# Achieving net zero: exploring the contribution of new woodlands

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## Abstract

With the adoption of achieving net zero by 2050, reducing greenhouse gas emissions is of increasing importance. While woodlands have the potential to contribute to achieving the climate change targets through the carbon they sequester, planting rates within Northern Ireland remain low. This study reports on a spatial land-use model which has been developed to capture the ecosystem services delivered by alternative land-uses to understand the low planting rates. The model identified that while planting an additional 1,600 ha of woodland annually in Northern Ireland has the potential of reducing GHGs by 1.5 million tonnes of $CO_2e$ in 2050, reducing emissions from the agricultural sector in Northern Ireland by 26% and total emissions from Northern Ireland by 7%. However, the study found that when only ecosystem services with market values were considered, tree planting would incur a cost. Including greenhouse gas emissions into the model demonstrated that planting new woodlands delivered net benefits, with greater GHG reductions from the same area of woodland planted as the carbon value used within the model increased. In addition, 87% of avoided GHGs were due to the cessation of agriculture, rather than carbon sequestration. Policy implications for these results are discussed.

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## *1 Introduction*

The importance of the Land Use, Land Use change and Forestry (LULUCF) sector is increasingly being recognised through its role in off-setting Green House Gas (GHGs) emissions to meet climate change targets. With a potential target of reducing GHGs to achieve net zero emissions by 2045, Northern Ireland as a whole and the agricultural sector which is responsible for 27% of emissions is under significant pressure.

The potential of planting new woodlands and increasing carbon sequestration to offset GHG emissions and therefore contribute to achieving climate change targets was first introduced in the Kyoto Protocol of 1997. Despite the recognition of the role of woodlands can play in meeting climate change targets, woodland planting in Northern Ireland has remained low (<200 ha/year), minimising their potential contribution to achieving net zero.

To understand why these rates are so low and explore how they can be enhanced, this study reports on a spatial land-use model for Northern Ireland (LUMNI), which has been developed to capture the ecosystem services delivered by alternative land-uses, taking into account both market and non-market benefits and the spatial variation of the ecosystem services. This edit of the model is focused on the land-uses of agriculture and woodlands and includes the ecosystem services of agricultural and timber production and climate regulation. LUMNI has the capacity to capture:

1) All the potential impacts of the alternative land-uses by adopting an ecosystem services approach with sub-models for each ecosystem service (including agricultural production), which use both market and non-market valuation methods to estimate all costs and/or benefits from each potential land-use.
2) The spatial variation in the ecosystem services delivered by the alternative land-uses with each sub-model be based on land parcels (5 $KM^2$).

This edit of LUMNI has focused on two land-uses: agriculture and woodlands and benefits relating to agricultural produce, timber, and carbon with respect to both land-uses. Four spatial sub-models were developed to capture these benefits for 5$km^2$ land parcels across Northern Ireland:

1) Agricultural land-use sub-model.
2) GHGs from agriculture sub-model.
3) Timber sub- model.
4) GHG from timber production sub-model.

A range of carbon values were used with the LUMNI, including the £240 tonne of $CO_2e$ recommend for government guidance as the GHGs from agriculture and woodlands are not traded goods. It must be noted that the value of non-traded carbon has been revised following the adoption by the UK of net zero emissions by 2050. With the potential of carbon markets becoming established for woodlands, two additional values were used, £20 /tonne of $CO_2$e, the value of carbon sequestered by woodlands in recent auctions in the UK and £80/ tonne of $CO_2$e the price of carbon traded in the UK ETS.

In this paper, the land-use model will be explored with the sub-model approach within a spatial format (section 2), followed by an explanation of the scenarios used (section 3), followed by the results of both the sub-models and the combined LUMNI are presented (section 4) with conclusions in Section 5).

## *2 Methodology*

A Land-Use Model for Northern Ireland (LUMNI) has been developed based on The Integrated Model (TIM) developed by Bateman et al (2014) for Great Britain. The model is based on a framework of sub-models for each ecosystem service, where each sub-model identifies the economic benefits of each ecosystem service under potential land-uses.

This is a 'proof of concept' spatial Land-Use Model for Northern Ireland (LUMNI) to enable the economic benefits delivered by alternative land-uses to be compared. While some land-uses are mutually exclusive and others can co-exist on the same land area, it must be recognised that in Northern Ireland, all land is currently in use, delivering ecosystem services to society whether that involves agricultural production, land used to support nature or for urban and industrial use. Therefore, the LUMNI is based on a change in land-use, and like most economic models on marginal rather than absolute values.

As previously highlighted, a key issue within land-use decision making is that not all the benefits or costs are accrued by the landowner. By adopting an ecosystem service approach, LUMNI has the potential to include the non-market values into the optimisation process as well as the financial impacts. Through the sub-model framework of the LUMNI it is possible to assess the impact of a change in land-use when only the market values are considered as well as when the economic values when the social values are also included. This can be seen below:

> Private Benefit = Market value of new land-use – Market value of existing land-use
>
> Economic Benefit = Market and non-market values of new land-use – Market and non-market values of existing land-use

If this analysis shows a difference between the two, with an alternative land-use delivering greater benefits than the existing land-use when the social benefits are included, then this indicates that there is a potential role for government intervention to influence a change in land-use.

