Cent. Eur. For. J. 68 (2022) 61–71 sciendo DOI: 10.2478/forj-2022-0001 CENTRAL EUROPEAN Forestry Journal

http://www.nlcsk.sk/fj/

ORIGINAL PAPER

Woodland planting on UK pasture land is not economically feasible, yet is more profitable than some traditional farming practices

Jessica Flack[1]*, Martin Lukac[2,3], Lindsay Todman[2]

[1] *University of Reading, Whiteknights, School of Archaeology, Geography and Environmental Science, PO Box 217, Reading, Berkshire, RG6 6AH, United Kingdom*
[2] *University of Reading, Whiteknights, School of Agriculture, Policy and Development, PO Box 217, Reading, Berkshire, RG6 6AH, United Kingdom*
[3] *Czech University of Life Sciences Prague, Faculty of Forestry and Wood Sciences, Kamýcká 129, CZ – 165 00 Praha - Suchdol, Czech Republic*

Abstract

Increasing ecosystem service provision is a key strategy of the UK's ongoing agricultural and environmental policy reforms. Enhancing forest cover by 4%, particularly on the least productive agricultural land, aims to maximise carbon sequestration and achieve net zero by 2050. Multiple factors affect the sequestration potential of afforestation schemes and landowner participation in them, highlighting the need for spatially explicit research. We used the InVEST Carbon Model to investigate the Loddon Catchment, southeast England as a study area. We assessed the carbon sequestration potential and economic feasibility of three broadleaved woodland planting scenarios; arable, pasture, and stakeholder-approved (SA) scenario. We found that over a 50-year time horizon, woodland planting on arable land has the greatest sequestration potential (4.02 tC ha^{-1} yr^{-1}), compared to planting on pasture land (3.75 tC ha^{-1} yr^{-1}). When monetising carbon sequestration at current market rates, woodland planting on agricultural land incurs a loss across all farm types. However, when including the value of unpaid labour, lowland pasture farms presently incur a greater loss (−€285.14 ha^{-1} yr^{-1}) than forestry (−€273.16 ha^{-1} yr^{-1}), making forestry a more economical land use. Subsidising up to the social value of carbon (€342.23 tC^{-1}) significantly reduces this loss and may make afforestation of pasture land more appealing to farmers. Woodland planting on lowland pasture land would increase forest cover by up to 3.62%. However, due to the influence of farmer attitudes on participation, it is more realistic for afforestation to occur on lowland pasture land in the SA scenario, equating to a 0.74% increase.

Key words: carbon sequestration; land use; afforestation; planting scenarios; ecosystem services; climate change mitigation

Editor: Bohdan Konôpka

1. Introduction

The Climate Change Act 2008 legally requires England to reach "net zero" greenhouse gas emissions by 2050. Agricultural land covers around 63% of England and produces approximately 10% of territorial emissions; significant management changes are required to meet the net zero target (MHCLG 2020; DBEIS 2021). Key agricultural and environmental strategies include the application of Environmental Land Management Schemes (ELMS); planting 11 million trees across 24 million hectares, including woodland planting on the least productive agricultural land; and the introduction of a "Forest Carbon Guarantee Scheme" to strengthen the domestic market for carbon storage and sequestration (CSS) services.

There is strong potential for CSS through woodland planting on agricultural land. Carbon storage is defined as the pool of carbon within an ecosystem, and carbon sequestration is the process where carbon dioxide is removed from the atmosphere by photosynthesis and stored in a terrestrial system (Evans 2013). For example, a 4% increase in UK forest cover could abate 24% of annual agricultural greenhouse gas emissions by 2050 (CCC 2020). However, the efficiency and scale of CSS, or the participation in afforestation schemes are variable and depend on multiple environmental and socioeconomic factors, highlighting the need for research that considers the idiosyncrasies and spatially explicit differences (Morison et al. 2012; Howley et al. 2015; Hyland

*Corresponding author. Jessica Flack, e-mail: jess.flack@hotmail.com

et al. 2016; Gregg et al. 2021).

There are notable differences in the CSS potential between broadleaved and coniferous woodlands. Broadleaved woodlands tend to have a higher carbon storage capacity than coniferous woodlands, due to the longer lifespan and a greater wood density of broadleaved species, therefore sequestering more long-term carbon per unit of land (Morison et al. 2012). In contrast, coniferous species tend to be faster growing and initially have a higher annual sequestration rate, approximately 20% higher than broadleaved species, thus sequestering more carbon in the short-term (EftEC 2015). There are significant regional variations in sequestration rates even within England; coniferous species sequester more carbon as the wetter climate and acidic soils provide a more suitable habitat for coniferous species in the north and west, whereas the drier climate in the south and east is more suited for broadleaved growth (Gregg et al. 2021).

Temperate forest soils hold approximately 63% of the total forest carbon stock in this biome (Vlek et al. 2017). Research on the relationship between CSS and soil type in forests is conflicting and limited, however, the consensus is that soil type does affect CSS potential. For instance, an assessment of British forest soils found that carbon storage was 13% higher in clayey gleysols compared to sandy cambisol soils (Vanguelova et al. 2013). In contrast, Grunelberg's (2014) study of climatically similar soils in Germany found carbon storage to be 45% higher in cambisols compared to gleysols. Furthermore, afforestation of high yield class agricultural land results in greater CSS potential than planting on low yield class land (Matthews et al. 2020; Gregg et al. 2021). To illustrate the difference, cumulative sequestration in a 200-year-old broadleaved woodland is on average 1350 CO_2e ha^{-1} in yield class 12 land compared to 624 CO_2e ha^{-1} in yield class 4 land (Gregg et al. 2021). However, the high value of prime agricultural land creates a trade-off between farm income and climate regulation services, often making woodland planting unfeasible (Nijnik et al. 2013).

There are mixed views towards afforestation within the farming community, with three distinct groups. The first see afforestation conflicting with their "productivist" values and cultural beliefs. This group, regardless of finances, is unlikely to participate in forest planting schemes (Watkins et al. 1996; Howley et al. 2015; Ryan et al. 2018). The second group, the "environmentalists", are often in the younger age categories, have high levels of environmental awareness, and are positive about agri-environmental schemes (Hamilton et al. 2015; Hyland et al. 2016). Finally, there are those that are motivated by practicalities, such as financial incentives, rather than cultural beliefs (Ryan et al. 2018; DEFRA 2021). Improving wildlife and providing conservation habitats are often the principal objectives, followed by the provision of other ecosystem services such as scenic quality (Lawerence et al. 2010; Dunn et al. 2020; DEFRA 2021). CSS is typically a low priority for farmers (Reid et al. 2021). Because of this, the planting of broadleaved species over coniferous is advocated due to the benefits to biodiversity and perceived aesthetic quality (Gregg et al. 2021; Reid et al. 2021).

