Climate mitigation options through afforestation

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The establishment of new forests has a highly significant role to play in addressing our climate challenges and ensuring that we can build a significant future carbon sink by mid-century. Net removals of carbon dioxide from afforestation is the largest land-based mitigation option available and the main contributor towards the 26.8 MtC O_2 EU Effort Sharing emission reduction target 2021 – 2030.

Teagasc, in conjunction with FERS Limited and the Department of Agriculture, Food and the Marine (DAFM), have developed an online Forest Carbon calculation tool (www.teagasc.ie/forestcarbontool). This tool provides a non-technical and user-friendly way to estimate how much carbon can potentially be removed through various forest establishment scenarios and other climate mitigation pathways, such as through harvested wood products (HWP). To achieve accurate estimations, users of the Forest Carbon Tool need to familiarise themselves with the range of assumptions, methodologies and system boundaries described within the tool assumptions description, as well as the requirements and scope for future tool enhancements.

Carbon pools and fluxes

At forest level**,** carbon balances are based on net emissions or removals from five pools (reservoirs of carbon). These consist of above- and belowground biomass pools, the litter pool, the deadwood pool and the soil carbon pool (Figure 1). Continuous and complex carbon transfers (termed fluxes) occur between these pools. Carbon dioxide (CO_2) is absorbed from the atmosphere and sequestered by trees during photosynthesis with a corresponding release of oxygen. The rate of carbon uptake is affected by many factors, such as tree species, yield class, soil type, previous land use and forest management activities such as harvesting. Such processes involve the long-term allocation of carbon into above- and belowground forest biomass and the turnover of biomass into dead organic matter and soils. Carbon is returned to the atmosphere via autotrophic respiratory losses, and heterotrophic decomposition losses from dead organic matter and soils. Where carbon uptake exceeds loss, a forest is regarded as a "sink". Conversely, if loss exceeds uptake, then a "source". The resultant carbon balance is the sum of all carbon stock changes.

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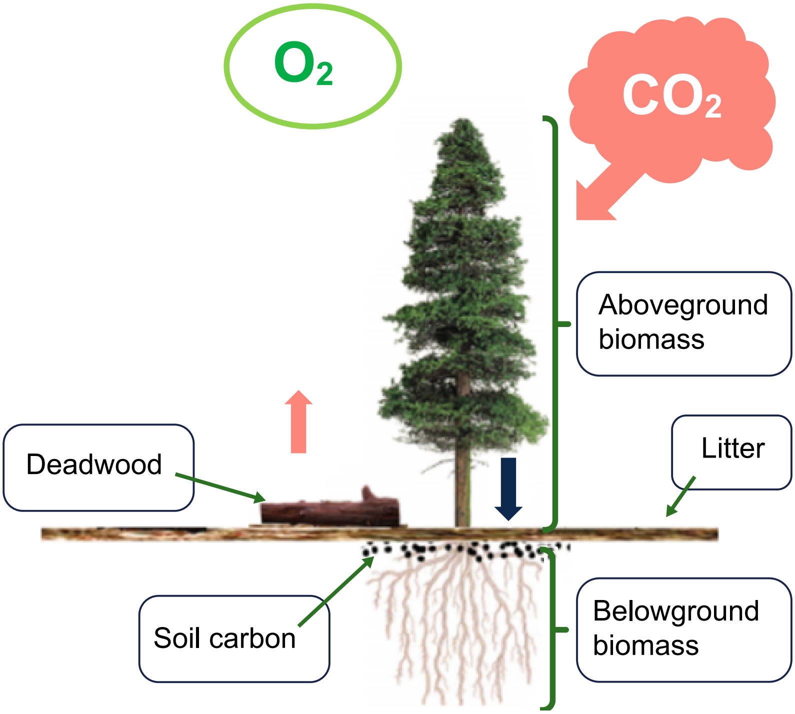

Figure 1: *Carbon pools at forest level (from Hendrick and Black 2009).*

In addition to carbon sequestration in a growing forest, the long-term storage of carbon in harvested wood products (HWPs) represents a well-recognised and important carbon pool. Substitution of fossil fuels with wood energy from sustainably managed forests is a further carbon mitigation pathway. These three pathways are incorporated into the Forest Carbon Tool. A further important pathway, not included in the current system boundaries, is the substitution of energy intensive building materials such as concrete and steel with wood products which can have a high level of impact ranging from -2.3 to 15 t C per t C of wood, with typical values 1-3 tC per tC wood used for replacement (Sathre and O'Connor 2010). For example, using 1.0 tonne of wood instead of concrete can lead to an average reduction of over 2 tonnes of CO_2 emissions over the life cycle of a product.