To account for the spatial impacts of each land-use, the LUMNI and its sub-models are based on parcels of land, rather than Northern Ireland in its entirety. This enables the sub-models to capture the differences in location whether caused by topography or socio-economic conditions, where each of these factors may have different impacts on each of the ecosystem services in question. To capture the spatial variation in the delivery of ecosystem services, Northern Ireland was divided into 5 Km$^2$ land parcels, with LUMNI applied at the parcel level. Therefore, the potential net benefit from a change in land-use was determined for each 5 Km$^2$ land parcel.

This edit was focused on four sub-models reflecting (1) agricultural production, (2) GHGs from agriculture, (3) timber production,and (4) GHGs from new woodlands (carbon sequestration). In (1) and (3), market prices were used while in (2) and (4), a range of carbon values were used.

## 2.1 Carbon values

To calculate the value of GHGs emitted, a range of carbon prices were used. Following (BEIS, 2021), the value recommended by government guidance is £240 tonne of $CO_2e$ in 2020 as the GHGs from agriculture and woodlands are not traded goods. It must be noted that the value of non-traded carbon has been revised following the adoption by the UK of net zero emissions by 2050. With the potential of carbon markets becoming established for woodlands, two additional values were used, £20 /tonne of $CO_2e$, the value of carbon sequestered by woodlands in recent auctions in the UK and £80/ tonne of $CO_2e$ the price of carbon traded in the UK ETS.

Each of the sub-models will be discussed in turn.

## 2.2 Agricultural sub-model

To determine the economic values from agricultural production, a profit function model was developed to investigate the relation between farm profit (Net Cash Income (NCI)) and the input factors of production using representative farm businesses for Northern Ireland. As LUMNI needed the value of agricultural production for each parcel of land to compare the benefits from agricultural production with the other ecosystem services, the model was developed to estimate the value of total agricultural output for each of the 5 $km^2$ land parcels.

This was based on:

1) DAERA's annual Farm Business Survey (three consecutive years 2016-2018) which contains information on representative enterprises' inputs of production and financial indicators.
2) DAERA's agricultural census which contains information on crop areas, livestock numbers and farm labour for each of the 5$km^2$ land parcels.

The production factors estimated by the model relate to (1) the area of land under arable production (cereals, potatoes) and (2) headage numbers for livestock (dairy cows, cattle, sheep, and pigs) in a) Severely Disadvantaged Areas (SDA), b) Disadvantaged Areas (DA) and c) the lowlands (non-Less Favoured Areas (non-LFA)). To include specialised farms as well as diversified farms (multi-input), interactions between the production factors were permitted. This took account that on some farms there will be competition for inputs (primarily land) as well as complementary uses for example on SDA and DA beef cow farms, sheep may be able to access land for foraging on less palatable grass which were inaccessible to cows and tend to remain outdoors for longer in the year. This approach was adopted due to the large variation in output prices observed for specific factors of production, such as potatoes.

The primary aim of the profit function model was to derive marginal cash income or marginal profit values for each unit of input factor of production, assuming constant returns to scale. This will enable the values of total agricultural output for each of the 5km$^2$ land parcels to be estimated by multiplying these per unit marginal cash incomes with the data on livestock and arable production from the agricultural census.

## 2.3 GHGs from agriculture sub-model

As previously highlighted, agricultural production has the potential to emit or remove GHGs. The changes in agricultural production identified in the agricultural sub-model form the basis of changes in GHGs emissions sub-model.

The analysis uses guidance developed by the Inter-governmental Panel on Climate Change (IPCC) (1996, 2006 and 2019) to determine the impact on GHGs emissions from changes in agricultural output identified in the agricultural sub-model for each land parcel. Each signatory to the climate change agreements must submit an annual GHG Inventory which includes total GHGs and details the emission sources and sinks. To ensure that each country's annual submissions are complete and comparable, the IPCC (1996, 2006 and 2019) provides guidance on the quantification of GHG emissions and removals from anthrophonic sources using internationally agreed methodologies. Research is still on-going to improve this guidance to take into account scientific and other technical advances.

Emissions from the agriculture sector consists of emissions from livestock, agricultural soils (excluding those included in the LULUCF sector) and agricultural machinery (BEIS, 2021). This study focused on the main GHGs from agriculture in Northern Ireland, namely:

1. Enteric fermentation (Methane $CH_4$) – 54%.
2. Manure management (Methane ($CH_4$) and nitrogen ($N_2O$) – 20%.
3. Fertilisation (N) – 16%.

Underlying GHG emissions calculations in the IPCC guidance are the 'Emission Factor' (EF) - a coefficient which quantifies the emissions or removals per unit of activity and the extent of emitting activities being undertaken the 'Activity Data' (AD). Emissions are equal to the AD multiplied by the EF. Since 2006, the IPCC guidance has adopted a tiered approach reflecting the availability of data and modelling expertise in each of the participating countries when calculating the ADs and EFs. The tiers are:

- Tier 1: is the simplest approach where equations and default parameter values provided in the latest version of IPCC guidance can be used, e.g., the emission and stock change factors. Requires: country-specific data for AD.
- Tier 2: this extends Tier 1 for the most important land-use or livestock categories, where country or region-specific data are used for the EF.