Finally, financial incentives are particularly relevant to those neutral or pro-planting. In a recent farm survey on the upcoming ELMS, financial motives were the strongest driver for participation in the scheme (DEFRA 2021). The agricultural industry in England is heavily reliant on government subsidies, with an average 61% of farm profit coming from EU Direct Payments (DEFRA 2018). There has been some research on the economic feasibility of woodland planting and the role of subsidies (Hardaker 2018; O'Neill et al. 2020). O'Neill et al.'s (2020) study did not include timber production as a source of income and found that when discounting subsidies and using the sale of carbon on the private market as the income source, a carbon price of €48.40 tCO_2eq^{-1} was required to be comparable to sheep farming, making afforestation currently unfeasible without government subsidies.

This study aims to improve the research gap concerning afforestation of farmland by evaluating the potential CSS and economic feasibility of broadleaved woodland planting on agricultural land in the Loddon Catchment, southeast England. Using the spatial Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) Carbon Model, we considered three woodland planting scenarios: forest planting on (i) arable and (ii) pasture land as identified by land classification, and (iii) a "stakeholder-approved" (SA) scenario. Using the Loddon Catchment as a case study, our primary research question concerned the economic feasibility of a woodland planting scenario on agricultural land to provide CSS.

2. Materials and methods

2.1. Study site and modelling approach

The Loddon Catchment covers an area of 68,277 ha across three counties in southeast England, UK: Berkshire, Hampshire, and Surrey (Loddon Observatory 2021). With a temperate oceanic climate, the mean annual temperature is 10 °C and mean annual rainfall is 650 mm (Met Office 2016; World Bank Group 2020). Carbon sequestration potential of the arable, improved grassland[1], and SA scenarios (see below) was calculated with the InVEST Carbon Model (ICM), using carbon pool data, and 5 m resolution present-day[2] and future land use

[1] In this paper the term "broadleaved" and "deciduous" woodland, and "improved grassland" and "pasture", are used interchangeably, as they are in the UK BAP Broad Habitat and UKCEH Land Cover class definitions (UKCEH 2020).

change (LUC) rasters (Natural Capital Project 2021; Stanford University 2021). We considered four biophysical carbon pools in the landscape: aboveground living biomass, belowground living biomass, soil, and dead matter (Natural Capital Project 2021). The carbon pool data to 1 m depth for the land classes of interest, arable, improved grassland, and deciduous woodland, were collected from Natural England's review "Carbon Storage and Sequestration by Habitat" (Gregg et al. 2021). A literature review was completed to source additional carbon data complementary to the main database (Table 1).

Traditional agricultural practices, such as tillage and crop removal at harvest, are presumed to dominate in the arable land use in this study, hence we assumed that there is no permanent aboveground, belowground, or dead biomass carbon stock in arable land (Natural Capital Project 2021). Similar to arable, we assumed that there is a negligible amount of dead biomass in improved grassland land types (Natural Capital Project 2021). Mean carbon content in belowground biomass in forests was estimated using data from Patenaude et al. (2003), and calculated from aboveground biomass using the root to shoot ratio for broadleaved woodlands in temperate oceanic climates (IPCC 2019). Mean deadwood and litter data are from Patenaude et al. (2003) and the IPCC (2006). The woodland carbon pools were age-adjusted assuming linear growth over a time horizon of 50 years (2021–2071). Carbon pools for improved grassland and arable land use were assumed to be in a steady state, hence were not adjusted in the LUC scenarios.

2.2. Land use change scenarios

Three LUC scenarios were created using ArcGIS. An **arable planting scenario** was created by selecting first by land class and then by agricultural land grade (ALG)[3]. All arable land within the poorest grade, ALG 4, was selected for afforestation. The Loddon Catchment has 14,800 ha of arable land, of which, just 2.60% (385 ha) qualified as suitable for afforestation in this scenario, primarily in central and northern areas. The selection criteria for the **pasture planting scenario** were similar to the arable scenario, all land classified as improved grassland with ALG 4 was selected. The Loddon Catchment currently contains 20,000 ha of pasture; 17.42% (3564 ha) was selected as suitable for woodland planting. The qualifying land was more evenly spread than in the arable scenario, however, there was a distinct lack of grade 4 land in the west of the catchment. The **SA scenario** was based on the results of a workshop organised by the LANDWISE project (Elwin et al. 2020). The Lower Loddon sub-catchment was the only area identified as suitable for woodland planting. Using a shapefile outlining the areas in the Lower Loddon approved for woodland planting by stakeholders, the same land class and ALG filter was applied as in the other scenarios. From the total area approved for woodland planting by stakeholders in the catchment (11,300 ha), 8.42% was identified as suitable, of which, 85% was pasture (809 ha) and 15% was arable (141 ha) (Fig. 1).

Table 1. The average, minimum, and maximum carbon values used for each land class in the InVEST model.

Land Class	Aboveground Biomass [tC ha^{-1}]			Source	Belowground Biomass [tC ha^{-1}]			Source	Soil [tC ha^{-1}]			Source	Dead Matter [tC ha^{-1}]			Source
	$\bar{X}$	Min	Max		$\bar{X}$	Min	Max		$\bar{X}$	Min	Max		$\bar{X}$	Min	Max	
Arable	0.00	0.00	0.00	a	0.00	0.00	0.00	a	120.00	51.09	173.17	b	0.00	0.00	0.00	a
Improved Grassland	2.26	1.47	4.03	c	1.18	0.71	1.67	c, d	130.00	72.00	204.00	b	0.00	0.00	0.00	a
Planted Deciduous Woodland (50 years)	139.43	27.43	244.00	b	25.24	5.27	34.00	e, f	151.00	108.00	173.00	b	5.33	2.30	9.38	e, f

[a]Natural Capital Project 2021; [b]Gregg et al. 2021; [c]De Long et al. 2019; [d]Lange et al. 2015; [e]Patenaude et al. 2003; [f]IPCC 2019.

