecosystem services.

4.6.1 UK ecosystem market

Two established ecosystem markets in the UK are the Woodland Carbon Code (WCC) and the Peatland Code (PC). Both provide land managers with payments for the carbon they store by changing their land use and management. Interest in these schemes from landowners and investors is increasing. Over a six-month period in 2020, the number of WCC registered projects almost doubled and predicted sequestration rose from 5.8 million to 8.3 million tonnes of carbon dioxide equivalent (Forestry Commission, 2020). As demand increases, so too does the price of carbon. The Woodland Carbon Guarantee is a government scheme that allows landowners to sell WCC units at a guaranteed price. Average auction prices have been as high as £24.11 per tonne carbon dioxide equivalent, whilst the most recent bidding (2020) averaged £17.31.

Other PES schemes include Biodiversity Net Gain (BNG), payments for water quality regulation and EnTrade. Developers in England are now required by the Environment Act 2021 to offset any negative impact upon local biodiversity through BNG, which includes paying for off-site habitat creation or enhancement. Numerous water companies are also paying farmers to invest in practices that reduce the flow of pollutants into waterways.

EnTrade is a UK initiative that facilitates the sale of ecosystem services. Ecosystem service providers can use the EnTrade marketplace to sell the ecosystem services to public, private and philanthropic sources who are seeking to offset their own impacts or simply to invest in environmental improvement.

4.6.2 Predicted trends in the UK ecosystem market

As more companies develop strategies for reaching net zero, and comprehensive plans to improve their environmental footprints, the markets for ecosystem services are likely to expand and increase in value. This is evidenced by the predicted increase to the market value of traded carbon. The UK's Department for Business, Energy & Industrial Strategy (BEIS) predicts that the value of one tonne of carbon dioxide equivalent will increase from £13 in 2018 to over £80 in 2030.

In conjunction with these trends, food wholesalers are under increasing pressure to demonstrate the sustainability of their produce. Pressure is leading them to incentivise land managers to take up sustainable practices. Likewise, the shift in agri-environment support in the UK aims to provide payments to farmers for the provision of public goods. Finally, a plethora of different sectors from insurance to housing, to multinational food companies are finding their activities increasingly exposed to climate change. Many of these companies will seek to invest in climate resilient forms of land management that can help increase the resilience of their businesses, this will expand the market for ecosystem services.

There are few examples of explicit investment in AFW through ecosystem service markets. One specific example is Upstream Thinking (see Case Study 6) whereby South West Water has invested in tree planting and other habitat creation, restoration and enhancement to reduce its operational costs. Similar schemes could be rolled out to provide a range of support for AFW. Flood prone areas and insurers could invest in alley cropping and tree, hedgerow and shelter belt planting to reduce flood risk and damage. Supermarkets could invest in tree planting on farms to improve animal welfare, meet net zero targets, and improve climate resilience. An example of this is the Woodland Free Range egg brand developed by Sainsburys (see Case Study 1). Larger vegetable box schemes could invest in farmers to trial innovative AFW fruit and nut production to expand their offering of UK products.

As with labelling and brand, however, this approach requires collective action from AFW providers, buyers, and consumers to raise awareness and investment in AFW. It also requires collaboration and fairness across supply chains, to ensure that those actors with most power do not meet their net zero plans at the expense of individual actors, predominantly farmers, who usually have less power. If this is not achieved there is the risk that AFW opportunities become neglected and ecosystem service investment and markets focus on larger scale investments providing singular ecosystem services such as carbon sequestration. This could exacerbate problems such as import dependence and raising land prices although these issues are beyond the scope of this report.

Case Study 7: Upstream Thinking – South West Water

Background

Upstream Thinking is an award-winning programme developed by South West Water. Payments are provided to farmers across the South West region of the UK to undertake management changes that will reduce agricultural point and diffuse pollution. The programme provides payments for a wide range of activities, but a significant percentage enhance the integration of AFW within farms.

The programme has paid farmers to plant 7,868 hectares of hedgerows and 357 hectares of riparian buffer strips *(*Grand-Clement et al., 2021*)*. The establishment of hedgerows aims to break up the hydrological connectivity of the landscape and, therefore, lower the volumes of run-off and soil loss from the land. The riparian buffer strips, which can be woodland or grass, distance agricultural activities from water bodies and intercept pollutants.

Cost benefit

Between 2015 and 2020, the project has allocated £25.9 million through capital grants and match funding. Due to the scale of the project and the diffuse nature of water pollution, it is difficult to accurately calculate the impact of the project upon the economic performance of South West Water's operations. Seasonal variation in rainfall and the long-time frames needed to reduce pollution make it hard to ascertain impact.

One report states a benefit cost ratio of 65:1 based on deferred investment in water treatment alone. Additionally, the project is expected to reduce operational costs of existing water treatment plants by 20%.

South West Water's annual operating costs in 2019 were £345.5 million. This means that the 20% reduction in costs from Upstream Thinking alone equates to almost £70 million, more than double the cost of the programme. Whilst it is impossible to say how much the agroforestry interventions have contributed to these savings; it is a clear example of how private payments for agroforestry can directly contribute to financial performance through enhancing the provision of ESs.

The benefits do not only flow to South West Water, but farms also participating in the scheme have recorded yearly increases to their bottom line of up to £20,000 per farm (Grand-Clement et al., 2021).

Additional benefits

There are numerous additional benefits, the 24,461 trees planted through the programme, as well as the hedgerows, store carbon, contributing to industrial and national carbon reduction goals. The interventions enhance the quality of habitat across the farms and water bodies. The interventions also enhance soil infiltration rates. This helps absorb and slow the run-off of water during heavy rainfall, potentially lowering the risk of flooding to downstream conurbations, infrastructure, and businesses.

5 Agroforestry and farm woodland policy and payment schemes

It is not only important to understand the performance and markets for AFW systems, but also to understand how policy has supported or disincentivised AFW production. In the following section, we provide a brief overview of past policy support in Europe and the UK. We then provide a more in-depth assessment of current policies related to agri-environment and woodland creation support schemes and how these intersect with AFW. We finish by considering how these are likely to change in the future. It is clear from our assessment that policy is shifting towards increased support for AFW, but this is happening incoherently and inconsistently across the UK's four nations.

5.1 Past policy and payment schemes

Over the past century, in Europe, policy has been a major driver in the reduction of AFW. Since the second world war and the widespread industrialisation of agriculture, yield maximisation has been the driving force behind European agricultural policy. Discourse has separated agriculture and forestry, either consciously or unconsciously, treating them as competing land use options. Hence, regulation and subsidisation has developed to support either system separately. Agroforestry, falling between the two systems, has often not qualified for subsidy payments, with the result that uptake and maintenance has been passively discouraged (Eichhorn et al., 2006).

The Common Agricultural Policy (CAP), up until the 2000s, was largely unsupportive of agroforestry. In the UK, the CAP and various national policies favoured agricultural production and blocked agroforestry, such as by limiting eligible agricultural land to 50 trees per hectare (Newman et al., 2018). Without support, AFW has rarely been economically competitive with other land uses (Newman et al., 2018).

Since 1992, as awareness of the services provided by forests and agricultural land has grown, reforms have made the CAP more supportive of AFW (FAO, 2011). Incentives have been put in place to increase tree planting, promote and support AFW, and enhance intercropping (Eichhorn et al., 2006; Newman et al., 2018). Between the years of 1990 and 2011, these regulatory changes likely influenced the 7% increase in forest cover on farms across the EU (FAO, 2011).

In 2015, further changes were made to the CAP and fields planted with up to 100 trees per hectare were made eligible for support (Newman et al., 2018). However, measures, regulations, and support have been implemented differently across Europe (Newman et al., 2018). Contradictions and discrepancies in regulations have left many farmers confused about agroforestry and its eligibility for support. The echoes of previous policies have left many farmers fearful that agroforestry will exempt them from subsidy payment. Moreover, subsidies have failed to support more heterogenous systems, instead providing payments mostly for linear features. Funding also failed to support already established systems, only providing support for new tree planting (Newman et al., 2018).

In summation, the CAP has provided inconsistent and often contradictory support for agroforestry. Other policies, such as the Rural Development Programme (RDP) have failed to support even the opportunities available with CAP for AFW support. As Britain leaves the CAP, it is restructuring the support offered to farmers. A variety of support packages have been developed to incentivise agroforestry.

There is evidence that the UK governments are seeking to provide greater support for agroforestry. In December 2020, a statement was published in response to confusion about the compatibility of agroforestry systems with the Basic Payment Scheme (BPS) (GOV.UK, 2020). The statement confirms that land growing certain trees is eligible for BPS, however densely grown. This includes individual scattered trees, such as in parkland or orchards; and lines of trees no more than two trees wide on agricultural parcels, such as in alley cropping silvoarable systems or grazed orchards. Support will continue to be provided if the area beneath the trees is used for agricultural activity and at least 50% of the area underneath the tree canopy is covered by grasses, other herbaceous forage, or arable land.

In publishing this statement, the UK government affirms, not just the BPS regulations, but also their desire to promote and increase AFW uptake. In the statement, AFW is presented as a viable method for supporting several goals in the 25 Year Environment Plan and Clean Growth Strategy. However, despite the increased interest in AFW, coherent support and advice is lacking. Below we highlight the various policies that offer partial support for AFW.

5.2 Agri-environment schemes

Table 7 lists the various agri-environment support schemes that are present across the different countries of the UK and highlights the options that provide the more direct support for AFW. The remainder of the section explores these schemes and the relevant options in more detailed and the varying levels of support they provide for AFW.

Table 7: Summary of UK agri-environment support schemes

Country	Scheme	AFW relevant support options
England	Countryside Stewardship	• supply and plant trees • creation of wood pasture • creation and management of traditional orchards • restoration of forestry and woodland to lowland heathland
Scotland	Agri-Environment Climate Scheme	• support for Ancient Wood Pasture • hedge and single tree planting
Wales	Glastir Glastir Advanced	• wood pasture • parks and gardens • orchard management • woodland – light grazing • tree and scrub – planting • tree and scrub – regeneration • various options for re-stocking and maintaining trees
Northern Ireland	Environmental Farming Scheme (EFS) Wider EFS Higher EFS Group	• Specified agroforestry support (400 trees/ha) • hedge planting and maintenance • creation of riparian buffers planted with native trees • creation of traditional orchards • planting native tree corridors • Support for co-operative action

5.2.1 Countryside Stewardship (England)

The Countryside Stewardship scheme (CS) provides agri-environment payments to farmers, foresters and other land managers to look after and improve the environment. It provides financial support for conservation, woodland creation, and pollution reduction management activities. A web search for agroforestry on the UK government's Countryside Stewardship grants page returns zero results. Despite this, there are several support options that relate to agroforestry.

CS provides funding to supply and plant trees (£1.28 per tree), with additional funding for tree guards. This payment can be used to plant single trees on any land that has not been woodland for at least 10 years, and within hedgerows; both these activities support enhanced agroforestry.

A more context specific funding option is wood pasture creation. The funding is available to create new wood pasture either where wood pasture once existed; or where it extends, links, or buffers existing wood pasture or priority woodland habitat. Support is also offered for management of wood pasture and parkland. This funding requires trees to be planted for habitat regeneration and for the area to be grazed by traditional breeds of cattle or deer. Whilst these options are useful for supporting parkland and wood pasture systems, they offer limited support for increasing this silvopastoral practice.

A similar option is available for supporting the creation and management of traditional orchards (GOV.UK, 2022). This includes recommendations that the surrounding grassland be grazed. This is evidence of policy support for agroforestry but, once again, provides limited capacity to encourage new systems to develop.

The final option worth highlighting is the restoration of forestry and woodland to lowland heathland (GOV.UK, 2022). Although this option requires a transition from forested area to heathland it is a measure that encourages increased AFW. Tree cover of under 15% is allowed and grazing of livestock is recommended. Therefore, this option can provide funding for silvopastoral systems, despite it being tied to a reduction in woodland area. It is worth noting, that in situations such as these, agroforestry could be associated with a reduction in tree cover.