- Tier 3: process-based models and inventory measurement systems are developed to address national circumstances, driven by high-resolution activity data and disaggregated at sub-national level.

To obtain the total agricultural emissions at a spatial level, the equations and default parameter values under Tier 1 and 2 of the IPCC (2019) guidance were conducted for enteric fermentation (Methane $CH_4$), manure management (Methane ($CH_4$) and nitrogen ($N_2O$) and fertilisation (N), for each 5 $km^2$ land parcels based on the number of livestock and cropland in each parcel.

### **2.4** Timber sub-model

The timber model within LUMNI is based on the expected timber yields for two representative commercial species in each of the 5$km^2$ land parcels across Northern Ireland. The model focused on

1) Sitka spruce, widely planted from the forestry industry due to its high yields and adaptability on poor soils.
2) Pedunculate oak, a native evergreen highly valued from the industry for its hardiness and durability.

Recognising that climatic changes impact on forest growth i.e., wind, soil and altitude, a Residual Maximum Likelihood (REML) model was used to identify yield class using inventory data from the Forest Service of Northern Ireland. The fixed effects fitted within the model were species, soil type (mineral, organic, organic mineral and ranker), wind speed (<5.5, 5.5-6.0, 6.0-6.5, 6.5-7.0, 7.0-7.5, >7.5) and elevation (<150m, 150m-300m, >300m).

A spatial model was fitted to the inventory yield class residuals taking account of the inventory grid coordinates. This spatial model estimated yield class residuals for the Forest Service managed areas and privately owned forests, enabling the Maximum mean annual increment (MMAI) to be obtained taking into account species, and the criteria yield class, percentage of species covering the plot, thinning regimes and spacing. For privately owned forests it was assumed that the:

- Felling age was 100 years for Oak and 50 years for Sitka Spruce;
- Spacing was 2.2 m for Oak and 2m for Sitka Spruce;
- Thinning regime was one early thin; and,
- Percentage of species covering the area was varied from 75% to 100% in increments of 5%.

To estimate timber output values for the hypothetical woodlands, expected timber yields for two representative commercial tree species within each 5$km^2$ grid squares were obtained:

1) Sitka spruce - planted on intensive pasture in areas below 150 metres of elevation;

2) Oak - planted on semi-natural land-use in areas above 150 metres of elevation.

These yields, the expected output per hectare would enable the value of timber production to be determined when combined with the price of timber using market price data.

### 2.5 GHGs from timber production model:

Planting new woodlands has the potential for sequestering carbon as well as the production of timber. To include the value of carbon from the new woodlands within LUMNI, there were two steps needed:

1) Estimate the amount of carbon sequestered by the new woodlands.
2) Estimate the value of the carbon which has been sequestered.

To obtain an estimate of the carbon sequestered by the woodlands, the established Woodland Carbon Code (Forestry Commission 2021) was used. This code has been developed to support the market for carbon through woodland creation and as such provides a robust evidence base for the new Woodland Carbon Guarantee (WCaG) scheme in England and Wales where landowners receive Woodland Carbon Units (WCU) for carbon sequestered by new woodlands which can be sold, rather than grants.

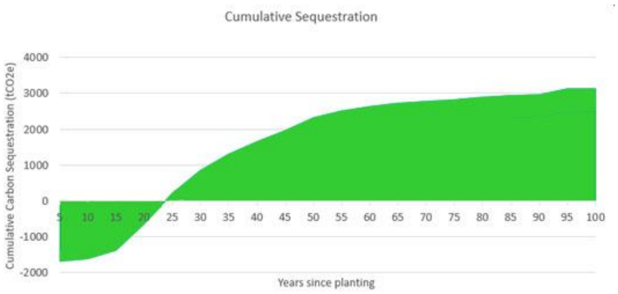
This code aims to encourage a consistent approach to woodland carbon-orientated planting projects and offers clarity and transparency to customers about the carbon savings that their contributions may achieve. A key aspect has been the development of recommended procedures for estimating woodland carbon stock for different tree species at a range of scales (Jenkins et al., 2011). This accounts for:

1. Carbon within the tree (including roots, stem, branch, and foliage) and debris – e.g., litter fall, or dead wood left in the forest at thinning.
2. Soil carbon content prior to woodland planting – either based on the previous land-use (woodland, semi-natural land, pastureland, or arable land) or the type of soil (organic, organo-mineral, or mineral soil).
3. Management of land – the intensity of the ground preparation and ongoing management will affect the carbon stored within the topsoil (0-30cm).

**It provides information on the carbon sequestration from a new woodland taking into account a range of factors which will affect the carbon sequestration rates including the tree species, the expected timber yields, tree spacing, and management regime, including carbon emitted during planting. The carbon sequestered over a lifetime is shown in**

Figure 2-1

Figure 2-1-Lifespan net emissions of a woodland



For the LUMNI, it was assumed that new woodlands would be:

a. Planted on agricultural land:
    i. Oak on semi-natural land-use in areas above 150 metres of elevation
    ii. Sitka spruce on intensive pasture in areas below 150 meters elevation.
b. As new woodlands will not be planted on peaty soil, 'mineral soil type was selected rather than organo-mineral,'
c. Assumed that medium disturbance would be caused to the soil for all new woodlands.