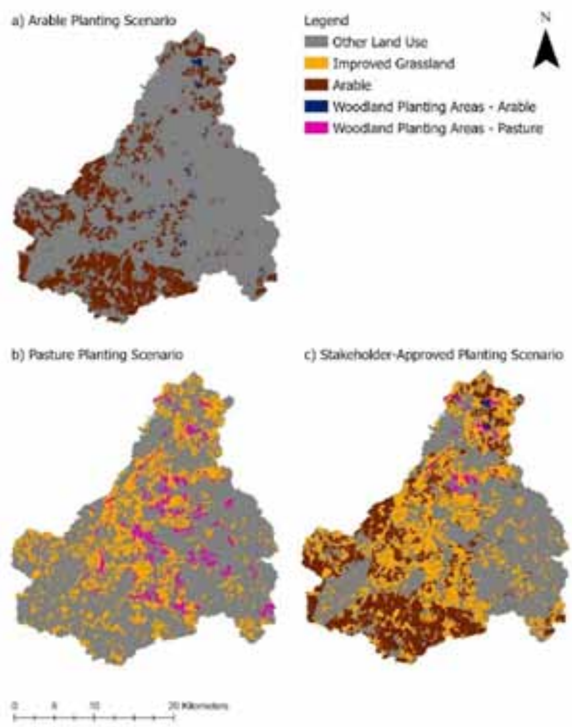

Fig. 1. Three scenarios for woodland planting on agricultural land in the Loddon Catchment, England. The catchment covers approximately 70,000 ha.

2 Data Sources: UKCEH (2019) Land Cover Map 2019 – Great Britain (Vector) – Geodatabase. License: Edina Environment Digimap and Environment Agency (2020) WFD River Catchments Cycle 2 – ESRI shapefile (polygons). License: Open Government License.

3 Data source: Natural England (2020) 1: 250 000 Provisional Agricultural Land Classification (ALC). License: Open Government License.

2.3. Carbon valuation

We used the ICM to calculate the market and social net present value (NPV) of carbon sequestration in all three scenarios. The valuation required three inputs; the "price per metric ton of carbon", "market discount in the price of carbon", and the "annual rate of change in the price of carbon (ROC)" (Natural Capital Project 2021). The UK Emission Trading Scheme (UKETS) market price of €97.78 tC^{-1}, and historical ROC between 2010–2021 of 4.37%, were used to estimate the market value of sequestration (DBEIS 2021). Current and historical prices used by the Woodland Carbon Code (WCC) are not publicly available, hence we used the UKETS prices even though they do not presently include the use of offset purchases (including forestry) (Maguire et al. 2021). Non-traded carbon price, €342.29 tC^{-1}, and predicted ROC between 2021–2071 of 7.93%, was used to calculate the social value (DBEIS 2021). A standard UK discount rate of 3.5% was used (HM Treasury 2020).

2.4. Economic feasibility of woodland planting

The economic analysis considered three main factors: the business-as-usual (BAU) gross margin for typical farm types, the gross margin for woodland planting using the market equivalent annual value (EAV) of carbon sequestration as the income source, and the difference between these two values. The BAU whole-farm gross margins for combinable crop, dairy, and lowland grazing beef and sheep (LGBS) farms were taken from the John Nix Pocketbook (Redman 2020) (Table 2).

The gross margins for woodland planting were calculated using the ICM's market EAV of carbon sequestration output for arable and pasture land, minus the Pocketbook values for farm woodland establishment and maintenance, general overhead expenses, and farm rent (Table 3). The average field size of areas suitable for afforestation in the arable and pasture scenarios was 5 ha and 2 ha, respectively, and the costs of woodland establishment were adjusted to account for economies of scale.

Table 2. Business-as-usual (BAU) whole farm costings, as listed by the John Nix Pocketbook (Redman 2020).

Farm Type	Combinable Crop Farm	Dairy	Lowland Grazing Beef and Sheep
Average Farm Size [ha)]	375	119	110
	Income [€ $ha^{-1}yr^{-1}$]		
Details	150 ha winter feed wheat, 75 ha spring malting barley, 75 ha spring beans	86 ha all-year dairy, 33 ha dairy youngstock	45 ha autumn sucklers, 69 heads beef finishing, 65 ha lowland ewes
Product income	827.63	2,293.20	508.49
Basic payment	232.96	252.00	252.00
Diversification	48.00	50.42	109.09
Agri-environmental income	0.00	0.00	87.28
Total Income	**1,108.58**	**2,595.62**	**956.86**
	Outgoings [€ $ha^{-1}yr^{-1}$]		
Paid labour	84.00	228.00	36.00
Unpaid labour	120.00	420.00	468.00
Casual labour	18.00	36.00	24.00
Total Labour	**222.00**	**684.00**	**528.00**
Machinery depreciation	144.00	246.00	144.00
Machinery running	132.00	252.00	138.00
Contract	102.00	204.00	78.00
Total Power and Machinery	**378.00**	**702.00**	**360.00**
Farm maintenance	30.00	114.00	54.00
Water and electricity	72.00	228.00	96.00
General overhead expenses	108.00	90.00	84.00
Total Overheads	**210.00**	**432.00**	**234.00**
Rent and Interest	**174.00**	**258.00**	**120.00**
Fixed costs*	810.00	1,818.00	1,122.00
Total BAU Gross Margin [€ $ha^{-1}yr^{-1}$]	**124.58**	**519.62**	**285.14**

* fixed costs are not included in the total BAU gross margin calculation.

Table 3. Gross margins for woodland planting. Annual average values over 50 years of woodland growth, derived from InVEST Carbon Model (ICM) outputs and John Nix Pocketbook (Redman 2020).

Farm Type	Details	Combinable Crop Farm	Dairy	Lowland Grazing Beef and Sheep
	Income [€ $ha^{-1}yr^{-1}$]			
Carbon sale at market price (equivalent annual value)	Sourced from ICM land use change scenario outputs	103.61	96.68	96.68
Total Income		**103.61**	**96.68**	**96.68**
	Outgoings [€ $ha^{-1}yr^{-1}$]			
Woodland establishment	<3 ha €8,160 and 3–10 ha €6,600 over the first 3 years	163.20	132.00	132.00
Woodland maintenance	€36 yr^{-1} after woodland establishment	33.84	33.84	33.84
Total Woodland Costs		**197.04**	**165.84**	**165.84**
General overhead expenses		108.00	90.00	90.00
Total Overheads		**108.00**	**90.00**	**90.00**
Rent and Interest		**174.00**	**258.00**	**120.00**
Fixed costs*		810.00	1,818.00	1,122.00
Woodland Planting Gross Margin [€ $ha^{-1}yr^{-1}$]		**−375.43**	**−417.16**	**−273.16**

* fixed costs are not included in the total woodland planting gross margin calculation.

All other farm costs were excluded because they were either accounted for within woodland establishment (e.g. labour), or no longer applicable (e.g. machinery running and depreciation). Notably, for consistency of calculations, the value of "unpaid labour" was included in the costings for productive farming and woodland planting income. A maximum subsidy equal to the ICM social EAV of carbon sequestered, less the ICM market EAV, was used to consider the effect of government subsidies.

