Natural Environment Valuation Online Tool

Technical Documentation

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Chapter 3b: Forest Greenhouse Gases Model

Land, Environment, Economics and Policy (LEEP) Institute

University of Exeter

Corresponding authors

Amy Binner a.r.binner@exeter.ac.uk

Authors

Brett Day

Nathan Owen

Ian Bateman

Greg Smith

Patrick Collings

Louis Haddrell

Lorena Luizzo

Carlo Fezzi

Collaborators

Forestry Commission / Forest Research

UCL

JNCC

University of Aberdeen

1. The forestry greenhouse gas (GHG) module: GHG flows from forestry activities

1.1. Forest greenhouse gases in NEVO

The greenhouse gas tab in NEVO displays predicted average annual amount and value of greenhouse gas sequestration from forestry in each decade (2020 – 2060). The quantity of sequestration is expressed in tonnes of carbon dioxide equivalent (tCO2e), with negative values corresponding to greenhouse gas emissions. The value of sequestration is expressed in pounds and is calculated using the social cost of carbon. Values are also discounted into the future using a default discount rate of 3.5%. The amount and value of soil sequestration resulting from the conversion of land cover from or to forestry is also included. Under the Explore functionality in NEVO these are zero as soil is assumed to be in equilibrium, however land cover changes in ‘Alter’ and ‘Optimise’ will generate soil sequestration.

The greenhouse gas module includes an estimate of soil carbon sequestration, greenhouse gases released through land use change and preparation of the ground for tree planting, storage in tree biomass, releases through thinning and felling, and variations in the durability of the products that can be made from different species and diameters of timber harvest.

Users can choose to view the average annual value of greenhouse gas sequestration across each decade or they can toggle to view an annuity equivalent of the net present value calculated across two full rotations of the managed forest to account for the time taken for soil adjustments to take effect. The forest greenhouse gas model takes into account the impact of climate change on forest growth rates and hence on the rate of greenhouse gas sequestration by averaging over the length of time that forests grow at different rates (known as yield classes).

Limitations

Woodland in NEVO is simplified to two representative woodland types (broadleaf and coniferous) and a mixed 60-40 planting option. However, the underlying models contain wide variety of species which may be of interest to more specialised users.

NEVO uses data on average 2km grid cell characteristics – this approach enables models to be run quickly in the online tool however it is not as refined as site by site calculation with more detailed information on soil types, environmental site classification and management options.

Likewise, simplifying assumptions are made about the management options chosen when planting a new woodland. This allows NEVO to provide a high level analysis which considers multiple ecosystem services. Users may also wish to undertake a more detailed site specific approach e.g. the WCC tool permits more detailed inputs on the ground preparation.

1.2. *Introduction*

This section describes research that estimates the annual GHG flows arising from the afforestation of land, accounting for the emissions and sequestration associated with standing trees, harvested wood products (HWP), deadwood (litter) and soil. These flows vary with the chosen forest management regime, which in our analysis entails ‘thinning and felling’, referring to a combination of felling at the end of a rotation (the lifetime of a tree crop) and ‘thinning’ of a proportion of trees at various points within the rotation (thus maximising overall timber revenues). This analysis is coherent with the Woodland Carbon Code guideline (2013) which requires permanent land-use changes and conversion of no-forest land. All carbon measures are expressed as tCO_2 equivalent and are directly comparable with Woodland Carbon Units. Our analysis is underpinned by the Forest Research CARBINE model (Thompson and Matthews, 1989), which is employed in a wide range of forest decision applications (Matthews and Broadmeadow, 2009), however its use here is confined to the estimation of GHG flows.

1.3. *Objective*

To estimate the effect of new planting on net annual carbon flows in livewood stands, harvested wood products (HWP), deadwood and forest soils, for representative conifer (Sitka spruce) and deciduous (Pedunculate oak) species’.

1.4. *Data*

When applied in a spatially explicit manner, the CARBINE model uses inputs regarding tree growth rates derived from the Ecological Site Classification (ESC) decision support system developed by (Pyatt et al., 2001). Drawing upon the yield tables provided by Edwards and Christie (1981), the ESC (2013) model provides site specific estimates of potential timber yield class (YC) at the 2km grid cell resolution across the entirety of Great Britain. Specifically, ESC predicts the maximum mean annual increment in timber volume by yield class (YC; measured in m^3/ha/yr) for new plantations, taking into account the local characteristics of planting sites.