To estimate the monetary value of the carbon sequestered, the annual amount of carbon sequestrated by a woodland can be multiplied by the carbon prices discussed in section 2.1 and used within the sub-model for GHGs from agriculture.

## 2.6 LUMNI optimising programme

In LUMNI, an optimisation programme is used to determine the land-use(s) which deliver the highest values. This integrates all the outputs of these sub-models, effectively comparing the benefits delivered by an alternative land-use and its costs, including the foregone benefits of the existing land-use -the opportunity cost. If the benefits delivered by the alternative land-use delivers exceed the costs, a net benefit there is an economic argument for a change to this land-use. However, if the alternative land use does not deliver greater benefits, then there is no justification to support that change.

The optimisation process with the sub-models included within LUMNI are run at the level of the land parcels, producing an ordering of those parcels in terms of the scale of the net benefits they deliver. This ordering will indicate the areas within Northern Ireland (if anywhere) where changing the land use will deliver the most benefits. If there is a role for government in guiding land-use change, this model will target the change to the areas which will ensure the maximum benefits are achieved.

## *3 Scenarios*

This edit of LUMNI is based on new woodland planting on agricultural land; where should new woodlands be planted in Northern Ireland and what are the net benefits of doing so. Scenarios were developed to explore the impact of different levels of planting based on the ecosystem services delivered by the two land-uses, i.e., the trade-off between the agricultural output and the associated emission of agricultural GHGs compared to the value of timber produced and carbon sequestered by the new woodlands.

LUMNI explored the potential for planting new woodlands in Northern Ireland by 2050 under the following 3 scenarios:

- Current rate of planting (200 ha/yr)
- Forests for Our Future Programme (900 ha/yr)
- Double woodland cover in Northern Ireland (1,600 ha/yr)

To identify where woodlands should be planted, an optimising programme was run for each scenario based on the woodlands being planted in 25-hectare blocks.

# *4 Results*

## 4.1 LUMNI sub-models

### *4.1.1 Results from the agricultural sub-model*

The profit function model developed in LUMNI to obtain the value of agricultural production at a spatial level by investigating the relation between farm profit (Net Cash Income (NCI)) and the input factors of production using representative farm businesses for Northern Ireland. Interactions in the model showed:

- Dairy farms in DA are more profitable if they included sheep, but less profitable if they included beef cattle. This suggests that dairy and beef cows are competing for similar resources while sheep and dairy production are complementary. Contrary, dairy farms in lowland areas would lose out by diversifying.
- For both dairy and potato farms, diversifying into cereals would have a negative impact on profits.
- In DA areas, mixed beef and sheep farms would be more profitable than farms which specialised in either beef or sheep.
- The largest dairy farms are not the most profitable as they are operating at a higher than their optimal size.

The primary aim of the profit function model was to derive marginal cash income or marginal profit values for each unit of input factor of production, assuming constant returns to scale. This enables the values of total agricultural output for each of the 5km$^2$ land parcels to be estimated by multiplying these per unit marginal cash incomes with the data on livestock and arable production from the agricultural census.

Comparing the results of the model at the Northern Ireland level are shown in Table 4-1. As can be seen, the estimated economic importance of each agricultural sector is broadly comparable to that found in the Agricultural Census of 2018 (DAERA, 2019). One difference is that the model over-predicts the output of sheep which can be attributed to the inclusion of subsidies in this model unlike the Agricultural Census figures (DAERA, 2019).

The value of the agricultural output for each of the 5 Km$^2$ land parcels is shown below in

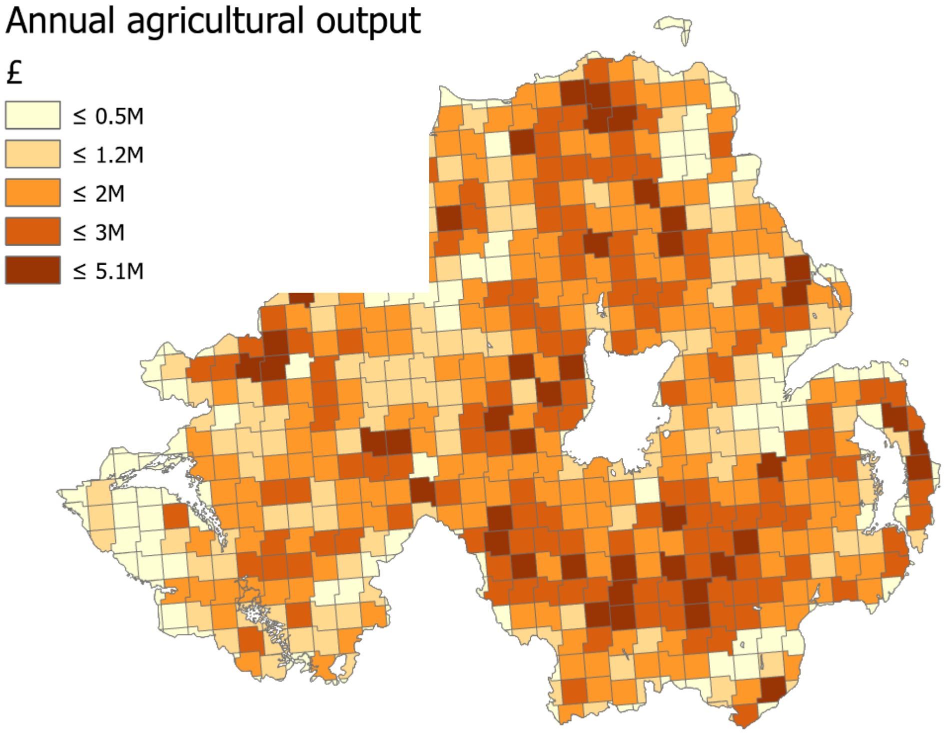
Figure **4-1**. As expected, the agricultural output in the land parcels correspond to the Agricultural Land Class Areas shown in