The review of CS options, reveals that there is no explicit or cohesive support for AFW systems. Land managers seeking financial support would have to tailor applications to meet their needs. Navigating the requirements of the different support options requires considerable research, which will not be possible or attractive to many applicants. The thorough guidelines provided for other options passively disincentivises agroforestry. Where CS does provide support for agroforestry, it is limited to already existing or previously established systems. This limits the scope of the funding to support new AFW projects and is a barrier to increased tree planting on UK farms.

5.2.2 Agri-Environment Climate Scheme (Scotland)

The AECS in Scotland provides funding to land managers seeking to implement environmentally beneficial practices. Most funding options are focused purely on agricultural management and conservation practices. However, several options do provide funding for AFW systems.

The option that supports the most explicit and integrated form of AFW is the support option for Ancient Wood Pasture. This provides funding for farmers to maintain, ancient wood pasture, regenerate the habitat through managed grazing and establish new trees. Any grassland with ancient wood pasture that is grazed by livestock is eligible. This is the only example of direct support for an AFW system. The term agroforestry does not appear on the AECS website. There are also a range of more focused support options including creation of hedgerows and the planting of individual trees within ancient wood pasture or hedgerows.

Much like the CS scheme, AECS only offers partial support for AFW. It provides scope to regenerate and maintain already established systems and enhance linear features, but fails to provide consistent, reliable, and appropriate support for developing new and more diverse agroforestry systems.

5.2.3 Glastir (Wales)

Glastir is a 5-year whole farm sustainable land management scheme available to farmers and land managers in Wales. The scheme is divided into two levels Glastir Entry and Glastir Advanced.

Glastir Entry provides funding for farmers who contractually agree to adhere to a range of sustainable practices. Funding is at a fixed rate and ensures enrolled farmers meet a minimum standard of sustainable management. In addition to this, farmers need to select a range of management options to apply to their enterprise. Each of these options is scored and a minimum score needs to be reached to meet the requirements of the scheme. Farmers can select the management options that best meet their needs. Interestingly, Glastir provides funding for the creation of new orchards. Something that is not present in the Scottish and English support schemes.

Glastir Advanced provides funding for a range of agri-environment practices. Options are selected from a longlist of management options that are suitable for the land being funded. Management options relevant to AFW include the planting of hedges and woodland strips, tree planting, and orchard creation.

The most noteworthy options include management options for wood pasture; parks and gardens; orchard management; woodland – light grazing; trees and scrub – establishment by planting; trees and scrub – establishment by natural regeneration; and a variety of options related to re-stocking and maintenance of trees.

Glastir provides a range of options that align with agroforestry but, like CS and AECS, fails to provide explicit support for agroforestry. Orchards, wood pasture, and parks and gardens, as well as linear features are the only features that are supported by the scheme. More structured and managed forms of agroforestry such as alley cropping, and specific forms of woodland grazing are not supported or mentioned.

5.2.4 Environmental Farming Scheme (Northern Ireland)

The EFS is a voluntary agri-environment support scheme for farmers and land managers in Northern Ireland. It is divided into three schemes: EFS Wider, EFS Higher and EFS Group. Applicants for the EFS Wider scheme must select several management options as part of their agreement. Each option has a specific payment rate per unit area or length.

Unlike the other agri-environment schemes assessed in this section, EFS Wider has specific funding available for the establishment of agroforestry. This support aims to increase the agroforestry planting to increase carbon sequestration, biodiversity, nutrient cycling and water quality. The funding supports the planting and protecting of 400 trees per hectare intersected with grazed or managed land. The option also provides a list of suitable tree species to plant and guidance on important aspects such as planting, spacing and animal stocking density.

Additionally, there a range of options that relate to agroforestry practices including hedge planting and maintenance, creation of riparian buffers planted with native trees, creation of traditional orchards, and planting native tree corridors. These options provide land managers with a range of options to enhance the availability of shelter, fodder, and woodland products across their land.

EFS Higher focuses on providing land managers with support when managing priority habitats. Three of the options relate to AFW practices which support the conservation, succession, and improved health of priority woodlands. The options are grazed ash woodland remedial management, grazed oak woodland remedial management and grazed wet woodland remedial management.

Another interesting component of the EFS scheme is the EFS Group Facilitation scheme. This scheme supports co-operative action by farmers in a specific area such as a river catchment. Proposals are invited from groups of farmers aiming to provide benefits to environmentally designated sites, priority species, and/or specified river catchments. Although there is nothing explicit about AFW in this scheme, this option offers innovative farmers considerable scope to trial AFW practices at scale and potentially work together to generate considerable environmental impact whilst also using collective action to access new markets for AFW produce.

Based on this assessment, the EFS provides the most thorough support for AFW across the nations of the UK and should be emulated. It gives considerable flexibility to farmers, whilst providing explicit funding for in-field tree planting, and AFW. Furthermore, it provides support for co-operative action, something that this report proposes is essential to the expansion of AFW.

5.3 Woodland creation support schemes

Table 8 lists the various woodland creation support schemes that are present across the different countries of the UK and highlights the options that provide the more direct support for AFW as well as the payment rates. The remainder of the section explores these schemes and the relevant options in more detailed and the varying levels of support they provide for AFW.

Table 8: Summary of UK woodland creation support schemes

Country	Scheme	Support option	Payment Rates (per ha)
England	England Woodland Creation Offer (EWCO)	Woodland 1ha or more. Can be spread over smaller blocks at a minimum width of 10m.	£8,500 for planting. £200 per year maintenance payments for 10 years
Scotland	Forestry Grant Scheme	Agroforestry	£1,860 - £3,600 for planting and £48 - £84 per year maintenance payments for 5 years (prices for 200-400 trees per ha respectively)
		Small and farm woodland	£2,400 for planting and £400 per year maintenance payments for 5 years
Wales	Glastir Woodland	Agroforestry	£1,600 for planting and £30 per year maintenance payments for 12 years.
		Native woodland	£3,000 for planting and £60 per year maintenance payments for 12 years. Additional premium payment of £350 to cover income forgone.
Northern Ireland	Small Woodland Grant Scheme	Woodland above 0.2 ha	£2,925 for planting and £350 per year for 10 years to cover income foregone
	Forest Expansion Scheme	Expansion of woodland over 3 ha.	Payment rate is not specified but covers establishment costs, income foregone and maintenance costs (years 1-5).

5.3.1 England Woodland Creation Offer (England)

The England Woodland Creation Offer (EWCO) is an initiative started in 2021 that will provide support for woodland creation until 2024/25. It aims to support the creation of 11,000 hectares of new woodland by 2023/24 with £15.8 million available.

This grant provides competitive funding to landowners, land managers and public bodies intending to create new woodland. It covers afforestation through natural colonisation as well as planting. Total areas as small as 1 hectare are eligible for funding; these can be spread across multiple smaller blocks at least 0.1 ha and 10 metres wide. Details of payment rates can be seen in Table 8.

EWCO provide potential support for some, but far from all agroforestry. Shelter belts can be planted to support semi-integrated silvopastoral systems providing shelter, shade, and potential fodder to livestock. However, the grant stipulates that the applicant must cease all agricultural activities once the EWCO agreement commences. This prevents the woodland being used for any grazing. This limits the potential of the grant to support more integrated silvopastoral systems. Farm woodland areas are, therefore, unlikely to provide space for woodland chickens, pigs and other livestock that could be integrated into the new habitat.

10-metre-wide strips of trees greater than 0.1 hectares could also be planted within arable fields to create alley cropped silvoarable systems. However, this required width and area is likely to be impractical for many farmers planning silvoarable systems.

The grant is not eligible for SRC and/or short rotation forestry. This may make it less attractive to potential agroforestry practitioners who may be seeking a quicker return on their investment or a system to align with short term tenancy agreements.

The restriction of all agricultural activity within EWCO funded woodland is unnecessarily restrictive. Agricultural activities, such as woodland grazing, can function within woodland and can even enhance the ecological value of these habitats.

5.3.2 Forestry Grant Scheme (Scotland)

The Forestry Grant Scheme (FGS) provides explicit funding to agroforestry projects (Ruralpayments.org, 2018). This support provides funding for farmers creating small scale areas of woodland within permanent pasture for sheep grazing (silvopastoral) or within agricultural land (silvoarable). Even the more conventional woodland creation grant (Ruralpayments.org, 2021) options stipulate that sheep can be grazed within the woodland if the trees are old enough to avoid browsing damage. Details of payment rates can be seen in Table 8.

Both grants only permit grazing of sheep due to the stated inability of the protection to cope with grazing of other species, such as cattle. However, there are cases of more diverse species being grazed in woodland and parkland habitats including, cattle, chickens, and pigs. Hence, restricting the grant to only permit sheep grazing may be unnecessary.

5.3.3 Glastir Woodland Creation (Wales)

Glastir Woodland Creation (GWC) offers flexible support for woodland creation. The scheme funds areas of woodland creation totalling 0.25 hectares. This area can be composed of smaller parcels of 0.1 hectares with no minimum width. The absence of a minimum width means this funding can be used for a range of agroforestry systems including alley cropping and shelter belts. Additionally, the grant provides explicit funding for agroforestry systems with a maximum of 80 trees per hectare. This funding option is suitable for funding parkland silvopastoral systems but is not suited to more densely planted forms of agroforestry such as grazed orchards, or woodland pasture systems. Details of payment rates can be seen in Table 9.

Capping the agroforestry grant at 80 trees per hectare limits the range of agroforestry options that can be supported. Providing funding based on the defined type of agroforestry such as alley cropping, woodland grazing, or silvoarable/pastoral orchards could provide land managers with more flexibility in their management. Although, defining the parameters of these systems to maintain clarity would need attention.

5.3.4 Northern Ireland Woodland Grant Schemes (Northern Ireland)

The Department of Agriculture, Environment and Rural Affairs (DAERA) in Northern Ireland offers two main woodland creation grants that differ based on the scale of the proposed woodland.

The most relevant to agroforestry is the Small Woodland Grant Scheme which provide funding to land managers establishing over 0.2 hectares of mixed native woodland. The woodland must be a minimum of 10 metres wide. This means it could potentially be used to establish shelter belts. However, the prohibition of any agricultural activity in the planted area prevents any more integrated agroforestry from taking place.

The other grant is called the Forest Expansion Scheme and provides funding for areas of woodland creation over 3 hectares. This is less likely to be attractive to farmers considering agroforestry. However, larger areas of woodland creation on a farm could be used to create continuous lines of shelter and supply fodder, wood chip, and timber for activities on the farm. Details of payment rates can be seen in Table 8.

5.4 The future of UK agri-environment and woodland creation support schemes

The UK leaving the CAP has triggered the restructuring of agri-environment support as well as a range of other related subsidies. The intent is to develop policies that pay land managers to provide more and wider ranging public goods from their land. Policies are being reshaped based on a large-scale process of consultation and trials. To date, there is considerable uncertainty around how the design of new schemes including the options and payment rates likely to be available. Whilst we will not go into depth on this rapidly evolving topic, we provide an overview of current thinking across the four UK countries below.

5.4.1 England

The Sustainable Farming Incentive (SFI) – part of the Environmental Land Management (ELM) scheme in England – is the most developed payment scheme today and is currently at the pilot stage. Over 900 farmers are taking part in the SFI pilot. In the pilot, a selection of 'standards' can be applied to the applicant's land and to various features, like hedgerows (GOV.UK, 2022) and farm woodland (GOV.UK, 2022). Farmers can choose ambition levels for each standard. Higher levels are associated with greater potential for improved sustainability but may incur greater costs and hence correspond to higher payments. New SFI standards will be introduced over time. Proposed standards include agroforestry (from 2024) and orchards (from 2025) (GOV.UK, 2021), however there are no publicly available details around these standards at present. The mainstreaming of the hedgerows and on-farm woodland standards is also planned over 2023-2025. Land managers entering SFI will be eligible to apply for capital grants for items such as tree planting, tree shelters and fencing.