These estimates provide the basic input to the CARBINE analysis of GHG sequestration and emissions associated with livewood, harvested wood products (HWP), deadwood (including litter) and soil carbon.

For newly created forest areas tree species, year of planting and age are set as analyst-controlled variables in addition to variables relating to management regime and rotation period (in years assuming a clearfell regime), which form the initial data inputs into CARBINE. In our analysis we adopt 2013 as the initial year of planting and following assumptions:

- no genetic or agronomic improvements;
- no pests or disease impact;
- no fertilization or irrigation.

As stated, in this analysis we focus on a single management regime: ‘thinning and felling’. Thinning involves the removal of wood at prescribed stages during the lifecycle of the stand. Thinning is assumed to start several years after planting (varying across species and YC) and then occurs at regular periods (e.g. every 5 years). Felling ages similarly vary by species and growth rates. The present analysis assumes species representative stands and tree density (on planting or regeneration) of 2,500 trees per hectare. The spatially explicit nature of the analysis allows the calculation of species-specific carbon sequestration in livewood. Stem volumes (in units of cubic metres over bark per hectare) for both ‘standing’ and ‘removed’ wood are assessed for the chosen management regime. Stem biomass estimates are obtained by multiplying the species-specific stem volume (from Edwards and Christie, 1981) by a species specific value of wood density expressed as oven dry tonnes of mass per cubic metre of ‘green’ timber volume Lavers and Moore (1983). In the case of SS and POK these values are 0.33 odt/m^3 and 0.56 odt/m^3 respectively as shown in Table 3b.1.

Table 3b.1: Tree species, growth rates represented in the CARBINE model

Tree species	*Growth rate** *(m^3/ha/yr)*		*Basic density†* *(odt/m^3)*	*Allometric coefficients‡*	
	Lowest	*Highest*		*fR*	*fB*
Sitka spruce	*6*	*24*	*0.33*	*0.45*	*0.35*
Oak	*2*	*8*	*0.56*	*0.50*	*0.80*

** Growth rate is defined as the maximum average rate of cumulative volume production over a rotation. (The average rate of production will vary with the specified rotation.)*

The figures reported in Table 3b.1 summarise the rate of growth (YC), density of wood and allometric coefficients for the two species under consideration. Here fR and fB are species-specific coefficients assumed to be constant with respect to tree age, size and growth rate. The values assumed for different tree species are based on interpretation of summary estimates of root, branch, foliage and stem biomass using the Forestry Commission forest stand biomass model BSORT (Matthews and Duckworth, 2005).