Figure **4-1**, with the land parcels with over £2 million relating to the Land Classes 1 (excellent quality), 2 (very good quality) and 3a (good quality). Likewise, the land parcels with output values of less than £0.5 million were classified as either 4 (poor quality) and 5 (very poor quality) or Urban.

### Table 4-1 – *Marginal cash income per input production factor and output*

| Agricultural sector | Marginal cash income/factor | Hectares & headage numbers (Agricultural Census 2018) | Estimated output (£'m) | Estimated share of Northern Ireland agricultural output (%) | | Share of Northern Ireland agricultural Output (%) (DAERA, 2019) |
|---|---|---|---|---|---|---|
| Cereals | 617.692 | 30,000 | 18.5 | 3.94% | | 3.7% |
| Potatoes | 3260.139 | 3,600 | 11.7 | 2.49% | | 1.7% |
| Dairy cows | 765.926 | 311,000 | 238.2 | 50.60% | | 51.9% |
| SDA (beef) | 379.435 | 117,000 | 44.4 | 9.43% | 18.93% | 16.5% |
| DA (beef) | 264.850 | 76,000 | 20.1 | 4.28% | | |
| Lowland (beef) | 396.696 | 62,000 | 24.6 | 5.22% | | |
| SDA (sheep) | 107.601 | 547,000 | 58.9 | 12.50% | 19.44% | 4.2% |
| DA (sheep) | 103.699 | 215,000 | 22.3 | 4.74% | | |
| Lowland (sheep) | 53.484 | 194,000 | 10.4 | 2.20% | | |
| Pigs | 34.109 | 634,000 | 21.6 | 4.59% | | 6.2% |

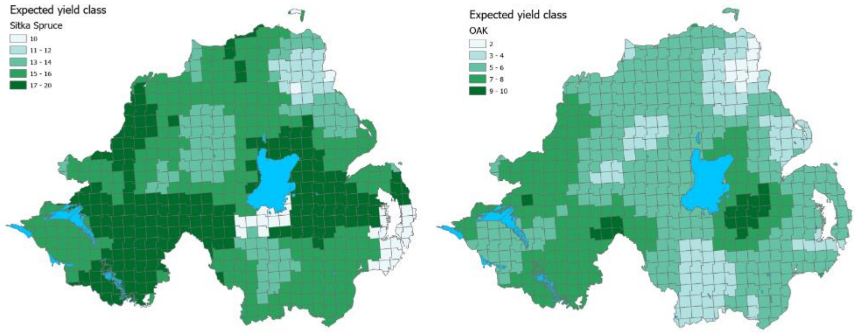
Figure 4-1 Total agricultural output



## 4.2 Results from the Timber sub-model

Using the spatial model estimated yield class residuals for the Forest Service managed areas and privately owned forests. The yield class residuals were then adjusted using the results from the REML model to derive yield class estimates for the Forest Service managed areas and privately owned forests. Based on the Maximum mean annual increment (MMAI) were obtained for each land parcel, these are shown in Figure 4-2.

**Figure 4-2 Expected yields for Sitka spruce (left) and oak (right)**



As can be seen, the yields for both species vary across Northern Ireland, with similar areas having the highest growth rates for both species, i.e., to the south east of Lough Neagh, the east of Lough Erne. However, the yield rates for the sitka spruce exceed those for oak in all land parcels.

### *4.2.1 Results from GHGs from agriculture sub-model*

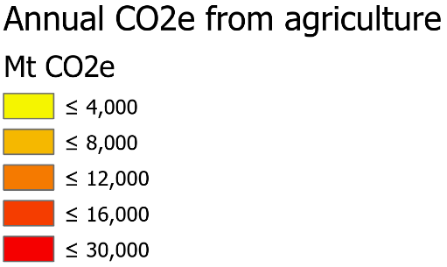
In this edit of LUMNI, the change in GHGs will result from the cessation of agricultural production when new woodlands are planted – this is not the carbon sequestered by the woodlands, that is considered in section 4.2.2.