The Local Nature Recovery (LNR) part of ELM is also likely to include some options relevant to agroforestry and farm woodland, however there are no details available at present. The third part of ELM, Landscape Recovery (LR), will target landscape scale habitat creation including woodland creation which may potentially, in some places, accommodate grazing livestock.

To inform the design of ELM, there is an Agroforestry ELM Test running until May 2023 focused on two factors, payment incentives and advice and guidance, which are significant barriers to increased uptake of agroforestry by UK farmers. The ELM Test is gathering evidence and opinion from a total network of 30 farms in six clusters representing the different types of agroforestry currently practiced in the UK (Organic Research Centre, 2020).

Future ELM design will ensure that private finance is not crowded out and that land managers are better off where they access private markets. The Government will also wish to avoid paying for the same actions that are already being paid for in a private scheme.

5.4.2 Scotland

Scotland's Third Land Use Strategy 2021-2026 commits to the expansion of forest and woodland cover and identifying more opportunities for agroforestry and farm woodlands. In late 2021, a consultation was held on Agricultural Transition and future national policy in Scotland; this acknowledged an increased role for woodlands/agroforestry/hedgerows for carbon sequestration and other ecosystem services. A National Test Programme has also been announced to help *inter alia* develop understanding of how sustainable farming can be supported and rewarded in future and ensure that the right tools and support are in place from 2025 onwards (Gov.scot, 2021). However, at present, there are no details available on future support payments for agroforestry and farm woodland in Scotland.

5.4.3 Wales

The Sustainable Farming Scheme (SFS) will be the future farm support scheme in Wales and will provide the main source of funding for Welsh farmers. SFS aims to support the wider objectives of Sustainable Land Management (SLM), the Welsh Governments guiding principle for future agricultural policy. SFS will begin in January 2025 and will be geared almost entirely towards addressing climate change and biodiversity loss.

An outline of SFS was published in 2022 with consultation and outreach continuing over 2023-24. Support will be structured into three layers, all providing support for farmers undertaking sustainable and publicly beneficial practices. The first layer is universal and stipulates actions that must be undertaken by all farmers enrolled in the scheme in order to receive a baseline payment rate. The second and third are Optional and Collaborative layers involving more complex, targeted actions or collaborative management change. These actions will be paid upon delivery.

Farmers will receive payments in return for farming in a way that promotes carbon storage, soil and water quality, and flood and drought risk mitigation, among other measures. This will include payments to farmers who choose to deliver positive benefits from planting and managing trees and woodland on their farms, and similar elsewhere. The outline proposal for SFS includes a section on the creation and management of existing agroforestry and woodland, and points to the role agroforestry can play in climate regulation, reducing ammonia emissions, and increasing tree cover. The Welsh Government has set ambitious plans to increase tree cover to 10% tree cover on farms. Although funding options explicitly for agroforestry have not yet been outlined, the SFS proposal indicates support will be included within the scheme when it commences in 2025.

5.4.4 Northern Ireland

A consultation on Future Agricultural Policy Proposals for Northern Ireland (DAERA, 2022) has recently ended. A Farming for Nature Package is proposed to include support for hedge creation and management, native tree planting, parkland and agroforestry. The consultation document acknowledges the ecosystem service benefits of integrating trees within crop and livestock farming systems; it also recognises that silvopastoral agroforestry has the potential to sustain grassland productivity which is particularly important in Northern Ireland. Farming for Carbon Measures highlight the importance of forestry, agroforestry and hedgerows in carbon sequestration. A series of 'Test and Learn' pilots will be undertaken to inform future design. No details are yet available on future support payments for agroforestry and farm woodland in Northern Ireland.

In summary, there is a huge amount of work to be done over the next three years in developing the next generation of agri-environment schemes across the UK. There is a lot at stake if agroforestry and farm woodland is to be appropriately supported and ambitious tree and woodland targets are to be achieved.

6 Modelling the impact of increased agroforestry and farm woodland on the UK agricultural economy

6.1 About the model

The model is designed to calculate the impact of increasing the area of agricultural land dedicated to AFW by 100%. This is modelled for various AFW scenarios. A custom scenario is also provided to give the user the ability to vary the percentage increase of different types of AFW. The model is constructed using partial budgets; it estimates the change in net income that will occur if a percentage of the area of each farm type is changed to an AFW scenario. This change in net income is calculated on a per hectare basis and then extrapolated across the entire area for each farm type to get the macro-economic impact on the UK agricultural economy.

6.1.1 Aims of the model

The aims of the model are:

- To model the economic impacts of an increase in sustainable agroforestry and farm woodland across the UK agricultural economy.
- To model the varying economic impacts of different types of agroforestry and farm woodland upon UK agriculture and the different farm types it is composed of.
- To model the impact public and private payments for public goods can have upon the economic performance of agroforestry and farm woodland in the UK.

6.1.2 Methodology

For a fuller description of the methodology see Appendix 1. Here we provide a high-level overview of the method and evidence used to produce the model.

The data and evidence for the model, including the baseline areas of AFW, is collated from the various June Agricultural Surveys and Farm Business Surveys that are undertaken across England, Scotland, Wales, and Northern Ireland. This data is supplemented with performance data from a wide array of peer reviewed literature. The model incorporates the main UK farm types, and associated areas and economic performance, as defined and record by DEFRA.

The land use change in the model relates to a change in area of any type of AFW rather than a change in canopy cover or number of trees. The economic impact of this change was modelled as a series of partial budgets projected over a 25-year period. Costs and benefits are divided across this timespan. This is an efficient and effective way to predict the impact of a change in management upon the key variables of each farm type. Approaching the modelling in this way allowed for the main attributes to be modelled without having to collate data on all aspects of the systems. Fixed costs, Basic Payment Scheme and agri-environment scheme payments were excluded from the model unless otherwise specified.

Projected impacts of various payment schemes are incorporated into the model to understand the impact of these upon AFW economic viability. In order to model the impact of current AFW related policies, the websites for each of the agri-environment support schemes and woodland creation schemes were reviewed to identify the options that could provide potential support to the AFW scenarios. An optional setting is provided in the model to apply these current payment rates to the modelled scenarios.

To explore potential future payment, hypothetical AFW income foregone payments are also incorporated into the model as an optional setting. This enables insights to be drawn about how future AFW payment support might be developed. These modelled hypothetical payments are based on a payment to compensate the land manager fully for any lost income, establishment costs and maintenance costs associated with the different AFW scenarios.

Finally, the impacts of varying carbon payments are also modelled. Simple carbon calculations are provided to approximate the carbon sequestration potential of each of the scenarios and, in turn, to generate predicted carbon payment rates. Average carbon sequestration figures for the different types of woodland were used.

6.1.3 Dashboard and overview

The dashboard and overview page of the model is the focal point of the model. It is where variables can be adjusted and the impacts of the different scenarios upon farm net incomes can be viewed. It also allows custom scenarios to be created. These custom scenarios can be constructed to apply different types and scales of AFW land use change to each of the different farm types. This allows insights to be drawn about which combinations of AFW land use change may have the most positive and negative impacts upon agricultural net income in the UK.

The dashboard and overview page displays the net incomes of the different scenarios as bar charts and tables to show the proportional change in net income for each scenario compared to the baseline.

6.2 Discussion of modelled results

6.2.1 Economic performance without policy or payment support

Modelling the impact of increased AFW with no policy or payment support for public goods demonstrates the impact of the land use change upon agricultural performance. It allows the identification of AFW land uses that have a net positive or a net negative impact upon the economic performance of UK farm types. Figure 1 and Table 9 show the net incomes of the different AFW scenarios upon the net income of all UK farm types. The following discussion provides an analysis of the financial performance of different scenarios and why these varying impacts may be occurring.

Figure 1: Estimated impact of agroforestry scenarios upon UK agricultural net income

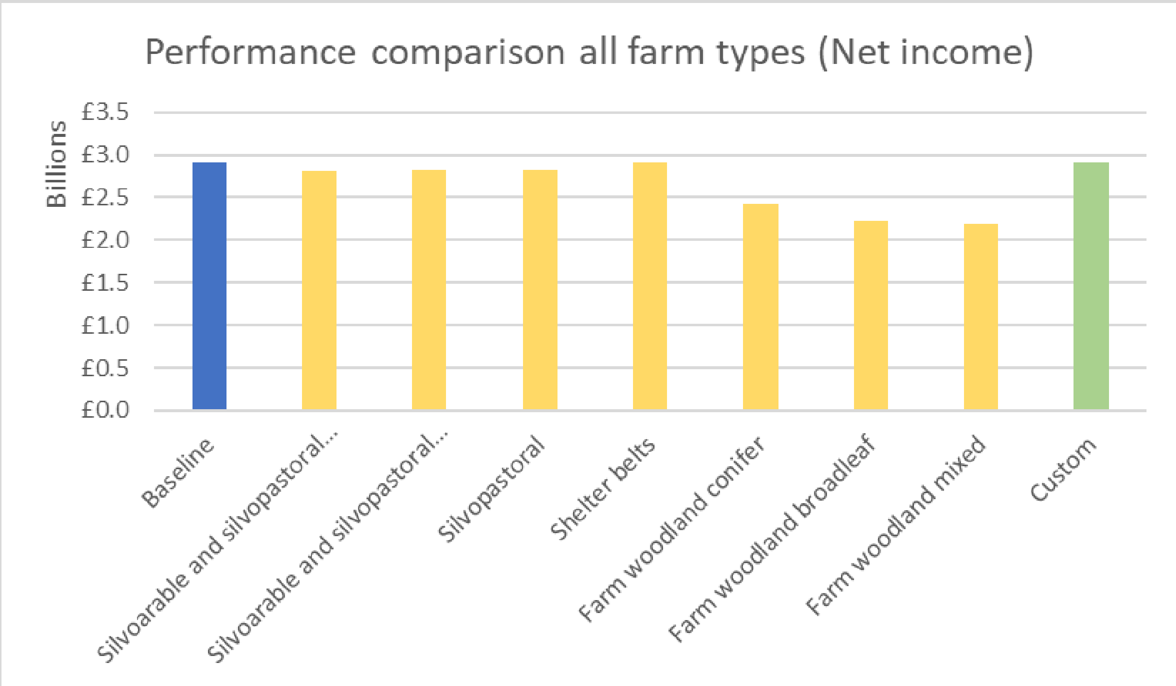

Table 9: Estimated impact of scenarios upon UK agricultural net income

Scenario	Change in net income (£)	Change in net income (%)
Silvoarable and silvopastoral orchards	-£95.7M	-3.3%
Silvoarable and silvopastoral timber production	-£85.1M	-2.9%
Silvopastoral	-£78.8M	-2.7%
Shelter belts	-£2.9M	-0.1%
Farm woodland conifer	-£479.4M	-16.5%
Farm woodland broadleaf	-£685.7M	-23.6%
Farm woodland mixed	-£716.2M	-24.6%

6.2.1.1 Best performing scenario

Shelterbelts are the only type of AFW that have close to a positive impact on the net income of UK agriculture. Net income was only reduced by 0.1% compared to the baseline. Table 10 shows the impact of an increase in shelterbelts to the net income of the various farm types.

Table 10: Estimated impact of shelterbelt scenario upon UK farm type performance

Impact of the Shelterbelt scenario upon net income		
Farm type	Change in net income (£)	Change in net income (%)
All farms	-£2.9M	-0.1%
Cereals	£1M	0.1%
Horticultural	£1.3M	0.9%
Dairy	£5.6M	0.8%
LFA Grazing	-£12.1M	-1.8%
Lowland Grazing	-£0.5M	-0.2%
Poultry	£1.7M	1.4%

The greatest proportional positive impacts on net income were to poultry and horticulture. Negative impacts were only predicted for LFA grazing and lowland grazing farms. This is because the proportional benefit of shade provision is greater for higher income farm types.