1.5. Methodology

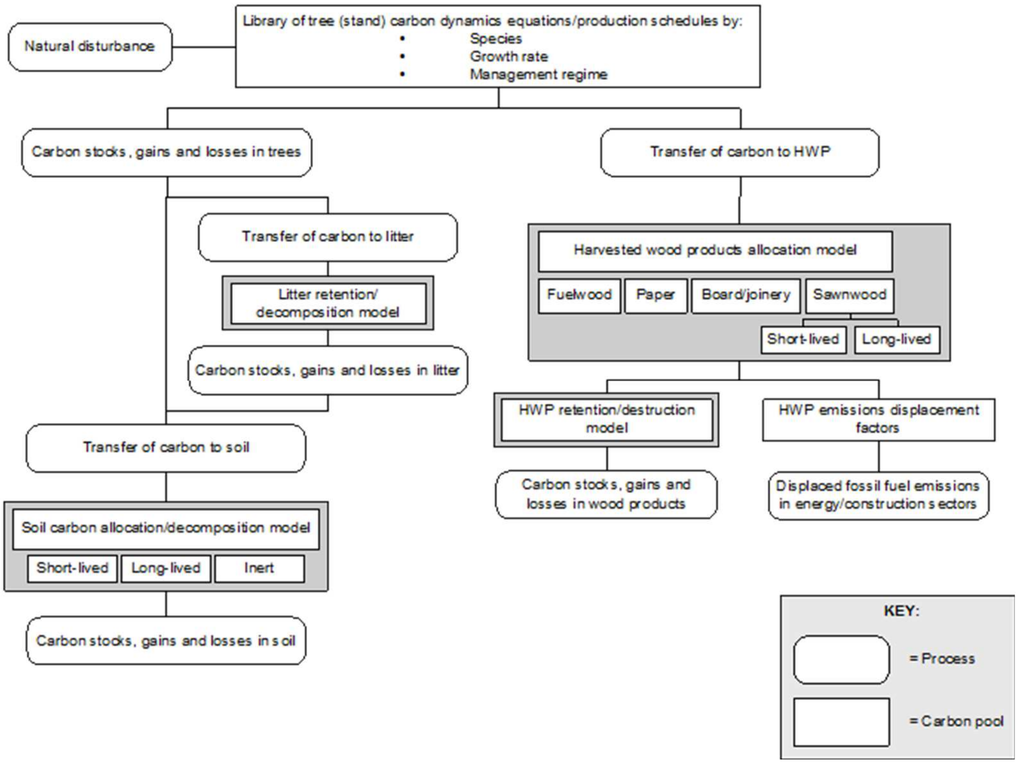
CARBINE is an analytical model of carbon exchanges between the atmosphere, forest ecosystems (trees, deadwood, litter and soil) and the wider forestry sector as a result of tree growth, mortality and harvesting (Thompson and Matthews, 1989; Matthews, 1991). Carbon sequestered in harvested wood of merchantable quality is allocated to HWP using a dynamic assortment forecasting model that accounts for variation in product out-turn specific to tree species and size classification of stem wood at the time of harvest (Rollinson and Gay, 1983). HWP are further categorised as long-lived and shortlived sawn timber, particleboard and paper. Each of these classes of wood products is modelled in terms of their service life and the consequent time profile of carbon emissions. So, for example, long-lived timber products have a much more delayed emission profile than say paper products. Emission profiles are set so as to emit all stored carbon over the lifetime of the relevant HWP. Carbon not sequestered in HWP is treated as waste and conservatively assumed to rapidly emit all stored carbon.

CARBINE consists of various sub-models, each estimating different aspects of forest carbon flows by calculating the stock levels at different points in time. The sub-models used in this analysis are:

- Carbon sequestered in and GHG emitted from livewood;
- Carbon sequestered in and GHG emitted from HWP;
- GHG sequestered in and GHG emitted from deadwood (litter);
- GHG associated with a range of soil types.

Note that a further CARBINE sub-model analysing the GHG implications of substituting timber for fossil fuels is not incorporated within the present analysis (although obviously such substitution raises the potential for afforestation delivering further net reductions in GHG emissions). The sub-models for livewood and deadwood each consist of four elements assessing stems, branches, foliage and roots. Total tree volume is converted to oven dry biomass using the values of wood density described in Table 3b.1 with a presumed carbon content of 0.5 tC per oven dry tonne of biomass (Matthews, 1993). Although the carbon content of woody dry matter is assumed to be constant, different tree species exhibit very different patterns of carbon sequestration because the dry matter content per unit volume (i.e. the wood basic density) is species-specific, as are relationships between crown, root and stem biomass (see Table 3b.1). An overview of the structure of the CARBINE model is provided in Figure 3b.1.

Figure 3b.1: Overview of the structure of the CARBINE model.



This provides an overview of the structure of the model, illustrating the processes and the various points of associated emissions.

To obtain estimates of carbon and biomass in tree roots, branches and foliage the model relies on simple allometric relationships with stem wood, as defined by Equations 3b.1 and 3b.2 respectively.