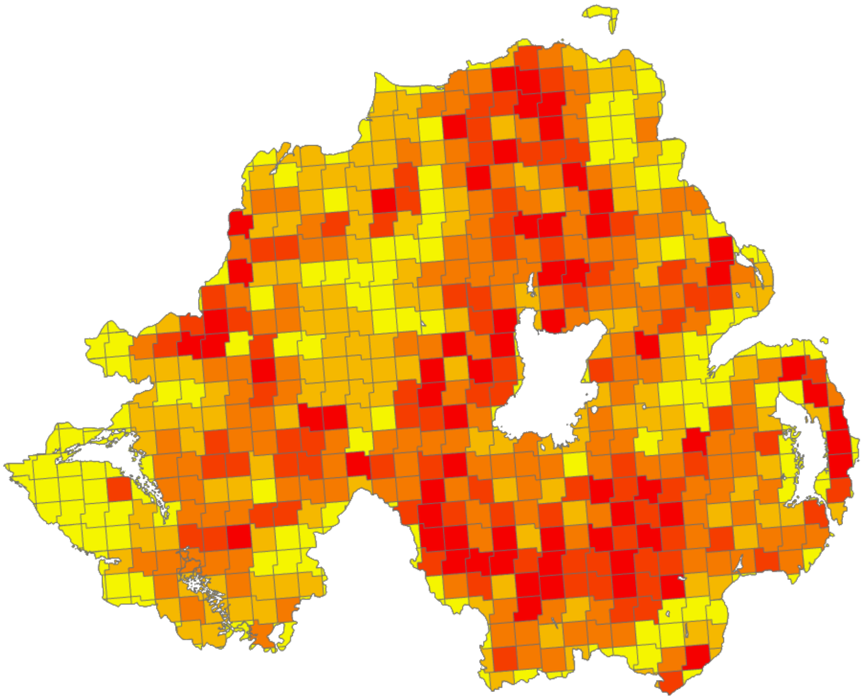
To calculate the emissions from agricultural production in carbon dioxide equivalents ($CO_2e$), coefficients for different agricultural land-uses from the IPCC (2019) and DAERA (2019) were applied to the outputs of the agriculture sub-model described in section 4.1.1.

Figure 4-3 illustrates the estimated carbon emissions for each of the land parcels. These largely follow the pattern of

Figure **4-1** with the land parcels with high GHGs being located in similar areas to those which had the highest agricultural production output. This is not unexpected given that the higher agricultural practices in Northern Ireland are those which have higher GHG emissions such as dairy enterprises.

**Figure 4-3** ***Total emissions from agriculture***





This approached estimated the total annual emissions of GHGS to be 5.6 $MtCO_2e$, comparable with the GHG Inventory.

### 4.2.2 *Results from GHGs from timber sub-model*

As recognised in the Marrakesh Accord Agreement, agricultural activities can be used to offset GHG emissions. To obtain an estimate of the carbon sequestered by new woodlands, the well-established Woodland Carbon Code (Forestry Commission 2021) was used with the carbon values previously discussed in section 2.1.

### 4.2.3 *Results from LUMNI:*

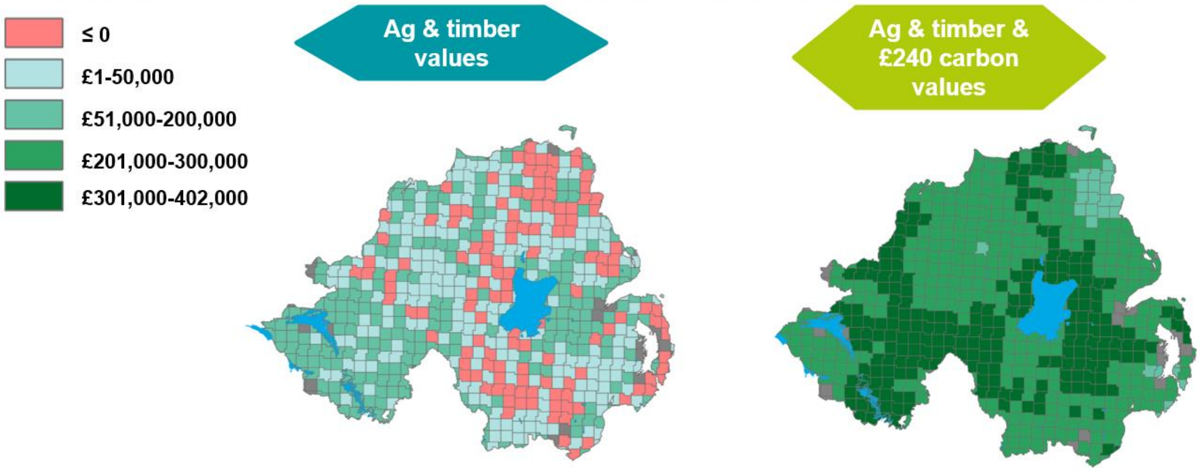
Each sub-model identified the potential benefits resulting from either agricultural use or woodland use in each of the 5 $km^2$ land parcels. To determine where new woodlands should be planted, an optimisation process was undertaken which identified the net benefits (or net costs) from planting new woodlands in each land parcel. This is shown in Figure 4-4 below, when no carbon value is included and when a carbon value of £240 /$tCO_2e$ was used.

This showed that when only private benefits are considered, there are few land parcels in Northern Ireland where the benefits of planting woodlands exceed the cost of losing agricultural production by more than £200,000, while many incur a net cost. In contrast, when a carbon value of £240/t $CO_2e$ is applied, then planting in all land parcels will exceed the cost of the forgone agricultural production, with many parcels having net benefits of over £301,000.

In addition to the change in the monetary benefits, there was also a change in the location of the planting with the introduction of the carbon value. Previously, woodland planting was most profitable in the poorer quality land to the west of

Northern Ireland. In contrast, the parcels which delivered the higher benefits were also located in the better-quality agricultural land, albeit not the best agricultural land where previously woodland planting would have incurred a net cost.