6.2.1.2 Other scenarios

All the remaining scenarios reduced UK agricultural net income. The scenario that caused the greatest reduction was the conversion of land to farm woodland, with mixed farm woodland showing the greatest loss. This is because the complete loss of agricultural incomes from the area and high upfront establishment costs and ongoing maintenance costs are not compensated for by the timber income, which is only modelled over a 25-year period, and no assumptions are included for productivity benefits from a fully integrated farm woodland system. Table 11 shows the impact of an increase in mixed farm woodland to the net income of the various farm types.

Table 11: Estimated impact of mixed farm woodland scenario upon UK farm type performance

Impact of the mixed farm woodland scenario upon net income		
Farm type	Change in net income (£)	Change in net income (%)
All farm types	-£716.2M	-24.6%
Cereals	-£182.3M	-16.7%
Horticulture	-£23M	-16.3%
Dairy	-£128.9M	-19.4%
LFA Grazing	-£205.6M	-30.5%
Lowland Grazing	-£155.1M	-72.6%
Poultry	-£21.3M	-18.2%

Impact upon all farm types were negative, with LFA and lowland grazing systems showing the greatest proportional low in net income. High income loss was also modelled for poultry and dairy farm types.

6.2.1.3 Discussion of the economic performance of the shelterbelt scenario with no policy or payment support

Without policy or payment support, it is only the impact on agricultural performance that enables a transition to greater AFW planting to be profitable. Hence, it is logical that shelterbelts are the most economically viable scenario since they are predominantly structured to enhance agricultural performance through the provision of shade and shelter.

The enhancement of agricultural performance from shelterbelts is proportionally greater the higher the income per gross margin. This is because the proportional gains to productivity lead to a higher increase in income relative to costs. The greater performance of the horticultural, dairy and poultry farm types and the negative performance of the lower productivity farm types is evidence of this.

By varying the predicted impact of shelter upon agricultural performance within the model, it was possible to change whether the shelterbelt had a positive or negative impact upon UK agricultural net income. Hence, further exploration of the effect shelterbelts have on agricultural performance is essential to better predict the impact upon farm income. This is also true, although usually to a lesser extent, for other silvopastoral and silvoarable options. Many of which have the potential to be carefully designed to impart optimal benefit upon agricultural productivity.

6.2.1.4 Discussion of the economic performance of the broadleaf and mixed farm woodland scenario with no policy or payment support

On agricultural land, the direct income from trees is generally lower than agricultural income. Hence, woodland planting on agricultural land is usually going to reduce the net income. Intuitively, therefore, it is to be expected that the farm woodland scenarios reduced net income by the greatest amount, especially as there is no evidence base for enhanced productivity through a fully integrated farm woodland system. The model shows that without support payments conversion of productive agricultural land to woodland is unlikely to be viable.

Proportionally, the reduction in net income is lowest for cereal farms. The income reduction per hectare is lowest for the less productive systems, especially LFA grazing. However, because of the lower net income of these systems, the proportional reduction of income and increased costs are greater. This means that the repercussions of woodland conversion on the profitability of LFA systems would be greater.

6.2.1.5 What it means for UK agroforestry and farm woodland

Based on the results of the model, without public or private support for the public goods it provides, AFW is seldom an economically viable alternative to agricultural production. This corresponds which much of the literature that has shown that without payment for ecosystem services AFW reduces net income (Kay et al., 2019; Lehmann et al., 2020; Kaske et al., 2021).

AFW appears to only be profitable when it is intentionally developed to enhance agricultural performance. Shelterbelts are the obvious example of this type of AFW, but grazed orchards, silvopastoral timber systems, and silvopastoral systems also provide benefits to agricultural performance. The performance benefits from these AFW systems increase the net income of dairy and poultry farms. Based on current evidence, these two farm types are the only types where the performance benefits from shade and wind reduction counterbalance the costs of establishing and maintaining the AFW. This is likely one reason why systems such as shelterbelts, hedgerows, grazed parkland, woodland pasture systems, and to a lesser extent grazed orchards, are the more common forms of AFW in the UK alongside the historic, cultural, and aesthetic value of these management features.

Interestingly, although LFA grazing reduced by the least net income due to a conversion to AFW land use, the lower profitability of these systems means they are less able to absorb that reduction and, hence, without financial support would be unlikely to transition to more integrated AFW systems. On the other hand, there is a greater reduction to the net income of cereal farms, but the higher total income means the proportional reduction is lower. This means these kinds of farms have potentially more scope to dedicate areas to AFW for non-economic reasons such as for the amenity and ecological value they can provide. This, however, depends on the values of the farmer and does little to guarantee or incentivise an increase in AFW.

6.2.2 Economic performance with current policy support

Modelling the impact of increasing the area of AFW with current policy support allows us to analyse the degree of alignment between each AFW scenario and current public support. Comparing this to the level of payment necessary to support each AFW scenario in the model and the predicted public goods provided by each system can give us an indication of the degree of support current policy is providing to AFW. Table 12 shows the change in net incomes for the different AFW scenarios upon all UK farm types with and without policy support. The following discussion provides an analysis of the most beneficial and detrimental scenarios and why these varying impacts may be occurring.

Table 12: Estimated impact of scenarios upon UK agricultural economy with current policy support

Scenario	Change in net income all farm types without current policy support	Change in net income all farm types with current policy support
Silvoarable and silvopastoral orchards	-3.3%	-2.7%
Silvoarable and silvopastoral timber production	-2.9%	-2.5%
Silvopastoral	-2.7%	-2.6%
Shelter belts	-0.1%	0.4%
Farm woodland conifer	-16.5%	-8.5%
Farm woodland broadleaf	-23.6%	-15.6%

Farm woodland mixed	-24.6%	-16.6%

6.2.2.1 Best performing scenario

When current policy support payment is applied to the model, the shelterbelt scenario generates an increase to net agricultural income across the UK. It also meant that this net increase was predicted for all farm types apart from LFA grazing.

The provision of current policy support made the most significant impact on UK agricultural net income for the farm woodland scenarios. Providing the support to LFA grazing and Lowland Grazing farm types was especially impactful and increased the net income for these scenarios by 15% and 24% respectively. This meant that on LFA grazing farms coniferous farm woodland became a more economically viable land use option than continuing agricultural production.

6.2.2.2 Other scenarios

Despite the sizeable change in net income, broadleaf and mixed farm woodlands still led to the greatest loss in net income for UK agriculture. Even with policy support, these scenarios fail to compensate for the loss of income from the higher productivity farm types. The inclusion of current policy support had the least impact upon the AFW with lower density tree planting. This is because current schemes either do not support sparse planting or only provide payments for planting single trees. Silvopastoral systems are especially poorly supported by current policy schemes.

6.2.2.3 What it means for UK agroforestry and farm woodland

In its current form, policy support is proportionally greater for AFW with higher density tree planting. The relevant support schemes tend to prioritise and, therefore, fund tree planting. Proportionally this has a lesser impact on higher income systems, on the other hand, for less productive, more extensive systems this support makes woodland planting a potentially profitable option.

When policy support is paired with the income from coniferous planting this appears to provide an especially attractive alternative to LFA grazing. Whilst this does provide support for increased tree planting in certain areas it could also cause unintended consequences. Coniferous planting on LFA land could have negative impacts on biodiversity and the availability of agricultural jobs in these areas. Meanwhile, this support will not incentivise planting on arable land and therefore many of the public goods provided by increased tree cover may be less present in more productive areas.

6.2.3 Economic performance with agroforestry and farm woodland income foregone payment

Modelling the impact of increased AFW area with an income foregone payment focused explicitly on AFW, and the public goods this system contributes to, allows us to assess which scenarios can benefit the economic performance of farm types and how much this kind of support for AFW would cost the public sector. This indicates how policy might be restructured to provide support for AFW and potentially more efficient support for tree planting and public goods provision across the agricultural sector. Table 13 shows the change in net incomes for the different AFW scenarios upon UK agriculture with and without the AFW income forgone payments. The following discussion provides an analysis of the most beneficial and detrimental scenarios and why these varying impacts may be occurring.

Table 13: Estimated impacts of scenarios upon UK agricultural economy with AFW income foregone payments

Scenario	Change in net income all farm types with no support	Change in net income all farm types with AFW income foregone payment	Cost of current policy support payments	Cost of income foregone payments
Silvoarable and silvopastoral orchards	-3.3%	1.8%	£16.4M	£147.8M
Silvoarable and silvopastoral timber production	-2.9%	1.8%	£6M	£137.2M
Silvopastoral	-2.7%	2.3%	£3.5M	£145.7M
Shelter belts	-0.1%	1.9%	£13.9M	£59.5M
Farm woodland conifer	-16.5%	0.0%	£233.5M	£479.4M
Farm woodland broadleaf	-23.6%	0.0%	£233.5M	£685.7M
Farm woodland mixed	-24.6%	0.0%	£233.5M	£716.2M

6.2.3.1 Best performing scenario

Given that the income foregone payments entirely cover the costs and lost income, the results in Table 13 predictably show that the AFW systems that confer greater benefits to agricultural performance are those that lead to a greater increase in net income. Intuitively then, the silvopastoral and shelterbelt scenarios provide the greatest improvement to the net income of UK agriculture. Interestingly, for all the livestock farm types the silvopastoral scenario has a higher net income than the shelterbelt scenario when the income foregone payment is provided. This is because there is greater scope to establish silvopastoral systems across UK agriculture than shelterbelts. Which we assume are only likely to be planted along certain edges of fields. This means the silvopastoral systems can have a positive impact upon a greater proportion of UK agricultural land.

6.2.3.2 Other scenarios

It is unsurprising that the farm woodland scenarios perform the worst when income foregone payments are provided. This is because they provide no modelled performance benefit to the farm types.

6.2.3.3 What it means for UK AFW

A key insight from the modelling of the AFW income foregone payments is that the silvopastoral scenario can provide a positive increase to the net income of livestock systems if compensation is provided for the income foregone.

The silvopastoral scenario requires a greater proportion of pastoral land to be dedicated to silvopastoral planting to lead to an increase in AFW area that is equivalent to the other scenarios. Hence, in the silvopastoral scenario, a greater proportion of livestock farms receive the performance benefits from shade than in the other scenarios. This occurs with minimal loss to the area of pasture available on the farms. It, therefore, offers a potentially attractive form of AFW for livestock farmers. It is worth noting that if shelterbelts were modelled to cover a similar area the impact on net income would be greater. However, this would require development of many in field shelterbelts, something that was considered unlikely when developing the scenarios.

Despite the potentially highly beneficial nature of newly established silvopastoral systems, based on our modelling, this is the scenario that is least supported by current policy payments in England. Current policy payments provide farmers with a negligible proportion of the income forgone from establishing a silvopastoral system. In contrast, current policy support provides at least a quarter of the income foregone for the shelterbelt and farm woodland scenarios over the modelled 25-year period.

There is, therefore, a clear need to revaluate policy payments to provide more effective support for silvopastoral systems, along with silvoarable and silvopastoral orchards and timber production systems. Policy payments need to take into greater consideration the specific costs that are incurred when establishing and maintaining AFW systems and the public goods that are provided.

6.2.4 Economic performance with varying carbon payments

The price of carbon will have a considerable impact on which kinds of land use are incentivised. We use the predicted price of traded carbon as calculated by the Department for Business, Energy and Industrial Strategy (BEIS) to reflect possible payments for carbon in 2021 (£20 per tonne CO_2e) and pricing in 2030 (£80 per tonne CO_2e). 2030 is the latest date for which BEIS provides a prediction of carbon pricing.