3. Results

3.1. Carbon sequestration potential

The ICM showed that the highest annual carbon sequestration from woodland planting could reach 4.02 tC ha^{-1} yr^{-1} on arable land over 50 years of growth (Fig. 2). Carbon sequestration in pasture land was 6.8% lower, at 3.75 tC ha^{-1} yr^{-1}, due to the higher initial carbon storage in grasslands compared to arable land. The largest gains in both land types were in aboveground biomass, representing on average 71% of the sequestration. At the catchment scale, the pasture scenario had the greatest total sequestration potential of 668,540 tC. The total sequestration in the SA and arable scenarios was much less, at 180,256 tC and 77,402 tC, respectively. Additionally, there was high variability in the range of carbon sequestration, particularly in the aboveground biomass. This is in line with the minimum/maximum ranges of the values used in the ICM (Table 1).

3.2. Economic value of carbon sequestration

Using a market carbon price of €97.78 tC^{-1}, a discount rate of 3.5%, and a ROC of 4.37% (HM Treasury 2020; DBEIS 2021), the highest market NPV over the 50-year time horizon was planting on arable land in the arable and SA scenario, at €5,180.64 ha^{-1}. The NPV was slightly less when planting on improved grassland, at €4,834.08 ha^{-1}. This equates to an EAV of €103.61 ha^{-1} yr^{-1} and €96.68 ha^{-1} yr^{-1} in arable and pasture land, respectively. The highest total NPV of carbon sequestration in the Loddon Catchment was valued at €17.23 million in the pasture scenario. The social NPV of carbon sequestration was considerably higher than the market value when raising the carbon price to the social value of €342.29 tC^{-1} and corresponding ROC to 7.93% (HM Treasury 2020; DBEIS 2021). Similar to the market valuation, the highest EAV was in arable land at €261.50 ha^{-1} yr^{-1}. The highest total social NPV in the Loddon Catchment was in the pasture scenario, valued at €43.48 million (Table 4).

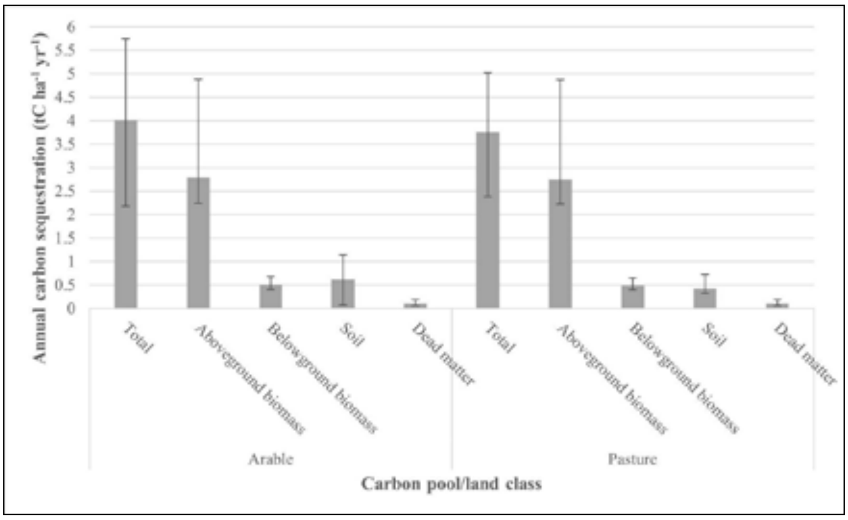

Fig. 2. Mean annual carbon sequestration by woodland planting on arable and pasture land, shown as totals and divided to individual carbon pools, error bars represent the minimum/maximum range. Carbon sequestration by land type rather than by LUC scenario is shown.

Table 4. The market and social net present value (NPV) per hectare, total NPV, and equivalent annual value (EAV) of carbon sequestration in the land use change scenarios.

Planting Scenario	Area [ha]	Market			Social		
		NPV [€ ha^{-1}]	Total NPV [€]	EAV [€ ha^{-1} yr^{-1}]	NPV [€ ha^{-1}]	Total NPV [€]	EAV [€ ha^{-1} yr^{-1}]
Arable	385.5	5,180.64	1,996,981	103.61	13,075.20	5,040,096	261.50
Pasture	3563.6	4,834.08	17,226,954	96.68	12,200.64	43,478,773	244.01
SA* Arable	141.4	5,180.64	732,751	103.61	13,075.20	1,849,362	261.50
SA* Pasture	809.5	4,834.08	3,912,997	96.68	12,200.64	9,875,938	244.01
SA* Combined	950.9	5,007.36	4,645,750	100.15	12,637.92	11,725,298	252.76

*Stakeholder Approved.

3.3. Economic feasibility of forest planting

The final part of the study considered the economic feasibility of woodland planting. Out of the three BAU farm types, dairy farming is the most profitable with a gross margin of €519.62 ha^{-1} yr^{-1}, followed by combinable crop farming earning €124.58 ha^{-1} yr^{-1}. Importantly, due to accounting for the value of unpaid labour, LGBS farming operates at a loss of −€285.14 ha^{-1} yr^{-1}. Our evaluation showed that, without government subsidies, the woodland planting gross margins were at a loss across all farm types. The greatest loss was in dairy farming, at −€417.16 ha^{-1} yr^{-1}, while the smallest in LGBS farming, at −€273.16 ha^{-1} yr^{-1}. Comparing the BAU and woodland planting gross margins, we found that conversion to woodland would leave combinable crop and dairy farmers financially worse off compared to BAU. Interestingly, planting on pasture land in LGBS farms would earn €11.99 ha^{-1} yr^{-1} more. Therefore, even though LGBS farms would still be working at a loss, this would be less of a loss than continuing with traditional farming practices (Table 5).

We infer that the arable scenario and arable areas within the SA scenario are currently economically not suitable for woodland creation. The picture is more complex in the pasture scenario. Whilst afforestation is not currently feasible on dairy farms, the areas practicing LGBS farming could be more suited to woodland creation, given the existing losses in BAU practice. Furthermore, a government subsidy up to the social value of carbon, a maximum of €157.90 ha^{-1} yr^{-1} on arable land and €147.32 ha^{-1} yr^{-1} on pasture land is unlikely to change the outcome for areas operating combinable crop or dairy farms. However, this may make woodland planting more appealing to LGBS farmers as there is a greater difference (€159.31 ha^{-1} yr^{-1}) between the BAU and woodland planting margins.