Equation 3b.1:

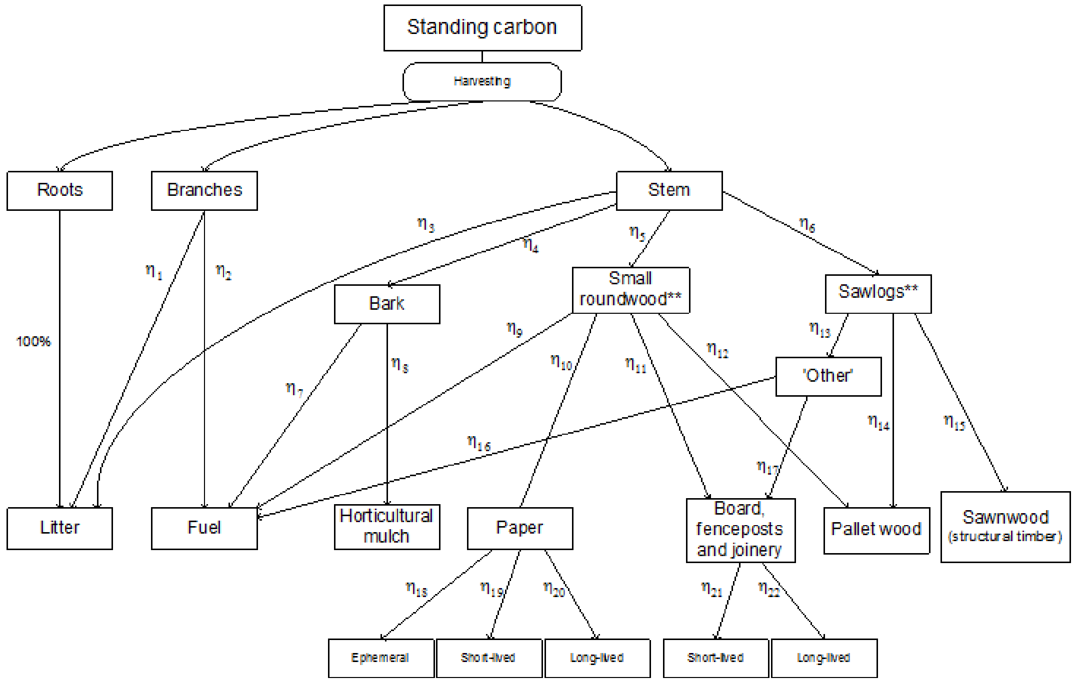
$$\text{Root carbon or biomass} = fR \times \text{Stem carbon or biomass}$$

Equation 3b.2:

$$\text{Branch + foliage carbon or biomass} = fB \times \text{Stem carbon or biomass}$$

Figure 3b.2 illustrates the CARBINE approach to allocating harvested wood between forest litter and primary products. Branchwood from harvested trees is assumed to be either used as wood fuel or left on site as part of the litter pool. The proportions allocated to be left on site or harvested for fuel are determined by simple partition coefficients, η_1 and η_2 (Figure 3b.2). These coefficients are both set to 50%. The first step in the ultimate allocation of harvested stem wood to primary products involves an initial allocation to waste wood left as litter in the forest and to three ‘raw’ stem wood categories of ‘bark’, ‘small roundwood’ and ‘sawlogs’. The proportion of stem wood allocated to litter is determined by a partition coefficient, η_3, which is set to a standard value of 10% FC_stats (2013). The allocation of the remaining stem material to bark, small roundwood and sawlogs (otherwise known as a product assortment) is determined respectively by the partition coefficients η_4, η_5 and η_6, which depend on the size and shape of the harvested trees. In turn, tree size and shape depend on many factors but notably tree species, growth rate and the relevant management regime (Matthews and Mackie, 2006). The specific definitions used for small roundwood and sawlogs also influence these allocations.

Figure 3b.2: **The allocation of harvested wood inherent in the CARBINE model**



* Proportion varies with tree size and shape

** (not including bark)

Source: BVCM report on tool and data 13 June 2011, R. Matthews

Assumptions regarding sawlog size are taken from previous applications of CARBINE and the calculation of bark, small roundwood and sawlog partition coefficients (η_4, η_5 and η_6) is based on standard tables given in Matthews and Mackie (2006) and Edwards and Christie (1981). However, some modelling of these results is necessary to enable the values in the tables to be accessed by variables available in CARBINE. The general form of the equations for estimating η_4, η_5 and η_6 expressed as percentages is given by Equations 3b.3, 3b.4 and 3b.5.