The model only provides carbon payments for carbon sequestered through tree planting and maintenance. This is not to say that other parts of the system, such as pasture do not sequester carbon, it is merely to reflect the current situation in the UK where payments are limited to woodland. We have however, expanded payments beyond their current scope, as defined in the WCC, to cover less densely planted areas of tree cover. In a sense, we present a hypothetical situation where payment is provided on a per tree basis. This is to give an approximation of how carbon payments impact all types of AFW. In its current iteration, WCC carbon units, and therefore payments, would only be a possibility for the farm woodland scenario.

Table 14: Net income compared to the baseline for UK agriculture with carbon payments

	£0 per tonne CO2		£20 per tonne CO2		£80 per tonne CO2	
Scenario	Change in net Income compared to baseline	% Change in net income	Change in net Income compared to baseline	% Change in net income	Change in net Income compared to baseline	% Change in net income
Silvoarable and silvopastoral orchards	-£95.7M	-3.3%	-£78.4M	-2.7%	-£26.6M	-0.9%
Silvoarable and silvopastoral timber production	-£85.1M	-2.9%	-£54.2M	-1.9%	£38.4M	1.3%
Silvopastoral	-£78.8M	-2.7%	-£68.3M	-2.4%	-£36.9M	-1.3%
Shelter belts	-£2.9M	-0.1%	£13.5M	0.5%	£62.7M	2.2%
Farm woodland conifer	-£479.4M	-16.5%	-£93.5M	-3.2%	£1,064.1M	36.6%
Farm woodland broadleaf	-£685.7M	-23.6%	-£469.9M	-16.2%	£177.5M	6.1%
Farm woodland mixed	-£716.2M	-24.6%	-£506.1M	-17.4%	£124.3M	4.3%

6.2.4.1 Best performing scenario

With payments at £20 per tonne CO_2e, shelterbelts provide the greatest increase to net income. This carbon payment alone is enough to ensure shelterbelts have a positive impact on net income of UK agriculture.

When carbon pricing is increased to £80 per tonne CO_2e coniferous farm woodland becomes the most profitable scenario. Coniferous farm woodland becomes the most profitable option for all farm types except for horticulture, dairy and poultry. All scenarios lead to an increase in net income for UK agriculture. Coniferous farm woodland is the optimal scenario for cereal, LFA grazing and lowland grazing farms. The silvopastoral scenario leads to the greatest increase in net income for dairy and poultry farms and shelter belts are the best option for horticultural systems.

Unsurprisingly given that carbon payments are only provided for tree planting, it is the AFW scenarios with more dense tree planting that receive the greatest benefits from the increase payments.

6.2.4.2 Other scenarios

At the current carbon payment rate of £20 per tonne CO_2 the farm woodland systems continue to be the worst performing with all clearly being a non-economically viable alternative to agricultural production. This is not true, however, for LFA grazing, where even the current pricing makes coniferous farm woodland planting a potentially more profitable alternative to farming.

When the carbon payment is increased to £80 per tonne CO_2 the silvopastoral scenario becomes the worst performing, culminating in a loss of net income across UK agriculture. The less densely planted AFW scenarios tended to benefit less from the increased carbon payments. Compared to the performance benefit provided to agriculture by these scenarios, carbon payments had little impact on the net income.

6.2.4.3 What it means for UK agroforestry and farm woodland

Carbon payments offer considerable opportunity for increasing AFW planting and could potentially lead to significant changes in land use. This could have beneficial and deleterious consequences.

Rising carbon payments for carbon sequestration through tree planting is likely to incentivise the conversion of certain agricultural land to coniferous woodland, and, to a lesser extent, other forms of woodland and shelterbelts. This will lead to an increase in domestic carbon sequestration, provided any timber harvested is not burned and any clear-felled trees are replanted. It is also one of the most well validated and quantifiable forms of carbon sequestration and, hence, will help the government and organisations evidence net zero trajectories.

Carbon payments will also provide some support for other forms of AFW, especially when stacked with the performance benefits AFW can provide to agricultural production and other support mechanisms. Carbon payments alone, however, are likely to provide less support for agroforestry than for woodland, and particularly coniferous, planting.

A repercussion of this support for coniferous planting is that agricultural production in the UK could shift. It could lead to reduced agricultural productivity and changes to rural economies in certain, and particularly upland, areas. Furthermore, this increase in woodland profitability may distort land prices and demand in these areas making certain farms less profitable and restricting access to agriculture for new entrants. The incentivisation and increase of coniferous planting would also impact habitat available to local biodiversity.

At the landscape level, high carbon payments could affect rural economies. Increasing land price and pressure from carbon offsetting could exacerbate this. Coniferous woodland could become an increasingly attractive land use in certain areas. This could culminate in regions disproportionately providing certain ecosystem services. Less productive areas could provide improved flood, climate, and air quality regulation, whilst more productive areas could be limited to provisioning services. This could increasingly expose certain areas to climate, flood, pest, and disease risks.

In many ways, narrowly focused carbon payments, such as those modelled, could lead to a more precarious form of land management, whilst not necessarily reducing carbon emissions as these may simply be passed over to other nations as more food needs to be imported.

Finally, these carbon payments fail to acknowledge the potentially large carbon sequestration potential of extensive silvopastoral systems. Research has begun to show that parkland grazing systems, like those modelled in the silvopastoral scenario, can generate high carbon sequestration whilst maintaining agricultural productivity. There is clearly a need to validate the potential of these systems for carbon sequestration and develop ways to compensate farmers for it. Doing so could be a more efficient, more integrated, and more resilient way of reducing net carbon emissions.

7 Opportunities, challenges and recommendations for agroforestry and farm woodland in the UK

This final section draws together the breadth of work undertaken and summarised in this report. In Section 7.1 we summarise the opportunities for UK AFW. This is presented in Table 15, which is broken into three different sections; opportunities related to the physical implementation of AFW, those related to AFW economics and markets, and finally opportunities for improving AFW policy and support. For each topic, we cover the opportunities that exist in the UK that, if acted upon could enhance the viability and uptake of AFW.

Section 7.2 goes on to highlight the remaining challenges that need to be tackled to enhance AFW viability and uptake across the UK. The challenges are presented in Table 16, which is again divided into sections corresponding to the section in the opportunities table (Table 15).

The final sections (Section 7.3 to 7.5) propose recommendations for consideration in response to the barriers and opportunities outlined. The aim of these recommendations is to enhance AFW uptake across the UK.

7.1 Opportunities for UK agroforestry and farm woodland

Table 15: Summary of the key opportunities for UK AFW

Opportunities for the implementation of agroforestry and farm woodland across the UK	
Climate & environmental opportunities	Increasing awareness of climate risks including flooding, droughts, and extreme weather. AFW can enhance the resilience of the land-based sector to these risks. Awareness of this will help to encourage uptake.
	UK tree planting targets and grant support will increase interest in tree planting. As awareness of the private and public benefits of AFW grows, there is likely to be more interest in integrated AFW systems. To encourage adoption, these systems and practices will need to be incentivised. Carbon payments and AFW focused grant support can play a role.
	AFW systems provide an attractive way to meet national carbon reduction targets whilst limiting the trade-offs with other ESs. Silvopasture, parkland and wood pasture can sequester comparable, or greater, amounts of soil carbon than woodland systems (Beckert et al, 2016). Whilst carbon storage in above ground biomass is lower for silvopastoral than for woodland

	systems, maintaining livestock production can reduce the risk of carbon leakage through increased intensity and land use conversion elsewhere.
	Growing national interest in ecological restoration is likely to increase the number of land managers exploring sparse tree AFW systems that emulate more naturalistic grazing environments.
Supply chain opportunities	Awareness of the animal welfare benefits of AFW systems is likely to increase pressure for land managers to uptake AFW. Pressure will come from customers and procurers. Support from multinationals aiming to improve animal welfare, such as Sainsburys, is evidence of this trend.
	Pressure is increasing for the livestock sector to reduce its environmental impact upon, for example, water courses, climate change and biodiversity. Procurers are pressuring farmers to adhere to specific environmental standards. Shelterbelts, sparse tree planting and watercourse buffering are all AFW methods that will meet these aims.
	80% of UK forest products consumed are imported. Domestic production of these goods needs to increase. On-farm timber production, if made economically viable, has the potential to reduce reliance on imports, and supply to the rapidly growing market for local ethically sourced products.
Performance opportunities	The shade and shelter from AFW systems can also enhance livestock and arable performance. Our modelling shows that this can increase dairy incomes by as much £494 per hectare. Communicating and validating this benefit across UK farm types is essential for enhancing uptake.
	AFW shade and shelter benefit could enhance livestock production resilience and reduce feed input costs for livestock using energy to stay warm. As climate change impacts rise this will become increasingly important.
	New technologies such as automated harvesting and GPS livestock collars may make certain AFW systems more viable. Our modelling work shows that certain costs, such as fencing silvopastoral orchards, account for a large proportion of the total cost. Technological developments that help to reduce these costs will improve AFW viability.
	Climate change may make the UK a more suitable climate for nut and quality fruit production, helping to enable domestic production.
Opportunities for agroforestry and farm woodland economics and markets	
Improved economics from orchard systems	Increased land use efficiency from systems such as grazed orchards can provide farmers with additional income without reducing productivity of the main agricultural activity.

	Specialised sheep breeding (e.g. Shropshire and similar breeds) for AFW may provide additional revenues to certain farmers and promote AFW.
Natural capital and Payment for Ecosystem Service (PES) schemes	Increasing interest in ecosystem service markets could incentivise the establishment of schemes funding a wider range of AFW systems. This would make a range of AFW systems economically viable.
	BNG, private payments for flood risk reduction, payments from water companies to enhance water quality regulation, and a range of other PES schemes will provide increasing sources of funding for AFW development.
	The model shows that if current carbon pricing payments were provided to all AFW systems it would be enough to ensure shelterbelts have a positive impact on UK agricultural net income. Hence, even small carbon payments could encourage farmer uptake of certain AFW practices.
	The UK government is looking to encourage private PES by establishing a blended finance approach that incorporates private and public finance. This could provide considerable support for AFW and good returns on investment for companies investing in AFW optimised for the provision of ecosystem services beneficial to their enterprise performance. This has been evidenced by the approach taken by water companies like South West Water (see **Case Study 7**).
Need for domestic, sustainable forest products	Timber markets and prices have steadily increased over the past 10 years and domestic production is increasing at a faster rate than imported timber. In the model, we assume a low price for timber produced from AFW systems (£12.50 per tonne of poplar). If AFW is trialled and developed to produce higher value timber, this could increase AFW timber production viability. This needs to be balanced against the increased management costs.
	Subsidies for small biomass boilers may provide farmers with additional incentives to produce more woody biomass through AFW systems.
	Environmental and ethically labelled products and local supply chains offer premium markets for AFW products. Multinationals can enhance awareness of these products whilst simultaneously enhancing supply chain resilience.
	Increasing domestic production of AFW fruit and nuts could lower the carbon footprint associated with the transport of these goods.

	Many of the countries the UK imports fruit from are under increasing threat from climate change, producing these products locally could help enhance the security of UK fruit supply.
Opportunities for improving agroforestry and farm woodland policy and support	
Carbon targets	Mounting pressure for all UK industries to reach net zero and to meet more diverse ESG targets is likely to generate more support for AFW.
	UK tree planting targets continue to increase government support for woodland creation, at least in the short term, this should benefit AFW.
	Rising carbon prices and efforts to develop payments for soil carbon storage and possibly in-field agroforestry carbon storage should support AFW planting. Environmental benefits from parkland grazing systems may be greater than converting pasture to woodland at a farm scale. AFW approaches can retain agricultural productivity whilst enhancing ecosystem service provision.
Changing agri-environment support	The UK devolved authorities are increasingly interested in encouraging the adoption of AFW systems for the multiple benefits they provide.
	Attractive financial support is now available in countries such as England, for planting small woodland areas. EWCO provides high payments for woodland creation, though it is still too early to predict what impact this will have on increased farm woodland planting across the country.
	The Environmental Farming Scheme in Northern Ireland currently provides the most complete support for AFW expansion- in the UK. The overhaul of current land management policy across the UK post-Brexit provides opportunities for rethinking support for AFW, both in terms of focus and the type/level of funding. For example, in England, ELM aims to provide payments to land managers for the provision of public goods, whilst Scotland, Wales, and Northern Ireland are developing similar schemes. There is already a proposal for an agroforestry standard to be developed within the SFI part of the ELM scheme.
	The model shows that if government support schemes provide land managers with all or most of the capital expenditure to develop AFW systems, AFW scenarios that confer performance benefits to agriculture become attractive options. Shelterbelts become profitable for all farm types if capital expenditure costs are provided, and orchard systems and other silvopasture systems become profitable land use changes on LFA and lowland grazing farms.