4. Discussion

4.1. Carbon sequestration

The findings complement existing research, deciduous afforestation on arable land results in an increase in carbon sequestration, however, the rates of sequestration vary. A UK modelling study by Garcia de Jalon et al. (2018) observed significantly higher sequestration in aboveground biomass at 20.42 tC ha^{-1} yr^{-1}, compared to our result of 2.79 tC ha^{-1} yr^{-1}. Poulton´s (2003) research on natural regeneration found a 2.24 tC ha^{-1} yr^{-1} increase in aboveground and belowground biomass over 120 years. The same variation occurs in research reporting on afforestation of pasture land; Ostle et al.'s (2009) review reports modest soil carbon sequestration of 0.1 tC ha^{-1} yr^{-1} over 90 years, whereas Upson et al. (2016) complemented our observation of a 0.3 tC ha^{-1} yr^{-1} increase in soil carbon. This variation may be explained by environmental factors, such as differences in soil and vegetation type, management practices (Senapati et al. 2014; England et al. 2016; Gregg et al. 2021), or the carbon pool data sources and modelling packages used in desk-based research (Tupek et al. 2010; Sharps et al. 2017; Bartholomee et al. 2018).

The large differences between the total sequestration potential in our scenarios are mostly due to the size of suitable areas for afforestation in each scenario. Using the selection criteria, areas with a low ALG were approximately nine times greater in pasture land than arable land, in the SA scenario, 85.1% of the indicated land was improved grassland. Grassland is often considered the"most suitable" for afforestation due to the widespread focus of planting on low quality, yet accessible, land (Burke et al. 2020; Wilkes et al. 2020). This inevitably incurs a trade-off with livestock production, however, a shift in consumption patterns towards more sustainable low-meat diets could reduce the need for pasture land in the future (Willett et al. 2019; Wilkes et al. 2020). Furthermore, to meet the net zero targets, the UK's land use strategy is to increase forest cover from 13% to 17% by 2050, largely on low-grade agricultural land (HM Government 2018; CCC 2020). The pasture planting scenario is the only scenario to meet this target, increasing forest cover in the Loddon Catchment by 5.22%. In comparison, the arable and SA scenario would increase cover by 0.56%, and 1.39%, respectively.

Table 5. A summary of the economic analysis comparing afforestation to business-as-usual (BAU) farming.

Farm Type	Combinable Crop Farm	Dairy	Lowland Grazing Beef and Sheep
Income [€ ha^{-1} yr^{-1}]			
Carbon sale at market price (equivalent annual value)	103.61	96.68	96.68
Total Income	**103.61**	**96.68**	**96.68**
Outgoings [€ ha^{-1} yr^{-1}]			
Woodland establishment	163.20	132.00	132.00
Woodland maintenance	33.84	33.84	33.84
General overhead expenses	108.00	90.00	84.00
Rent and interest	174.00	258.00	120.00
Total Outgoings	**479.04**	**513.84**	**369.84**
Woodland Planting Gross Margin [€ ha^{-1} yr^{-1}]	**−375.43**	**−417.16**	**−273.16**
BAU gross margin [€ ha^{-1} yr^{-1}]	124.58	519.62	−285.14
Woodland Planting Vs. BAU [€ ha^{-1} yr^{-1}]	**−500.02**	**−936.78**	**11.99**
Effect of government subsidy			
Maximum government subsidy [€ ha^{-1} yr^{-1}]	157.90	147.32	147.32
Woodland Planting Gross Margin [€ ha^{-1} yr^{-1}] (including the maximum subsidy)	**−217.54**	**−269.83**	**−125.83**
Woodland Planting Vs. BAU [€ ha^{-1} yr^{-1}] (including the maximum subsidy)	**−342.12**	**−789.46**	**159.31**

4.2. Value of carbon sequestration

Very few European studies consider carbon sequestration as a source of income to landowners through emission offset schemes, such as the WCC, instead of timber production (Hall 2018; Ovando et al. 2019; O'Neill et al. 2020). O'Neill et al.'s (2020) report on afforestation of UK pasture land is the only study that provides comparable data. They found a much lower market NPV of €148.19 ha^{-1} over 25 years, however, this is likely because they only provided NPV data for natural regeneration, which typically takes longer to establish than active planting, therefore sequestering less carbon over the same period (O'Neill et al. 2020).

Much of the research valuing carbon sequestration concentrates on monetising the positive environmental externalities gained from it, i.e. social value. Results from similar afforestation modelling studies are varied. Garcia de Jalon et al. (2018) show that woodland growth on arable land in Bedfordshire, England, has a far lower social EAV of €35.79 ha^{-1} yr^{-1} over a 30-year time horizon. In contrast, Giannitsopoulos et al. (2020) estimated the social EAV from afforestation on arable land of €231.82 ha^{-1} yr^{-1}. The variation can be explained by the price of carbon and the discount rates used in valuation calculations. They have a significant and nonlinear effect on NPV, sometimes greater than the amount of carbon sequestered (Bateman & Lovett 2000). For example, Giannitsopoulos (2020) demonstrated that due to discount rates, raising the carbon price by 66.50% resulted in a 98.43% increase in NPV. Moreover, a GIS analysis showed that a 40% and 50% increase in discount rates resulted in a 40% and 63% increase in NPV (Bateman & Lovett 2000). This highlights the need for clarity in both the carbon price and discount rates used in the assessment of carbon sequestration to avoid under or over-valuation.

4.3. Economic feasibility

The results of the economic analysis generally agree with the trends described in existing literature. The overarching theme is that the high production value of arable land prevents woodland planting, and in some circumstances, the comparatively low value of pasture land makes afforestation an economically viable option (Nijnik et al. 2013; O'Neill et al. 2020; Kaske et al. 2021). Similar patterns have been found in studies using timber production as the income source rather than carbon sequestration (Garcia de Jalon et al. 2018; Giannitsopoulos et al. 2020). O'Neill et al. (2020) found that for active woodland planting on sheep pastures, a government subsidy of €244.01 tC^{-1} is necessary to break even, which is lower than the social carbon price used in this paper (€342.23 tC^{-1}). In comparison, we calculated a subsidy of €273.16 ha^{-1} yr^{-1} required to break even when afforesting pasture, which is slightly greater than the estimated social value of €244.04 ha^{-1} yr^{-1}. This is likely because O'Neill et al. focused solely on sheep farming, whereas the general pasture values used in this study include more profitable beef production (Redman 2020).