Equation 3b.3:

$$\eta_5 = 100 \times (1 - \eta_4 - \eta_6)$$

Equation 3b.4:

$$\eta_4 = 100 \times (1 - \text{fUB (dbh)})$$

where fUB (dbh) is a function for estimating underbark stem wood volume (or biomass or carbon) as a fraction of overbark stem wood volume (or biomass or carbon) and dbh is taken as the quadratic mean of the diameter breast height of the harvested trees (Matthews and Mackie, 2006). The parameter η_6 is defined as:

Equation 3b.5:

$$\eta_6 = 100 \times (\text{fUB (species, dbh)} \times \text{fSAWLOG (dbh)})$$

where fSAWLOG (dbh) is a function for estimating overbark sawlog volume (or biomass or carbon, for conifer or broadleaf sawlogs as defined above) as a fraction of overbark stem wood volume. Parameterization of fUB (dbh) and fSAWLOG (dbh) relies on piecewise relationships with respect to the quadratic mean dbh of harvested trees (for a fuller explanation the reader is directed to the work of Matthews and Mackie, 2006, and Edwards and Christie, 1981). These relationships also depend on tree species (or species group) and whether the stand has been thinned or not. The values assigned to other relevant partition coefficients are described in Table 3b.2.

Table 3b.2: Partition coefficients for allocation of 'raw' harvested wood material to primary wood product categories

Timber species group	Species-specific partition coefficients								
	Small roundwood				Sawlogs			'Other'	
	η_9	η_{10}	η_{11}	η_{12}	η_{13}	η_{14}	η_{15}	η_{16}	η_{17}
Spruces	20	20	35	25	70	0	30	43	57
Oak	80	20	0	0	80	15	5	56	44

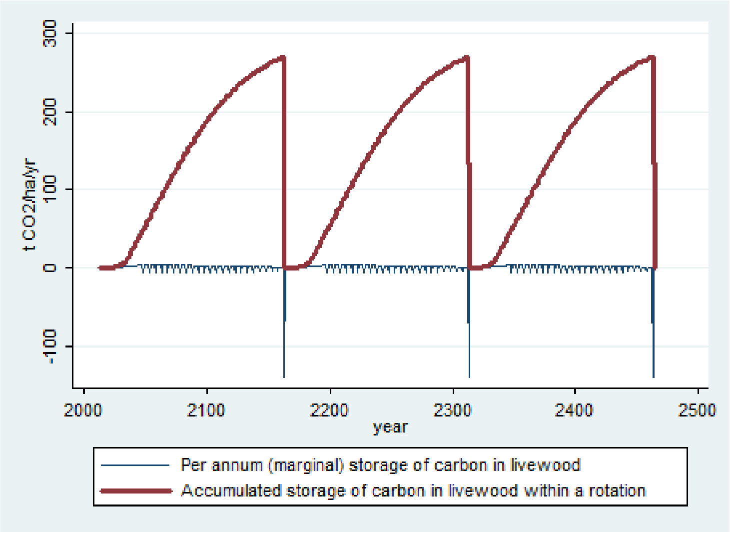
Source: Matthews and Mackie (2006)

Finally, the soil carbon sub-model runs concurrently with the forest sub-model. Initial soil carbon is estimated based on land use/cover (e.g. arable, pasture, etc.) and soil texture (sand, loam, clay or peat). The structure and parameterisation of the soil carbon sub-model is based qualitatively on the Roth-C agricultural soil carbon model (Coleman and Jenkinson, 1996).