	Public funding of AFW could cost effectively support provision of public goods. The UK governments could benefit from increasing their understanding of the costs and benefits of AFW systems. For example, according to the model, an additional £5 million towards shelterbelt establishment and £90 million towards silvoarable/silvopastoral orchards would be enough to incentivise planting across UK agricultural land, whilst also enhancing agricultural productivity. This is small compared to the funding required to double the area of broadleaf farm woodland. Landscape scale change and public goods may be cost effectively delivered by providing financial support to AFW systems.
	Increased focus on landscape level ecological regeneration, supported by public and private payments, will incentivise AFW. Hedgerow networks, shelterbelts and low input, high biodiversity habitats such as scrubby pasture, parkland and woodland can all support landscape regeneration.

7.2 Challenges for UK agroforestry and farm woodland

Table 16: Summary of the key challenges for UK AFW

Challenges for the implementation of agroforestry and farm woodland across the UK	
Poor data availability	Failure to define and assess UK AFW systems makes making the case to support and promote AFW uptake difficult.
	Evidence of the impact and performance of UK AFW systems is limited. Well validated, communicated, and quantified assessments of these systems is needed to incentivise uptake.
Unfamiliarity with AFW across the land-based sector	Managing and avoiding trade-offs in AFW systems is often complex and poorly understood. The trade-off between livestock shelter and shade reducing pasture growth is just one example.
	Silvoarable implementation in the UK is low. Land managers are unfamiliar with the challenges and benefits of these systems. They also lack the confidence and tools to manage these mixed systems.
	Timber producing AFW systems such as those developed by Bryant and May for poplar growing failed due to unpredicted changes in the market for poplar timber. Awareness of this will have left some farmers cautious about investing in similar arrangements.
	Land managers usually either specialise in forestry or farming; few are knowledgeable in both. The cross-sectoral knowledge required for effective implementation of AFW is lacking.
	Farmers are likely to be hesitant to invest in the long-term planning and rotations required for AFW. There is also the issue of the permanence of committing to such a land use option.
	Under current felling regulations, planting trees constitutes, in effect, an irreversible land use change. Permission is generally required to fell trees, and replanting is usually required. Many remain uncertain whether felling licenses apply to agroforestry systems. If they do this will disincentivise many farmers.
Systemic challenges	Brexit and COVID-19 have threatened the flow of seasonal labour into the UK. This is a risk for AFW; especially for orchard fruit harvesting.
	Negligible UK nut production and an absence of any nut processing facilities make it an unattractive enterprise for most land managers.

	Managing AFW to maximise profitability, particularly if products such as higher value timber, fruit, and nuts are to be produced, requires specialised machinery often inaccessible to farmers
	Agricultural advisory infrastructure is based on agronomy and yield enhancement, rather than on cross disciplinary knowledge and resilience enhancement. This limits awareness of AFW as a viable agricultural land use option.
	AFW generally struggles to access the economies of scale that make more conventional woodland enterprises viable. System level innovations and collaborations will be necessary to increase the viability of small scale dispersed AFW.
Challenges for agroforestry and farm woodland economics and markets	
Market challenges	Difficulty predicting timber value over the 25 years or more needed before harvest leads many farmers to avoid timber production. Current prognosis and trends would suggest improving markets, though.
	Land managers producing comparatively small volumes of timber tend to struggle to produce good quality timber, identify the most appropriate markets and optimise the returns from the sale of their timber. Reasons for this include relatively high harvesting and management costs, lack of knowledge, and limited experience of the timber market. This culminates in profitability being a challenge for AFW timber production.
	The current saturated dessert and cider apple market and difficulty producing good quality fruit from AFW orchards can restrict profitability.
Costs	Management costs are comparatively higher for smaller scale and low-density systems, making AFW systems harder to run competitively.
	High UK labour may make fruit and nut production uncompetitive with imported alternatives. This is evidenced in the model as labour and transport costs make up nearly half the costs for AFW orchards.
	Low returns on bioenergy production and the high volumes required to access commercial markets mean it is unlikely to be a profitable market for AFW. This is true for biomass harvested from hedges and from SRC.
Lack of current support for AFW	Timber production systems require lengthy time periods to generate a return on investment. These time periods are unfamiliar and unattractive to farmers. This is not considered within the model as establishment costs and final sales are distributed evenly across the entire rotation period. If establishment costs were presented up front

	and discount rates on final sales were applied, timber production systems would look less attractive.
	Few PES schemes for AFW systems currently exist. WCC does not currently fund small scale or low density AFW projects. Carbon payments are only available for woodland planting.
Challenges for improving agroforestry and farm woodland policy	
Current policy is often poorly suited to AFW support	Agroforestry policy and support is inconsistent and incoherent. Most UK countries fail to recognise explicitly the benefits of agroforestry and neglect to support woodland creation that integrates with agriculture.
	Agroforestry policy and support is hard to interpret and poorly understood by land managers and advisers. Many farmers still believe it will negatively impact their eligibility for other support (e.g. BPS).
	Agroforestry systems are not defined, recorded, or quantified in annual surveys of UK agriculture. This implicitly reduces the perception of these systems as viable and widespread land management options.
	It is unclear which policy makers or departments are responsible for development of AFW policies. There is a need to identify a department that can define, measure, and develop appropriate support for UK AFW, as well as to ensure that land managers can deal with single rather than multiple agencies to develop a range of AFW systems on their land.
Future policy	Uncertainty around future policy and markets after leaving the CAP will make farmers hesitant to invest in long-term land use changes like AFW.
	In specific areas, rising carbon payments risk driving up land prices and incentivising more intensive forms of woodland planting based on whole farm tenure change. This would make agroforestry a less attractive land use option as it would devalue the diverse ecosystem services provided by these more integrated tree planting options. Integrating increased carbon payment rates into the model caused net incomes from coniferous woodland planting to be more than five times the next most profitable scenario. This kind of increase to incomes from coniferous planting would distort the land-based economy.

7.3 Recommendations for improving agroforestry and farm woodland implementation

AFW offers a viable and cost-effective way to enhance tree planting across the UK without reducing agricultural production and, therefore, offshoring the impacts of the UK food system. The integrated tree planting associated with AFW offers possibilities to enhance the provision of a wide range of ESs. Furthermore, AFW has the potential to enhance the performance and resilience of UK food production. Awareness of these benefits across the farming, public and private sectors is increasing, however, implementation remains slow.

There are several systemic barriers to the practical implementation of AFW. The land-based sector is poorly equipped to manage this multifunctional land use. AFW practitioners are often unable to access economies of scale. Local supply chains and markets are often poorly suited to AFW products such as timber and nuts. Knowledge and education in the land-based sector remains siloed, restricting the capability of land managers to maximise the profitability of AFW systems. A sparsity of advisors knowledgeable of AFW adds to this issue.

If implementation of UK AFW is going to increase, the opportunities provided by AFW need to be more fully evidenced for UK conditions and the issues tackled. Below we provide recommendations for supporting increased AFW implementation.

Systems developments

- Farm advisory bodies and the UK government need to clearly define the management features of typical, and viable AFW systems to make implementation and uptake more attainable.
- Approaches taken by businesses to support agroforestry across their supply chains – along with other regenerative and agroecological practices - need to be better communicated and incentivised.
- The associated welfare and environmental benefits of agroforestry need to be clearly communicated to consumers.
- Different forms of fruit and nut production should be explored in the UK to better understand the viability of these industries, especially as the climate changes. If viable, policy support should be provided to develop local processing and supply chains as well as land management changes.

Knowledge

- Research, validate and communicate the performance and environmental impacts of AFW in various contexts upon various enterprises across the UK. Research needs to be undertaken transparently with farmers.
- Validate the potential carbon storage benefit of various AFW systems along with the cost per tonne of carbon sequestered through AFW compared to more conventional approaches.

- Education, courses, CPD and ongoing professional training need to be established within and outside of agricultural universities that teach farmers and foresters about agroforestry to bridge the gap between the two sectors.

Innovation

- The benefits and potential of technology to support AFW needs to be further explored. Innovation needs to be supported through public grants and cross-sectoral communication. In certain cases, specific technology needs to be developed or made available to potential agroforestry practitioners to enable labour intensive tasks where a workforce is becoming increasingly hard to source. Technologies such as collarless farming, smart agriculture, automated farming, biological inoculants, and smart agriculture all offer potential benefits to AFW (Cumulus, 2021).
- Systemic innovations to enable small scale dispersed AFW systems to access advice, contract work, equipment, and supply chains could help farmers access higher prices for AFW products. Cooperative models, service schemes, technology sharing and rental could all help reduce this scale issue.

7.4 Recommendations for improving the agroforestry and farm woodland economy and market

Strategically increasing UK AFW has the potential to enhance the performance and profitability of the agricultural economy by restructuring the economic landscape to one more supportive of a range of agricultural activities. Moreover, AFW can generate new markets for AFW products with positive environmental impacts. There is growing demand for locally produced products across all sectors. Marketing AFW products as ethical and environmental may help to improve the profitability of these systems. In addition, growing interest in PES schemes provides a potential avenue for increased AFW support.

Despite this potential, numerous economic and market barriers exist for AFW. Variable markets for AFW products such as timber, fruit and nuts make it hard to generate profit from the sale of these products. Long returns on investment to offset relatively high establishment, maintenance and labour costs in the UK exacerbate these issues. Additionally, current PES schemes, such as the WCC, fail to effectively support AFW, devaluing the public goods they provide within the UK economy.

Listed below are our recommendations on how to begin to respond to the economic and market opportunities and challenges that the UK AFW sector faces.

PES support

- Integrating AFW systems into agriculture whilst maintaining or enhancing productivity need to be incentivised through increased alignment with public and private PES schemes and campaigns to raise awareness.

- Blended finance for ecosystem services needs to be developed to fund a full spectrum of public goods. This will provide the best support for integrated land use options such as AFW.
- PES schemes, including the WCC, needs to fund sparser and smaller areas of woodland planting. Collaborative group certification approaches should be facilitated as an option for land managers wishing to lower the time and cost of registration.

Marketing and supply chains

- AFW options that maintain and enhance productivity need to be further promoted and incentivised by companies across supply chains and sectors who wish to enhance the resilience of their enterprises.
- Actors across supply chains need to develop and enhance premium markets for AFW products, environmental and ethically labelled products could help establish these markets.
- Supply chains, local markets, skills, and technologies need to be developed and supported to help establish local and resilient supply chains for goods such as fruit, nuts, and timber.

Innovation

- Innovative co-operative schemes and services will need to be explored and developed to enable AFW practitioners to access high value timber markets.
- AFW specific technologies need to be developed to help reduce management and labour costs.
- Collaboration, support, and agreements may need to be put in place to reassure AFW practitioners that markets will be available for any timber they produce.

7.5 Recommendations for improving agroforestry and farm woodland policy

It is clear from an assessment of policies across the UK that each country takes a different approach to agroforestry. Countries differ in the degree of support that they provide, how explicit that support is, and how they define different AFW practices. The source of support also varies, with some countries deeming AFW suitable for agri-environment support and others positioning it as woodland creation.

There will obviously be variation in the types of AFW that will be optimal across the nations and contextually specific support will be needed. However, the current level of inconsistency within and between the support schemes is unhelpful in several ways.