An important finding of this study is that afforestation of pasture land may have better financial prospects than continuing with agriculture. However, in practice, farmers may not want, or be able to, convert to forestry. When excluding the value of unpaid labour and assuming that the land is owner-occupied, the BAU gross margins no longer show a loss, explaining why most farms continue to be viable (Redman 2020). The skill set needed for grazing operations is often provided by unpaid family workers. In contrast, the skills required for conversion to carbon forestry may not be available for free, thus tipping the balance against economic attractiveness of afforestation, particularly for farming households fitting the "cash-poor, asset-rich" stereotype (Lawrence & Edwards 2013; Wynne-Jones 2013; Redman 2020). Furthermore, financial incentives are not the only driver of change in farming communities; cultural beliefs, "productivist" values, and previous poor experiences of agri-environmental schemes may stop farmers from participating in woodland planting, particularly in older generations (Watkins et al. 1996; Howley et al. 2015; Ryan et al. 2018; DEFRA 2021). Hence, it is important to consider afforestation scenarios in areas accepted by potential participants, as done here in the SA scenario.

The reliance on government subsidies is a common economic agricultural issue. In England, EU Direct Payments represented 61% of farm profits (DEFRA 2018), making it difficult for domestic forestry markets to compete without similar government support. However, the EU Direct Payments will be phased out by 2025 in England and replaced with ELMS, which is a natural capital scheme (HM Government 2018; Coe & Finlay 2020). If ELMS reduces the overall amount of payments and ties these to the delivery of specific environmental goods such as carbon sequestration, conversion to forestry could become far more attractive, if not the default option on marginal land due to the economic unfeasibility of agriculture (Manzoor et al. 2021). Considering the social value of carbon sequestration is a common method used to evaluate the trade-offs between climate regulation services and food production. However, by only focusing on carbon sequestration, there is a risk of underrepresenting the value of concurrent services (Giannitsopoulos et al. 2020). For example, a valuation of air quality regulation, biodiversity, and recreational co-benefits provided by afforested areas in the WCC estimated an additional social value of €413–€945 tC^{-1} sequestered (EftEC 2015). Conversely, trade-off analyses including the multiple ecosystem services provided by woodlands often fail to account for the social value of food production on agricultural land and only include the production value to farmers as an income source (Garcia de Jalon et al. 2018; Giannitsopoulos et al. 2020), thus, underestimating the true societal value by excluding the health and nutritional benefits provided by food consumption.

It is unrealistic that all suitable land in the pasture scenario will be planted, farmer attitudes to participation in afforestation schemes do play a role (Howley et al. 2015; Ryan et al. 2018; DEFRA 2021). It is more probable for woodland planting to occur on the pasture farmland within the SA scenario. This equates to a smaller expansion in forest cover of 0.74%, far below the 4% target (CCC 2020). The focal area of this study represents relatively productive land, however, it is likely that a far more significant amount of afforestation may happen on marginal land in hilly areas of Wales and Northern England as a result of changes in the subsidy or the trading environment (Manzoor et al. 2021). Abandonment of marginal farmland all over Europe has been taking place for decades (Ruskule et al. 2016), significant tracts of Eastern Europe are reverting back to forest (Vinogradovs et al. 2018; Slawski et al. 2020). Clearly, the challenge for the new Common Agricultural Policy is to provide targeted incentives to support purposeful afforestation of marginal land without spending resources on speeding up natural secondary succession on land already undergoing or prone to abandonment.

4.4. Limitations and further research

The CSS estimates in this study may be conservative as the ICM assumes a linear trend of carbon sequestration over time. Sequestration typically follows a nonlinear path, leading to an underestimation of carbon uptake in the initial stages of ecosystem development (Natural Capital Project 2021). Similarly, although the ICM valuation accounted for discount rates and ROC, it was outside the scope of this study to include the same variables when calculating the BAU gross margins used in the economic analysis, overestimating the value of future food production. Finally, we were able to partially account for farmer preferences and prevailing farm types within the Loddon Catchment. However, the lack of data prevented this study from being spatially explicit with some environmental factors, such as soil type, which are known to influence CSS (Vanguelova et al. 2013; Grunelberg et al. 2014). Future studies on CSS would greatly benefit from a wider, more certain, knowledge base on terrestrial carbon storage, particularly by soil type within agricultural land cover. Additionally, further work to understand the local and regional variances in farmer attitudes towards woodland planting would improve the understanding of the barriers to participation and identify potential actions to improve stakeholder approval.

5. Conclusions

A key strategy of the ongoing environmental and agricultural UK policy reforms is to increase forest cover, and associated carbon sequestration, particularly on low quality agricultural land. We found that when using income from the market sale of carbon sequestration, woodland planting on agricultural land results in a gross margin loss across all considered farm types. Subsidising up to the social value of carbon significantly reduces this loss and may make afforestation of LGBS pasture land more appealing to farmers.

Woodland planting on LGBS pasture land would increase the forest cover in the Loddon Catchment by up to 3.62%, achieving close to the 4% target required to reach net zero by 2050. However, farmer attitudes have major influence on participation in woodland planting schemes. Therefore, it is more realistic for afforestation to occur on lowland pasture land in the SA scenario, equating to a much smaller expansion in forest cover of 0.74%.

Before moving forward with afforestation schemes, more consideration must be given to the food system implications, and the techniques used to assess the amount and value of ecosystem services provided in both agricultural and wooded landscapes. Finally, future research should concentrate on expanding the terrestrial carbon storage knowledge base to provide evidence for carbon-based finance.

Acknowledgement

We would like to thank the LANDWISE project team for the provision of the workshop results used to construct the SA scenario. Martin Lukac received support from the European Social Fund EVA 4.0 (OP RDE, CZ.02.1.01/0.0/0.0/16_019/0000803).

References

Bartholomee, O., Grigulis, K., Colace, M. P., Arnoldi, C., Lavorel, S., 2018: Methodological uncertainties in estimating carbon storage in temperate forests and grasslands. Ecological Indicators, 1:331–342.

Bateman, I., Lovett, A., 2000: Estimating and valuing the carbon sequestered in softwood and hardwood trees, timber products and forest soils in Wales. Journal of Environmental Management, 60:301–323.

Burke, T., Whyatt, D., Blackburn, A., Rowland, C., Abbatt, J., 2020: Large-scale tree planting in the UK: feasibility and implications, Lancaster: UK Centre for Ecology and Hydrology, 9 p.

De Long, J. R., Jackson, B. G., Wilkinson, A., Pritchard, W. J., Oakley, S., Mason, K.E. et al., 2019: Relationships between plant traits, soil properties and carbon fluxes differ between monocultures and mixed communities in temperate grassland. Journal of Ecology, 107:1704–1719.