**Figure 4-4 The net benefits of planting new woodland, without and without carbon values.**



In the optimisation process, the “planting” of the new woodlands in 25-hectare blocks was allocated in turn to the land parcel where it would deliver the highest benefits. This was repeated until all the woodland areas were ‘planted’ for each of three scenarios highlighted in section 3 for the years 2018 to 2050.

## 4.3 Benefits delivered by new woodlands.

The results of the LUMNI for different tree planting scenarios based on the inclusion of different values are shown in Table 4-2.

As can be seen in Table 4-2, when only the private benefits were considered, i.e., using a carbon value of £0, planting any amount of trees will result in a net cost, ranging from £8 million for 200 ha planted each year, to £80 million for 900ha/yr and £156 million for 1,600 ha/yr. The cost per hectare of planting the new woodlands also increases as the amount of planting increases. While planting 200 ha a year incurs a net cost of £40,000/ha, this increases to £89,000 when 900 ha are planted each year and £98,000 when 1,600 ha are planted each year.

Introducing any of the three carbon values used in the analysis, while reducing the net costs of planting the new woodlands across all scenarios only delivers a net benefit when the carbon value is £240/t$CO_2e$. Using a value of £20 /tonne of $CO_2e$, the value of carbon sequestered by woodlands in recent auctions in the UK all woodland planting had a net cost, while only the 200ha/year woodland scenario delivered a net benefit when using the post-2019 traded carbon price of £80/tonne of $CO_2e$. Again, the cost per hectare increased as the amount of planting increased. The breakeven points for the carbon values were £101, £99 and £67 for each of woodland planting scenarios of 200, 900 and 1,600 hectares/year.

**Table 4-2 - The benefits from LUMNI**

| Planting scenario | Carbon price £/$CO_2e$ | Value in 2050 (£'m) | Value in 2050 (£'m/ha) |
|---|---|---|---|
| | | | |
| Current rate of growth (200 ha/yr) | £0 | -£8 | -£40,000 |
| | £20 | -£6 | -£30,000 |
| | £80 | £1 | £5,000 |
| | £240 | £32 | £160,000 |
| | | | |
| Forests for Our Future Programme (900 ha/yr) | £0 | -£80 | -£89,000 |
| | £20 | -£64 | -£71,000 |
| | £80 | -£17 | -£19,000 |
| | £240 | £118 | £131,000 |
| | | | |
| Double woodland cover in Northern Ireland (1,600 ha/yr) | £0 | -£156 | -£98,000 |
| | £20 | -£127 | -£79,000 |
| | £80 | -£38 | -£24,000 |
| | £240 | £202 | £126,000 |

### *4.3.1 The location of the planted trees:*

The increased costs per hectare of woodland planted is a consequence of amount of woodland being planted. For the 200 ha/year scenario, the new woodlands were able to be planted on the poorer agricultural land within Northern Ireland. However, in the increased woodland planting scenarios, the optimisation process had to select areas with higher agricultural productivity to plant the additional trees and therefore incurred higher costs. As the carbon value increased, planting trees on the higher quality land became viable as shown in Figure 4-4.

### *4.3.2 The amount of GHGs emitted/carbon sequestered:*

As can be seen in Table 4-3, in 2050, the planting 1,600 ha/year scenario would reduce GHGs by of 1.5 million /tonne of $CO_2e$ (compared to 2019). Reducing the area of trees planted would reduce the avoided GHGs to between 118,485 and 253,592 $tCO_2e$ if only 200 hectares were planted each year, depending on the carbon value used.

**Table 4-3 GHG emissions and carbon sequestration under the woodland planting scenario**

| | Carbon Value | Loss of agricultural emissions | Carbon sequestration | Total avoided GHGs |
|---|---|---|---|---|
| | | | | |
| Current rate of growth (200 ha/yr) | 0 | 86,983 (73%) | 31,502 (27%) | 118,485 |
| | 20 | 87,756 (74%) | 31,560 (26%) | 119,316 |
| | 80 | 94,421 (75%) | 31,979 (25%) | 126,400 |
| | 240 | 220,812 (87%) | 32,780 (13%) | 253,592 |
| | | | | |
| Forests for Our Future Programme (900 ha/yr) | 0 | 643,484 (82%) | 141,505 (18%) | 784,989 |
| | 20 | 644,042 (82%) | 141,580 (18%) | 785,622 |
| | 80 | 646,835 (82%) | 141,914 (18%) | 788,749 |
| | 240 | 758,551 (84%) | 142,655 (16%) | 901,206 |
| | | | | |
| Double woodland cover in Northern Ireland (1,600 ha/yr) | 0 | 1,228,048 (83%) | 251,145 (17%) | 1,479,193 |
| | 20 | 1,228,164 (83%) | 251,145 (17%) | 1,479,309 |
| | 80 | 1,228,728 (83%) | 251,364 (17%) | 1,480,092 |
| | 240 | 1,270,928 (83%) | 251,579 (17%) | 1,522,507 |

Increasing the carbon value reduces the GHGs emissions from the same area of woodland planted, for example using £240/t $CO_2e$ rather than £80/t $CO_2e$ resulted in 44,000 tonnes less of $CO_2e$ being emitted in the 1,600 ha /year scenario (2% improvement), while the amount of GHGs not emitted doubled under the current planting rate (131,000 tonnes of $CO_2e$). This is due to the higher carbon values increasing the cost of GHGs emissions from agricultural production, enabling woodlands to compete with agriculture on the better-quality land.