Firstly, it prevents land managers from understanding a clear and defined strategy for AFW enhancement. Secondly, it limits the scope for buyers, journalists, governments, NGOs, and the public to understand AFW and its benefits. Thirdly, it restricts communication, collaboration and understanding between farmers across the UK.

One risk associated with AFW funding is the potential overlap in funding options. Support could be provided for on farm tree planting by an agri-environment scheme or a woodland creation scheme. However, we argue that this overlap is necessary to incentivise integrated system development from both the forestry and the agricultural sector. How to fund these overlapping projects is beyond the scope of this report but will be necessary to tackle the current polarisation of forestry and agriculture and stimulate a more integrated approach.

In the recommendations below, we argue for an alignment of the various support schemes and propose key criteria for how these aligned AFW policy support schemes should be structured.

Clarifying AFW policy support

- Policy support schemes across the agricultural and forestry sectors must offer explicit support for agroforestry.
- Schemes should include consistent and defined examples of the various types of agroforestry, such as alley cropping.
- Support schemes should provide land managers with guidelines on how to structure AFW systems such as strip width, crop rotations, and species selection.
- All websites for the policy schemes must provide search results for interested actors searching for agroforestry support.

Enhancing financial support for AFW

- AFW support could be based on income forgone payments or on the value of the public goods provided by these systems. Blended private funding sources will provide an effective way to compensate land managers for these public goods.
- Support should focus on rewarding the public benefits provided by the maintenance of already established AFW systems. However, this should not be at the detriment of funding for the creation of new AFW systems.
- The EFS in Northern Ireland should be used as a good example of a clearly targeted AFW agri-environment support scheme.
- Group funding schemes such as those offered through EFS Group should be accessible to all UK farmers. This would benefit landscape level regeneration, large scale ecosystem service provision, and enabling farmers to access economies of scale for the sale of AFW products.

Restructuring AFW support options

- Certain agricultural activities such as extensive grazing should be allowed within planted AFW systems once it is deemed adequately resilient. Complete restriction limits the attractiveness of woodland planting to farmers and perpetuates the polarisation of agriculture and forestry.

- Funding should be provided for alley crop style orientation of woodland creation (narrow strips of trees within field, providing the total area exceeds a minimum requirement).
- Integration of agroforestry and support for this land management change needs to be based on a whole farm planning approach.

Appendices

Appendix 1 – Modelling methodology

Evidence base

The data and evidence for the model is collated from the various June Agricultural Surveys and Farm Business Surveys that are undertaken across England, Scotland, Wales, and Northern Ireland. These provide the most accurate and up to date summaries of farms and farm business incomes across the UK. Links and references to the specific documents used are provided in the model.

Peer reviewed literature was used to model the performance impact of AFW upon agriculture. Where possible, data was extracted from studies that took place within the UK and focused on a specific farm type. Where this was not possible, studies from areas with similar climatic conditions were used and the performance impacts were applied to the UK context. This approach has its limitations and points to a need for robust research in the UK to validate the impact of AFW upon agricultural performance across the different regions and farm types.

Land use change modelled

Land use change in the model relates to a change in area of any type of AFW rather than a change in canopy cover or number of trees. This is so that we can make direct comparisons between the land use changes. This does mean, however, that the tree planting for each scenario will differ. Coniferous farm woodland comprises the highest density tree planting, whilst silvopastoral planting has a far lower density.

It was deemed more important to model comparative land use changes and the integrated benefits that are generated from these changes than to compare change in canopy cover. This report aims to encourage a more integrated view of trees within agriculture, and the benefits they provide. It was reasoned that basing the analysis on tree planting alone would contradict this stance. Dense tree planting would be shown as a more effective way to meet this narrow aim, whilst neglecting the wider benefits of more integrated AFW systems. That said, it is possible to use the model to project specific tree planting targets, if desired. This was beyond the scope of the study but could generate interesting insights in the future.

In practice, this means that in the model one hectare of farm woodland is considered equivalent to one hectare of silvoarable and silvopastoral orchards, despite them have different tree stocking rates.

Financial data

Economic modelling was undertaken as a series of partial budgets. This is an efficient and effective way to predict the impact of a change in management upon the key variables of each farm type. Approaching the modelling in this way allowed for the main attributes to be modelled without having to collate data on all aspects of the systems.

Fixed costs were excluded from the partial budgets and model. This is because these costs remain largely unchanged for each scenario and farm type. Exclusion of the fixed costs may, however, have neglected some nuanced changes that would occur. For example, additional or different machinery may be required to manage livestock within orchards, or material costs may decrease on a farm as woodland may provide materials for fencing. However, these changes to fixed cost would be highly contextual and difficult to extrapolate or generalise across a farm type.

Financial data on the capital expenditure required to establish the AFW systems was included in the partial budgets. It was divided over the modelled 25-year period. Including this cost allows us to predict the investment necessary to transition to increased AFW planting across the farm types. This decision favours AFW systems with shorter rotations, such as timber and coniferous scenarios. This is because the capital expenditure for longer lasting systems will recur less frequently than for shorter rotation systems. Establishment costs would recur for these systems after, for example, felling for timber. For broadleaf systems, however, the establishment costs may not recur for centuries. Inclusion of establishment costs over a 25-year period, therefore, disproportionately favours short rotation systems. The inclusion of the capital expenditure, however, was deemed appropriate as it was assumed that farmers are unlikely to plan much beyond the modelled 25-year period.

We did not model the scenarios with the exclusion of the capital expenditure as, in reality, it was deemed to be an unlikely eventuality. Instead, we modelled how an income foregone payment might provide support for AFW planting and how this could be developed. This offsets the capital expenditure as well as income foregone with the land use change.

Basic Payment Scheme and agri-environment scheme payments have been excluded from the baseline scenario. This is to provide a clearer picture of the impact potential future support would have upon AFW.

Scenarios

Each of the scenarios that have been modelled have been defined based on the reviewed literature, case studies and discussions which have been presented earlier in this report. They are well validated but generalised depictions of how the various forms of AFW would be integrated into UK farm types.

Generalisation was necessary to quantify and compare the different scenarios. Integrating too much contextual specificity and variation across the different farm types was unfeasible given the macro-economic comparison targeted for this work.

This generalisation means that the scenarios do not represent the heterogeneity in structure, costs, and performance that exist across UK AFW. To get an accurate understanding of the impacts and costs on a specific farm, modelling needs to consider numerous factors that are specific to that site including soil condition, wind speed, weather patterns, and land use requirements. The aim of this model was not to provide this kind of context specific detail. Instead, it aims to define and analyse the average economic impact of typical AFW types upon the average farm types across the UK.

Below are summaries of the different AFW scenarios and identification of some of the assumption and limitations.

Silvoarable and silvopastoral orchards

The silvoarable and silvopastoral orchards scenario (tab 1 – SA SP Orchards in the model) is defined as the growing of strips of apple trees within agricultural fields. It is assumed that these strips are spaced 23m apart to allow for standard agricultural machinery to pass. These widths are modelled for both arable and livestock systems, theoretically allowing conversion to the alternative land use. 2.5m spacings are left between trees in the strips giving an average density of 160 trees per hectare. The tree strips have a width of 2m and run the whole length of the field, therefore taking up 8% of the area. This change in land use is modelled across equal percentages of each of the main UK farm types to effectively double the area of UK AFW.

It is assumed that only apples are grown in these systems as these are the only orchard produce that are currently grown in AFW orchards. However, similar systems could be developed for pears with comparable performance. Cider apples are the modelled fruit as it is generally believed that apples produced in AFW systems would be of lower quality due to less focused management and damage from machinery and grazing. A yield of 10 kg per tree or 1.6 tonnes per ha is modelled.

It is assumed that the orchard trees benefit livestock performance by providing them with shade. Evidence from two studies in New Zealand showed that shade can increase production in dairy herds by 3% (Kendall et al., 2006; Fisher et al., 2008). This performance impact is extrapolated across all livestock systems as there were no studies found that evidenced the impact of shade upon the other farm types. This is an area that warrants additional research, particularly given the considerable benefits possible for high value production systems such as poultry and dairy. To model this performance impact an 11% increase to gross margin was modelled for the good performance impact. This compensates for the 8% of the area lost to tree planting with the addition of an extra 3% performance benefit. A reduction to arable production from shade and headland of between 0% and 17.5% is also modelled for the relevant farm types (Sklenicka et al., 2005; Sunoj et al., 2020).

There is potential to establish AFW systems for nut production. This has the potential to influence the economic viability of AFW orchards systems, however, there is currently no data available about these systems, so it was unfeasible to model. Forward thinking farmers with access to local markets and supply chains, though, could likely maintain economically viable systems of AFW nut production. How much potential there is for nut production across the UK is uncertain. It is doubtful whether UK production would be price competitive with imported nuts.

Silvoarable and silvopastoral timber production

The silvoarable and silvopastoral timber production scenario (tab 2 – SA SP Timber Production in the model), as with the orchard systems, assumes that timber trees are grown in strips spaced 23m apart to allow machinery to operate between them, with 5m spacings left between trees in the strips giving an average density of 80 trees per hectare. The tree strips have a width of 2m and run the whole length of the field, therefore taking up 8% of the area. All systems were assumed to grow poplar harvested at 25 years. This is because it is a fast-growing variety that has been trialled in AFW systems. Hence, more data is available on the use of this variety. It is assumed that the felling, processing, and transporting of timber is managed under contract. An average poplar timber price of £12.50 per tonne is modelled (Nix, 2020). This change in land use was modelled across equal percentages of each of the main UK farm types to effectively double the area of UK AFW. The scenario was presumed to impact the farm types by providing increased shade and headland in the same way as for the orchard scenario.

There is a need to experiment with other timber tree varieties in AFW systems to better understand the impact these have upon arable and livestock systems. Coniferous varieties could potentially yield greater incomes for the farmer but may cause greater reductions to crop yields due to shade. High value broadleaf varieties, such as walnut and cherry, could also yield high incomes, but the slow growth rates are likely to be unattractive to farmers. Furthermore, farmers are unlikely to be highly experienced in managing trees for timber production and may be unable to grow trees suitable for high value timber production. It is these uncertainties that support the decision to model poplar production in this scenario.

Silvopastoral

The aim of the silvopastoral scenario (tab 3 – Silvopastoral in the model) was to model an increase in the planting of sparse tree cover across grazing land. This can be thought of as an expansion of newly planted parkland or more dynamic regenerating systems. This was defined as the planting of 16 broadleaf trees per hectare. It was assumed that these sparse trees would provide livestock with shade but would not reduce wind speed. The performance benefits were modelled accordingly. This change in land use was modelled across equal percentages of the main livestock UK farm types to effectively double the area of UK AFW. No land use change was modelled for the arable systems.

Shelterbelts

The shelterbelts scenario (tab 4 – Shelterbelts in the model) is based on a simplified selection of tree species and stocking densities for the purposes of the modelling. It was assumed that the species are a mixture of both conifers and broadleaved trees with a stocking density of 1,600 trees/ha and no open space. This is the equivalent of 2.5m by 2.5m spacing. It is assumed that the shelterbelts will be 10m wide, to qualify them for grant funding. The site preparation costs are the same as for farm woodlands (see Section 6.1.6.5).

Current hedgerow coverage across the UK was used as a proxy for how many shelterbelts could be established. It was assumed that wherever a hedge exists farmers could be willing to establish shelterbelts. It was assumed that in-field shelterbelt planting is less likely due to management complexity and unfamiliarity. There are approximately 200,000ha of hedgerows in the UK; assuming an average width of 3m gives 167,000km of hedgerows in the UK. We assumed that half of these hedges could have shelterbelts established along them. This would provide fields with shelter along two edges which could be strategically selected to maximise wind speed reduction. These shelterbelts were assumed to be 10m wide and would, hence, cover approximately 4% of UK agricultural area. The impact of a single shelterbelt established on a hectare of agricultural land was modelled and this was then projected across 4% of all UK agricultural land.