1.6. Results

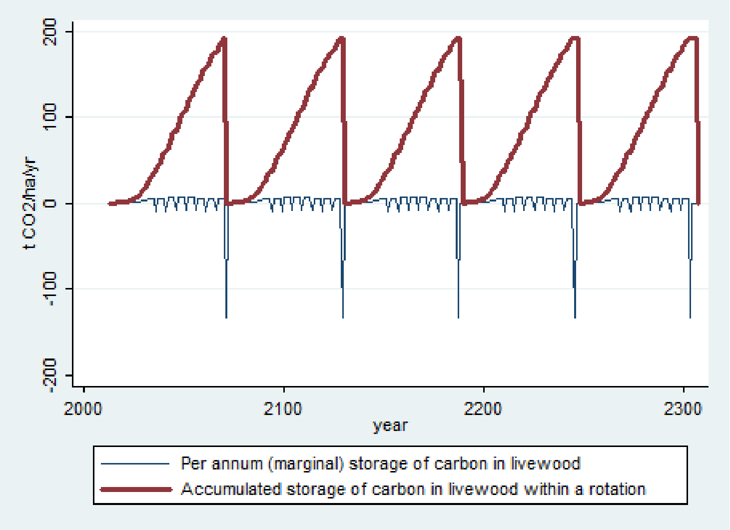
In this section we summarise certain key results from the CARBINE analysis of the GHG impacts of afforestation. Figure 3b.3 illustrates carbon sequestration (t CO_2eq/ha) in livewood for an area planted with Pedunculate oak (POK) growing at YC4. The two lines shown illustrate the livewood storage occurring in each year and the cumulative storage for each rotation (with felling clearly shown where the cumulative curve returns to zero and the per annum (marginal) curve records a major negative value as stored carbon is transferred from livewood to HWP or waste forms). The shape of the cumulative storage graph indicates that maximum marginal storage is reached about two-thirds of the way through the rotation. The graph also underlines the long term nature of rotations for deciduous species, with felling arising some 150 years after planting in this instance. Figure 3b.4 illustrates comparable curves for Sitka spruce (SS). While exhibiting similar marginal/cumulative relationships, SS rotations are typically much shorter (e.g. 58 years for YC14 SS).

Figure 3b.3: Carbon (t CO_2/ha) in pendunculate oak (YC4) livewood per annum (marginal) and accumulated within a rotation, over three rotations.



Source: CARBINE

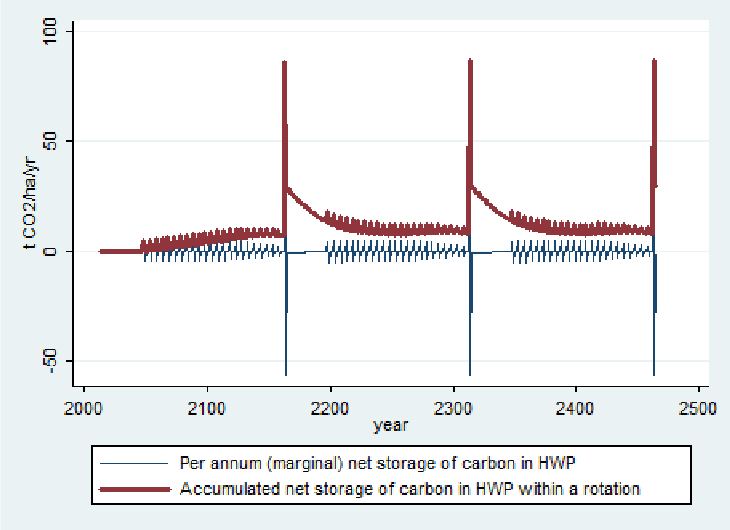
Figure 3b.4: Carbon (t CO_2/ha) in Sitka spruce (YC14) livewood per annum (marginal) and accumulated within a rotation, over five rotations.



Source: CARBINE

Continuing with the POK example, Figure 3b.5 graphs the marginal (per annum) and cumulative curves for the storage of carbon in HWP. This slowly increases over the first rotation and peaks immediately after felling. However, this peak is quickly reduced due to wastage and then more slowly erodes as we move further into the future as longer lived products slowly emit their stored carbon back into the atmosphere. This relationship is repeated for successive rotations. A somewhat similar pattern of build-up and then release is observed for carbon in forest litter.