Dunn, M., Sing, L., Clarke, T., Moseley, D., 2020: Attitudes Towards Landscape Benefits and Woodland Creation in Southern Scotland, Forest Research, 42 p.

Elwin, A., Clark, J. M., Short, C., Badjana, M., Neumann, J., Elwin, A., 2020: LANDWISE NFM scenario workshop initial findings for the Loddon Catchment – Report of Loddon Catchment workshop, 11 October 2019, for workshop participants and the Loddon Catchment Partnership. Unpublished.

England, J. R., Paul, K. L., Cunningham, S. C., Madhavan, D. B., Baker, T. G., Read, Z. et al., 2016: Previous land use and climate influence differences in soil organic carbon following reforestation of agricultural land with mixed-species plantings. Agriculture Ecosystems and Environment, 227:61–72.

Evans, M., 2013: 12.11 Peatland Geomorphology. In: Shroder, J. (eds.): Treatise on Geomorphology. Academic Press, p. 165–181.

Garcia de Jalon, S., Graves, A., Palma, J. H. N., Williams, A., Upson, M., 2018: Modelling and valuing the environmental impacts of arable, forestry and agroforestry systems: a case study. Agroforestry Systems, 4:1059–1073.

Giannitsopoulos, M. L., Graves, A. R., Burgess, P. J., Crous-Duran, J., Moreno, G., Herzog, F. et al., 2020: Whole system valuation of arable, agroforestry and tree-only systems at three case study sites in Europe. Journal of Cleaner Production, 23.

Gregg, R., Elias, J. L., Alonso, I., Crosher, I. E., Muto, P., Morecroft, M. D., 2021: Carbon storage and sequestration by habitat: a review of the evidence (second edition) – Natural England Research Report NERR094, York: Natural England, 58 p.

Grunelberg, E., Ziche, D., Wellbrock, N., 2014: Organic Carbon Stocks and Sequestration Rates of Forest Soils in Germany. Global Change Biology, 8:2644–2662.

Hall, S., 2018: A novel agroecosystem: Beef production in abandoned farmland as a multifunctional alternative to rewilding. Agricultural Systems, 167:10–16.

Hamilton, W., Bosworth, G., Ruto, E., 2015: Entrepreneurial younger farmers and the "young farmer problem" in England. Agriculture and Forestry, 61:61–69.

Hardaker, A., 2018: Is forestry really more profitable than upland farming? A historic and present day farm level economic comparison of upland sheep farming and forestry in the UK. Land Use Policy, 71:98–120.

Howley, P., Buckley, C., O'Donoghue, C., Ryan, M., 2015. Explaining the economic 'irrationality' of farmers' land use behaviour: The role of productivist attitudes and non-pecuniary benefits. Ecological Economics, 109:186–193.

Hyland, J. J., Jones, D. L., Parkhill, K. A., Barnes, A. P., Williams, A. P., 2016: Farmers' perceptions of climate change: identifying types. Agriculture and Human Values, 33:323–339.

Kaske, K., Garcia de Jalon, S., Williams, A., Graves, A., 2021: Assessing the Impact of Greenhouse Gas Emissions on Economic Profitability of Arable, Forestry, and Silvoarable Systems. Sustainability, 7:3637

Lange, M., Eisenhauer, N., Sierra, C. A., Bessler, H., Engels, C., Griffiths, R. I. et al., 2015: Plant diversity increases soil microbial activity and soil carbon storage. Nature Communications, 6:1–8.

Lawerence, A., Dandy, N., Urquhart, J., 2010: Landowner attitudes to woodland creation and management in the UK, Farnham: Forest Research.

Lawrence, A., Edwards, D., 2013: Prospects for new productive woodland in Scotland: Insights from stakeholders, Roslin: Forestry Commission, 75 p.

Maguire, P., Donofrio, S., Merry, W., Myers, K., Weatherer, L., Wildish, J. et al., 2021: A Green Growth Spurt – State of Forest Carbon Finance 2021, Washington DC: Ecosystem Marketplace, 64 p.

Manzoor, S. A., Griffiths, G., Rose, D. C., Lukac, M., 2021: The Return of Wooded Landscapes in Wales: An Exploration of Possible Post-Brexit Futures. Land, 10: 59–64.

Matthews, K. B., Wardell-Johnson, D., Miller, D., Fitton, N., Jones, E., Bathgate, S. et al., 2020: Not seeing the carbon for the trees? Why area-based targets for establishing new woodlands can limit or underplay their climate change mitigation benefits. Land Use Policy, 97: 104690.

Morison, J., Matthews, R., Miller, G., Perks, M., Randle, T., Vanguelova, E. et al., 2012: Understanding the carbon and greenhouse gas balance of forests in Britain - Forestry Commission Research Report, Edinburgh: Forestry Commission, 149 p.

Nijnik, M., Pajot, G., Moffat, A., Slee, B., 2013: An economic analysis of the establishment of forest plantations in the United Kingdom to mitigate climatic change. Forest Policy and Economics, 26:34–42.

O'Neill, C., Lim, F., Edwards, D., Osborne, C., 2020: Forest regeneration on European sheep pasture is an economically viable climate change mitigation strategy. Environmental Research Letters, 15: 104090.

Ostle, N., Levy, P., Evans, C., Smith, P., 2009: UK land use and soil carbon sequestration. Land Use Policy, 26:274–283.

Ovando, P., Begueria, S., Campos, P., 2019: Carbon sequestration or water yield? The effect of payments for ecosystem services on forest management decisions in Mediterranean forests. Water Resources and Economics, 28:100119.

Patenaude, G., Briggs, B.D.J., Milne, R., Rowland, C.S., Dawson, T.P., Pryor, S.N., 2003: The carbon pool in a British Semi-Natural Woodland. Forestry, 76:109–119.

Poulton, P., Pye, E., Hargreaves, P., Jenkinson, D., 2003: Accumulation of carbon and nitrogen by old arable land reverting to woodland. Global Change Biology, 9:942–955.

Redman, G., 2020: John Nix Pocketbook. 51st ed. Melton Mowbray, The Andersons Centre, 303 p.

Reid, C., Hornigold, K., McHenry, E., Nichols, C., Townsend, M., Lewthwaite, K. et al., 2021: State of the UK's Woods and Trees, Woodland Trust, 245 p.

Ruskule, A., Nikodemus, O., Kasparinskis, R., Prižavoite, D., Bojāre, D., Brūmelis, G., 2016: Soil–vegetation interactions in abandoned farmland within the temperate region of Europe. New Forests, 47:587–605.