It was assumed that wind reduction benefit would be provided by the shelter belts to crops and livestock. At the average UK wind speed of 4.2 m/s, it was assumed that shelter belts could provide a 15% increase to livestock productivity (He et al., 2017). A metanalysis of the impacts of shelterbelts upon crop production was used to estimate the impact, benefits to crop yield in related climatic regions ranged from 10% to 25% (Nuberg, 1998). It was assumed that livestock were excluded from the shelterbelts and therefore did not receive substantial shade benefits from the land use change. However, a reduction in crop yield from shade and headlands was modelled.

It has been assumed that there will be no viable timber production from the shelterbelts and so no estimate of timber income has been provided for this scenario. This may be a conservative estimate, but there is uncertainty around the economic viability of harvesting from shelterbelts. It is likely that innovative harvesting schemes and supply chains would be necessary to make harvesting economically viable, hence we excluded it from the modelling.

The change in agricultural land use to shelterbelts was modelled across equal percentages of each of the main UK farm types.

Farm woodland

Three different variations of the farm woodland scenario (tab 5 – FW in the model) are modelled to represent the varying reasons that UK land managers might undertake farm woodland planting. These are coniferous planting (Farm woodland conifer), broadleaf planting (Farm woodland broadleaf), and mixed coniferous and broadleaf planting (Farm woodland mixed).

The conversion of agricultural land to coniferous woodland was modelled to portray a more intensively managed farm woodland, focusing on timber production. For the purposes of the modelling undertaken, for conifer woodland, the stocking density is based on 2,500 trees/ha, but with 10% open space, which equates to an overall stocking density of 2,250 trees/ha. Harvesting would be managed under contract and take place after 40 years. It is assumed that spruce is the species being planted. Average revenues from thinnings and harvesting were annualised. An average standing price of £30.03 per m^3 and an average yield class of $16m^3$ per year was modelled (Nix, 2020).

A land use change to broadleaf farm woodland was modelled to depict a management option more focused on public goods and habitat provisioning. For broadleaved woodland, the stocking density is based on 1,100 trees/ha, but with 10% open space, which equates to an overall stocking density of 1,000 trees/ha. It has been assumed that timber production would only come from thinning and the woodland would never be clear felled. 45% of timber revenue is estimated to come from thinnings leading to annual yields of $2.7m^3$. Oak is assumed to be the species planted in this scenario. It was assumed that all timber harvested from thinnings would be sold as firewood at a price of £20 per tonne (Nix, 2020).

The costs to supply and plant this size of tree will vary, but for the purposes of the modelling undertaken a cost of £1.60/tree has been used. This estimated cost is based on the Forestry Commission standard costs used for the EWCO grants. The costs to supply and fix a tree shelter vary, but for the purposes of the modelling undertaken a cost of £2.00/tree has been used. This estimated cost is based on the Forestry Commission standard costs used for the EWCO grants.

The above cost estimates would be for creating woods up to 3 ha. For larger areas, fencing is likely be a more cost-effective option, as well as other economies of scale, and so establishment costs, may be reduced by as much as 30%.

The site preparation required, and, in turn, the cost of the woodland creation will depend on a range of factors, in particular the site characteristics and the objectives of the new planting. For the purposes of the modelling undertaken, it is assumed that some weed control and soil cultivations are likely to be required prior to planting the trees. An estimate of £80 per ha has been assumed, based on published costs in ABC (2020). An additional cost of £170 has been assumed for fertiliser application during site preparation ABC (2020). It is however recognised that site preparation costs, might also include works such as subsoiling, drainage works, and scrub clearance resulting in a significantly higher cost.

Maintenance of newly established trees is key to their survival and ultimate success. Newly established trees require regular inspection and maintenance, including beating up and weed control. Beating up is the procedure carried out to replace any losses of newly planted trees that might occur during the first couple of years. This cost will depend on the failure rate and whether the trees have been protected by shelters or fencing. For the purposes of the modelling undertaken, the replacement of dead trees is assumed to be 20% of the establishment cost.

Weed control by herbicides is generally required for the first 2 to 4 years. Weed control can be done using mulch matts, mulching, manual labour, or herbicides. The costs of weed control by herbicide have been estimated at £100 using the estimates in the above-mentioned farm costing books.

The third and final land use change was for a mixed woodland approach that combines even plantings of coniferous and broadleaf varieties. For this scenario we assumed that the woodland is never clear felled, but harvesting is continually maintained through thinnings. The structure, incomes and costs of this scenario is extrapolated from the coniferous and broadleaf scenarios, with the slight difference that no income is modelled from clear felling of the conifers.

It is assumed that the farm woodland provided no performance benefits to the arable and livestock within each farm type. This is because the woodland conversion takes up the entire area and no grazing or growing occurs within the woodland. This will neglect benefits from novel AFW systems such as woodland grazing, however, these were assumed to be less common forms of AFW and the evidence of the impact is limited. This change in land use was modelled across equal percentages of each of the main UK farm types to effectively double the area of UK AFW.

Farm types

The model incorporates the main UK farm types, and associated areas and economic performance, as defined and recorded by the devolved administrations. Farms are categorised as a specific farm type if more than two thirds of the standard outputs align with the product associated with that farm type. Farms, therefore, do not exclusively produce the agricultural product by which they are defined. Cereal farms, for example, may also include livestock and horticultural production, this is true for all the farm types.

The economic data, therefore, is aggregated and averaged across the performance of all the different enterprises that exist within the farm type. It is this averaged economic data that provides the input for the partial budget. Land converted to AFW will reduce the productivity of the farm type by this averaged amount. The model is, therefore, based on the assumption that land use change to AFW occurs randomly, therefore, having an averaged impact upon economic performance. However, it is more likely that farmers would be more selective of where they plant trees, perhaps choosing less profitable land for certain AFW planting and more profitable land for AFW planting with performance enhancing potential. Our approach neglects this selectivity. However, decisions about where to plant are likely to be very personal and modelling them would impose our own subjective assumptions upon the calculations. Hence, average figures were deemed the best option, however, farmer selectivity should be considered when exploring any of the scenarios in more detail or impact on a smaller area.

AFW area across UK and across the different farm types

The baseline areas of AFW used in the model for each of the four countries are based on the June agricultural survey data. This will underestimate the actual amount of AFW present as it does not account for the more integrated and sparse areas of agroforestry that are discussed in this report. No accurate and consistent dataset of these types of land use currently exists across the UK. Hence, an attempt to approximate them for the different nations would be inaccurate. The farm woodland area is, therefore, the best proxy for AFW area but should be viewed with the understanding that actual AFW coverage will be higher. Future surveys should respond to this lack of accurate AFW land use data.

Despite this limitation, we do not consider this to drastically change or detract from the insights generated in the report. The economic impacts modelled are comparative and the conclusions are valid regardless of any underestimation of the baseline area of AFW.

Existing policy payments

An important output of the model was to increase understanding of the policy support provided to AFW across the different nations. The websites for each of the agri-environment support schemes and woodland creation schemes were reviewed to identify the options that could provide potential support to the AFW scenarios. A summary of this analysis has already been provided in Section 5 of this report. Details of these payment schemes are provided within the model in under tab '6 – Lists' Tables 6I to 6J. Throughout the modelling, we do not include Basic Payment Scheme (BPS) payments in the partial budget calculation, also we do not consider the impact of reducing BPS payments on overall farm profitability and viability.

AFW income foregone payments

Hypothetical income foregone payments were also incorporated into the model as an optional variable to be selected. This allowed insights to be generated about how future AFW payment support might be developed. These payments are based on a payment to compensate the land manager fully for any lost income, establishment costs and maintenance costs.

The decision was made not to factor in the impacts of agroforestry on crop and livestock physical performance into the income foregone payments. Performance impacts will change considerably with the context, this means factoring them into the income foregone payments could disadvantage and restrict AFW land use in certain contexts. Hence, we provide hypothetical income foregone payments based on the costs and benefits with a higher degree of certainty. This allows insights to be drawn about the potential for land managers to enhance their profitability by strategically establishing AFW systems with high performance benefits.

Carbon storage and biomass production

Simple carbon calculations are provided to approximate the carbon sequestration potential of each of the scenarios and, in turn, to generate predicted carbon payment rates. Average carbon sequestration figures for the different types of woodland were used. The evidence behind these sequestration rates is provided within the model. 10 tCO_2/ha was used as the figure for broadleaf woodland and 17.88 tCO_2/ha was used for coniferous woodland (Forestry Commission, 2012; Magnani et al., 2007; Clement, Moncrieff and Jarvis, 2003; Jarvis et al., 2009; Black et al., 2009; Fenn et al., 2010; Thomas et al., 2010). These figures are for a hectare of woodland. For the more sparsely planted systems the figure was simply divided by the proportion of the AFW scenario that is wooded.

Biomass production is estimated in a similar way. The calculation is based on the additional timber produced from each of the AFW scenarios on an annualised basis. Yield is estimated on a per tree or per hectare basis based on national survey data and applied across a hectare of the scenario. This is then estimated for the application of the scenario across proportions of UK farm types.

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Glossary

ABC – Agricultural Budgeting & Costing Book

AECS –Agri-Environment Climate Scheme (Scotland)

AFW – Agroforestry and Farm Woodland

Alley cropping - the planting of trees and agricultural crops in alternate rows. Tree rows should not exceed a width of two trees and canopy cover should be at least 5% of the area.

BAP – Biodiversity Action Plan

BEIS - Department for Business, Energy and Industrial Strategy (England)

BNG – Biodiversity Net gain

BPS - Basic Payment Scheme

CAP – Common Agricultural Policy

CCC – Climate Change Committee

CHP – Combined heat and power

CPD - Continuing Professional Development

CS – Countryside Stewardship

CSR – Corporate Social Responsibility

DAERA - Department of Agriculture, Environment and Rural Affairs (Northern Ireland)

DEFRA - Department for Environment, Food and Rural Affairs (England)

EFS – Environmental Farming Scheme (Northern Ireland)

ELM – Environmental Land Management (England)

ES – Ecosystem Service

ESG – Environmental Social Governance

EWCO – England Woodland Creation Offer

FAO – Food and Agriculture Organization

Farm woodland - land beneath stands of trees with a canopy cover of at least 20% or having the potential to achieve this.

FGS – Forestry Grant Scheme (Scotland)

GHG – Greenhouse Gas

Glastir – the Welsh Government's sustainable land management scheme

GPS - Global Positioning System

Grazed high value trees - areas grazed by livestock with a minimum of 5% canopy cover in which products harvested from the trees provide direct revenue to the land manager.

Grazed woodland - an area with tree canopy cover of at least 20% that is grazed in a strategic and managed way.

Grazing amongst sparse trees - grazed areas predominantly covered by communities of grassland, grass-like and herbaceous plants, shrubs, or small woody plants including sparsely occurring trees with a canopy cover between 5% and 20%.

GWC – Glastir Woodland Creation (Wales)

Hedgerows - rows of shrubs or trees enclosing or separating fields.

HLS – Higher Land Stewardship

IPCC - Intergovernmental Panel on Climate Change

LFA – Less Favoured Area

LNR – Local Nature Recovery (England)

LR – Landscape Recovery (England)

LUCAS - Land Use and Coverage Area frame Survey

NFI – National Forest Inventory

NGO – Non-governmental Organisation

NNFCC - National Non-Food Crops Centre

PC – Peatland Code

PES – Payments for Ecosystem Services

RDP – Rural Development Programme

RHI – Renewable Heat Incentive (UK)

SBP – Sustainable Biomass Programme

SFI – Sustainable Farming Incentive (England)

SFS – Sustainable Farming Scheme (Wales)

Shelterbelts - linear arrays of trees or shrubs planted to create a variety of benefits.

SLM – Sustainable Land Management (Wales)

SRC – Short rotation coppice

WCC – Woodland Carbon Code

WRME - Wood raw material equivalent

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