As the carbon price increases, woodlands will be planted on more productive land due mainly to reduction in GHGs emissions from agricultural productions; 73-87% of the reduction in carbon in 2050 resulted from the reduction in GHGs emissions from agriculture and the remainder from carbon sequestration.

## *5 Conclusions*

This application of LUMNI has shown that introducing a value of carbon ensures that planting new woodlands will deliver a net benefit to the landowner and contribute to achieving net zero. The financial value of timber alone is insufficient to offset their loss from agricultural production, apart from a few small areas of poor agricultural land. Including a carbon value of at least £101/tonne of $CO_2e$ will deliver net benefits when planting 1,600 ha of new woodland annually. However, using a higher carbon value will result in greater GHG reductions from the same area of woodland planted as woodlands will be planted on higher quality agricultural land.

Planting an additional 1,600 ha of woodland annually in Northern Ireland has the potential of reducing GHGs by 1.5 million tonnes of $CO_2e$ in 2050. This would reduce current emissions from the agricultural sector in Northern Ireland by 26% and total emissions by 7%.

The GHG reductions emissions from a change from agricultural use to woodlands are predominately from the cessation of agriculture (87%) rather than carbon sequestration from the new woodlands. This finding has a direct impact on the development of new incentive schemes for woodland planting. The English Woodland Carbon Guarantee (WCaG) scheme has recently been introduced which enables farmers to sell the carbon sequestered by their woodlands at auctions. The average price of carbon was £20 t/$CO_2e$ in its first four auctions (Forestry Commission, 2022). which is lower than the break-even value of £101/t$CO_2e$ for 13% of the GHGs included within the model. These results indicate that the current value for carbon used in the current strategy are unlikely in isolation to deliver the desired levels of woodland planting in the locations which will have the greatest contribution to achieving net zero.

*Need for financial support.*

When only the market prices (agricultural and timber production) are considered, limited woodland planting will occur as it will mostly incur a cost to the landowner as the loss of agricultural values will exceed the timber values and the landowner will not receive a financial reward for the other benefits delivered by the new woodlands. LUMNI identified a few areas where 25 hectares of woodland could be planted and deliver benefits to the landowner, but these were insufficient to support deliver y of 200 hectares a year over the 2018 to 2050 without incurring a net cost.

In order to increase the planting rates, the landowner will require a financial payment to outweigh the cost of forgone of agricultural production. LUMNI identified that the break-even carbon values, whereby the costs of lost agricultural production are met, were £101 tonne of $CO_2e$ for a planting rate of 1,600 hectare/year, £99 for 900 hectares/year and £67 for 200 hectares/year. However, this will reduce the GHG reductions compared to the carbon value of £240 tonne of $CO_2e$ recommended for use within government policy for non-traded carbon.

*Method of financial support*

Support for woodland creation is currently provided through the agri-environment schemes with payments based on costs incurred and income forgone. Carbon markets are beginning to be developed, rewarding landowners for the carbon they sequester with financial payments. The Woodland Carbon Code (Forestry Commission, 2020) provides the means to determine, quantify and validate the carbon being sequestered by new woodland. LUMNI demonstrated that the value of carbon needed to secure the largest reductions was the government recommended value for non-traded carbon which is far greater than the current tradable value. While it is conceivable that a carbon market could deliver the break-even values identified above, any payment would only relate to the 13-27% of the GHGs resulting from carbon sequestration. Unless a rationale can be provided to compensate landowners for not emitting GHGs, these payments in isolation will be insufficient to deliver the reductions in GHGs required. Payments for other ecosystem services may be used to fulfil this gap.

Caveats:

1) LUMNI assumes that any additional woodland planted will be managed to maximise the timber yield. This may be an unlikely assumption with the timber processing industry focused on softwood production rather than hardwood and dominated by timber from the Forest Service woodlands. Therefore, to realise the values included within the LUMNI may require the provision of support and guidance to ensure that these new woodlands are managed appropriately.
2) The LUMNI assumes that landowners will respond to the price signals which might not be the case. If there are other barriers, this may require additional support to change attitudes to tree planting.
3) It must be remembered that this model, is based on a relatively high geographical resolution of 5Km$^2$ grid squares, with new areas of woodland being 25 hectares each in size. Therefore, the conclusions from LUMNI can predict general trends rather than refined figures. For example, While the current scale of LUMNI does not permit the exploration of the impact of planting small woodlands. Landowners may be more willing to plant trees on small patches of poor-quality land on their farm and this may be seen as a way to increase the area of woodland within Northern Ireland and assist in meeting the GHGs reductions needed. However, LUMNI has identified that the GHG benefits from woodlands planted on poorer quality land are not as great as those planted on better quality of agricultural land due to the reduced contribution to GHG emissions from the change from agricultural use. In addition, small areas of poor-quality land are likely to have limited recreation values due to 1) a lack of recreational access and 2) the scale of the woodlands. This highlights the need for a LUMNI at a lower resolution to explore these trade-offs.