Ryan, M., O'Donoghue, C. & Hynes, S., 2018: Heterogeneous economic and behavioural drivers of the Farm afforestation decision. Journal of Forest Economics, 33:63–74.

Senapati, N., Chabbi, A., Gastal, F., Smith, P., Mascher, N., Loubet, B. et al., 2014: Net carbon storage measured in a mowed and grazed temperate sown grassland shows potential for carbon sequestration under grazed system. Carbon Management, 5:131–144.

Sławski, M., Tarabuła, T., Sławska, M., 2020: Does the enrichment of post-arable soil with organic matter stimulate forest ecosystem restoration–A view from the perspective of three decades after the afforestation of farmland. Forest Ecology and Management, 478:118525.

Sharps, K., Masante, D., Thomas, A., Jackson, B., Redhead, J., May, L. et al., 2017: Comparing strengths and weaknesses of three ecosystem services modelling tools in a diverse UK river catchment. Science of the Total Environment, 584–585:118–130.

Tupek, B., Zanchi, G., Verkerk, P. J., Churkina, G., Viovy, N., Hughes, J. K. et al., 2010: A comparison of alternative modelling approaches to evaluate the European forest carbon fluxes. Forest Ecology and Management, 260:241–251.

Upson, M., Burgess, P., Morison, J., 2016: Soil carbon changes after establishing woodland and agroforestry trees in a grazed pasture. Geoderma, 283:10–20.

Vanguelova, E. I., Nisbet, T. R., Moffat, A. J., Broadmeadow, S., Sanders, T. G. M., Morison, J. I. L., 2013: A New Evaluation of Carbon Stocks in British Forest Soils. Soil Use and Management, 29:169–181.

Vinogradovs, I., Nikodemus, O., Elferts, D., Brūmelis, G., 2018: Assessment of site-specific drivers of farmland abandonment in mosaic-type landscapes: A case study in Vidzeme, Latvia. Agriculture, Ecosystems & Environment, 253:113–121.

Vlek, P. L. G., Khamzina, A., Azadi, H., Bhaduri, A., Bharati, L., Braimoh, A. et al., 2017: Trade-Offs in Multi-Purpose Land Use under Land Degradation. Sustainability, 9:1–19.

Watkins, C., Williams, D., Lloyd, T., 1996: Constraints on farm woodland planting in England: a study of Nottinghamshire farmers. Forestry: An International Journal of Forest Research, 69:167–176.

Wilkes, M. A., Bennett, J., Burbi, S., Charlesworth, S., Dehnen-Schmutz, K., Rayns, F. et al., 2020: Making Way for Trees? Changes in Land-Use, Habitats and Protected Areas in Great Britain under "Global Tree Restoration Potential". Sustainability, 12.

Willett, W., Rockstrom, J., Loken, B., Springmann, M., Lang, T., Vermeulen, S. et al., 2019: Food in the Anthropocene: The EAT–Lancet Commission on healthy diets from sustainable food systems. Lancet, 393:447–492.

Wynne-Jones, S., 2013: Carbon blinkers and policy blindness: The difficulties of "Growing Our Woodland in Wales". Land Use Policy, 32:250–260.

Other sources

CCC, 2020: Land use: Policies for a Net Zero UK, London: Committee on Climate Change.

Climate Change Act 2008: (c.27). London: The Stationary Office. Available at: https://www.legislation.gov.uk/ukpga/2008/27/contents

Coe, S., Finlay, J., 2020: The Agriculture Act 2020, London: House of Commons.

DBEIS, 2021: 2019 UK Greenhouse Gas Emissions, Final Figures, London: Department for Business, Energy & Industrial Strategy.

DBEIS, 2021: Green Book supplementary guidance: valuation of energy use and greenhouse gas emissions for appraisal - Data tables 1 to 19: supporting the toolkit and the guidance. Available at: https://www.gov.uk/government/publications/valuation-of-energy-use-and-greenhouse-gas-emissions-for-appraisal

DEFRA, 2018: Moving away from Direct Payments – Agriculture Bill: Analysis of the impacts of removing Direct Payments. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/740669/agri-bill-evidence-slide-pack-direct-payments.pdf

DEFRA, 2021: Consultation outcome: Analysis of responses summary. Available at: https://www.gov.uk/government/consultations/environmental-land-management-policy-discussion-document/outcome/analysis-of-responses-summary

EftEC, 2015: Developing UK Natural Capital Accounts: Woodland Ecosystem Accounts, London: Department for Environment, Food and Rural Affairs.

Environment Agency, 2020: WFD River Waterbody Catchments Cycle 2. Available at: https://data.gov.uk/dataset/298258ee-c4a0-4505-a3b5-0e6585ecfdb2/wfd-river-waterbody-catchments-cycle-2

HM Government, 2018: A Green Future: Our 25 Year Plan to Improve the Environment, London: HM Government.

HM Treasury, 2020: The Green Book - Central Government Guidance of Appraisal and Evaluation, London: HM Treasury.

IPCC, 2006: Chapter 2: Generic Methodologies Applicable to Multiple Land-Use Categories. In: 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Institute for Global Environmental Strategies. Hayama, p. 2.27.

IPCC, 2019: Chapter 4: Forest Land. In: 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Intergovernmental Panel on Climate Change. Geneva, p. 4.19.

Loddon Observatory, 2021: Loddon Catchment. Available at: https://loddonobservatory.org/loddon-catchment/

Met Office, 2016: UK Regional climates – Southern England. Available at: https://www.metoffice.gov.uk/binaries/content/assets/metofficegovuk/pdf/weather/learn-about/uk-past-events/regional-climates/southern-england_-climate---met-office.pdf

MHCLG, 2020: Land Use in England, 2018, London: Ministry of Housing, Communities and Local Government.

Natural Capital Project, 2021: Carbon Storage and Sequestration. Available at: http://releases.naturalcapitalproject.org/invest-userguide/latest/carbon-storage.html

Natural England, 2020: Provisional Agricultural Land Classification (ALC). Available at: https://data.gov.uk/dataset/952421ec-da63-4569-817d-4d6399df40a1/provisional-agricultural-land-classification-alc

Stanford University, 2021: Natural Capital Project – Carbon. Available at: https://naturalcapitalproject.stanford.edu/software/invest-models/carbon

UKCEH, 2019: Digimap – Environment Data Download. Available at: https://digimap.edina.ac.uk/roam/download/environment

UKCEH, 2020: The UKCEH Land Cover Maps for 2017, 2018 and 2019, UK Centre for Ecology and Hydrology.

World Bank Group, 2020: Country – United Kingdom. Available at: https://climateknowledgeportal.worldbank.org/country/united-kingdom#