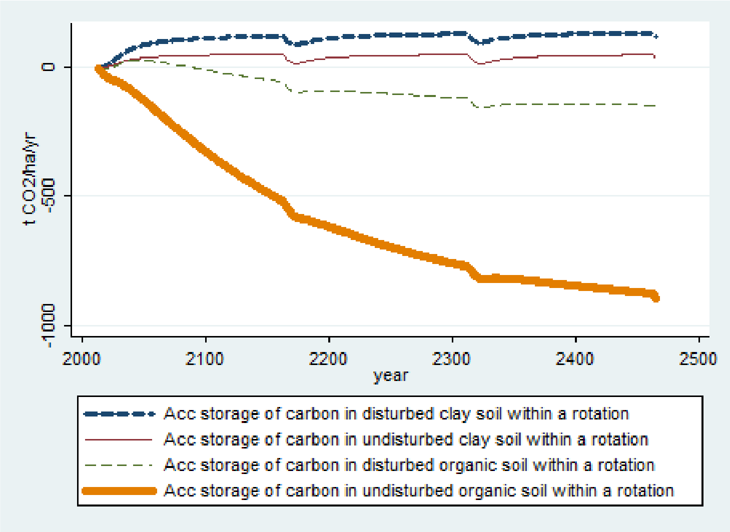
Figure 3b.5: Carbon (t CO_2/ha) in penduculate oak (YC4) harvested wood products (HWP) per annum (marginal) and accumulated within a rotation, over three rotations



Source: CARBINE

Key to any forecasts of the soil carbon contribution to net GHG flow is the ability to take into account the land-use prior to afforestation. This is differentiated according to whether prior soil use was either classified as disturbed or undisturbed. Still considering POK, Figure 3b.6 provides carbon profiles for both organic (peat) and clay soils, each being considered for both prior disturbed or undisturbed land use.

Figure 3b.6: Carbon (t CO_2/ha) in penduculate oak (YC4) accumulated or lost over three rotations for soil types: undisturbed clay; disturbed clay; disturbed organic; and undisturbed organic.



The most striking feature of this graph is the strong reduction in soil carbon which occurs when trees are planted on previously undisturbed organic soils (e.g. peatland). Table 3b.3 reports the quantity of carbon accumulated or lost over one rotation for different soil types. The negative values for organic soils confirm as in the Woodland Carbon Code guideline (2013) that the woodland creation on organic soil cannot be an eligible activity as it is associated to high quantity of carbon lost. This occurs because afforestation causes peats to dry out and release their previously stored carbon. As peatlands are superb stores of carbon the potential losses can be dramatic. In comparison afforestation of previously disturbed peatlands results in a much smaller level of losses – although this merely reflects the fact that previous disturbance will have already lead to drying out and carbon release. In contrast, the afforestation of most other soils results in an increase in carbon storage. Here the change is greatest for previously disturbed soils (such as arable areas subject to regular ploughing) which are likely to have suffered prior depletion of their natural carbon stocks.

Table 3b.3: **Carbon (t CO_2/ha) in penduncalate oak (YC4) accumulated or lost over one rotation for soil types: undisturbed clay; disturbed clay; disturbed organic; and undisturbed organic.**

Period	Disturbed mineral clay	Undisturbed mineral clay	Disturbed organic	Undisturbed organic
2013-2023	17.59	7.71	-1.58	-47.02
2024-2033	54.67	23.76	19.14	-69.14
2034-2043	77.37	33.40	26.44	-102.46
2044-2053	90.87	39.11	25.44	-141.70
2054-2063	99.26	42.58	20.16	-183.00
2064-2073	104.85	44.84	12.89	-224.18
2074-2083	108.87	46.44	4.79	-264.20
2084-2093	111.95	47.63	-3.53	-302.59
2094-2103	114.43	48.52	-11.79	-339.17
2104-2113	116.48	49.19	-19.85	-373.90
2114-2123	118.19	49.66	-27.67	-406.83
2124-2133	119.62	49.94	-35.21	-438.02
2134-2143	120.84	50.11	-42.44	-467.51
2144-2153	121.91	50.19	-49.32	-495.37
2154-2163	117.80	45.17	-60.92	-526.71
2164-2173	88.79	15.29	-96.99	-581.37

Source: CARBINE

Similar patterns of soil carbon change occur for coniferous afforestation.

1.7. Discussion and conclusion

The models described in this section are incorporated within our integrated modelling system as described subsequently in this report permitting assessment of the consequences of afforestation upon the sequestration and emission of GHGs. This assessment is comprehensive in that it embraces GHG in livewood, waste and forest litter, products and soil carbon.

1.8 References

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