Development of the Tool

The methods used to develop the Forest Carbon Tool are in line with IPCC guidelines and identical to those used in the national greenhouse gas inventory. The carbon modelling framework, CFS-CBM (Kutz et al. 2009) includes all carbon fluxes associated with forest carbon pools. As components are harvested, some of the timber transfers to the HWP pool (inflows). The HWP inflow and existing HWP stock is subjected to a 1st order decay curve using a half-life value of 25 years for wood based panels (Skog et al. 1998). Forest growth is based on published and validated data where available. Validation of CBM-modelled forest removals against available eddy co-variance data generally shows good agreement. Despite differences in respective modelling frameworks, good agreement is also found when current CBM-modelled and UK Woodland Carbon Code CO_2 removal estimates are compared.

For planting grant and premium categories (GPCs) such as Agroforestry (GPC 11) and Short Rotation Forestry (GPC 12), single tree growth models (Black 2016) were constructed and used based on best information currently available. Further information will be required regarding these categories which have been little-used to date, and future data capture, analysis and validation are recommended for inclusion to enhance carbon sequestration knowledge regarding such scenarios.

Using the Forest Carbon Tool

Users of the tool can select from a dropdown list of current planting and soil type options under the DAFM Forestry Programme 2014-2020 or otherwise from selected forest tree species or species groups. The tool outputs provide indicative values for mean annual CO_2 sequestration (tC O_2-eq. $ha^{-1}yr^{-1}$) and mean cumulative sequestration values (tC O_2-eq. ha^{-1}), the latter being an estimate of the (once off) maximum potential sequestration, termed the CAP value, derived over two forest cycles or rotations. Both of these are normalised measures of sequestration which allow comparisons over different rotation ages.

Annual carbon sequestration rates are not constant, but change significantly over rotations, as shown in the graphic outputs from the tool. Although growing forests capture and store CO_2 during active growth, activities such as forest thinning and harvesting give rise to emissions, which the tool also takes into account (see Figure 2).

Forest Carbon Tool outputs

Outputs from the tool indicate that mean annual sequestration rates (under the current assumptions described) can range from 1-9 t CO_2- eq. $ha^{-1}yr^{-1}$. Application of the tool can help inform decision making in terms of forest establishment and management options. It shows that all forest types and mitigation pathways can have an important role to play in climate change mitigation.

Figures 2, 3 and 4 provide summary examples of mean annual and mean cumulative sequestration (CAP value) for GPC 8, GPC 3 and GPC 11 planting categories, respectively. Broadleaf forests (e.g. alder, birch), while having a lower mean annual rate of carbon capture, also tend to have a high sequestration potential as indicated by the CAP value (Figure 2). Productive conifer species (e.g. GPC 3) such as spruce can return high sequestration rates, especially when their HWP are taken in account (Figure 3). While the net sequestration capacity from agroforestry scenarios is reduced when agricultural emissions are factored in, this planting category (GPC 11) has potential to move such mixed forest and livestock systems towards achieving carbon neutrality, as indicated in Figure 4.

Example 1: Broadleaf forest of alder / birch (GPC 8)

- Mineral soil
- Yield class 8
- Thinned
- Rotation of 75 years

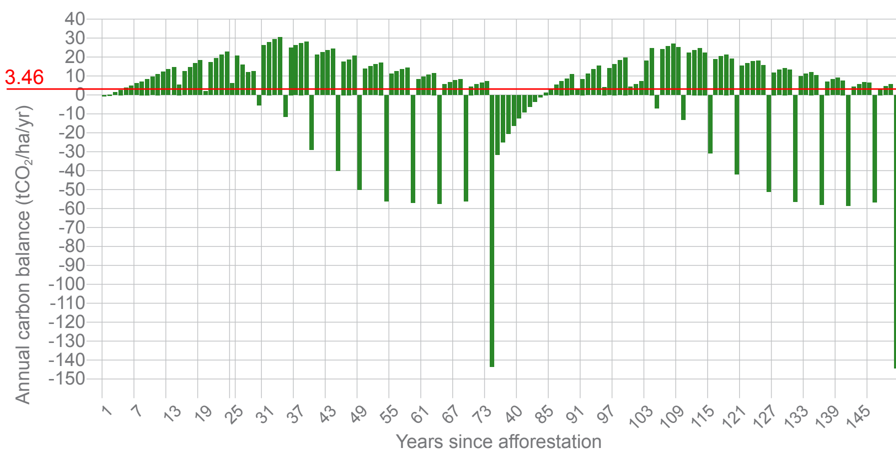

Figure 2: *Carbon sequestration from fast growing broadleaves e.g. alder / birch with 15% area retained for biodiversity enhancement (ABE - open space, hedgerows and retained habitat)) on a suitable mineral soil. The red line indicates the mean cumulative sequestration over two rotations.*

■	Mean annual CO_2 sequestration	3.46 t CO_2 - eq. $ha^{-1}yr^{-1}$
■	Sequestration potential (CAP)	471 t CO_2 - eq. ha^{-1}

Example 2: 15% Diverse Conifer / Broadleaf (GPC 3)

- 70% Sitka spruce with 15% birch and 15% ABE[3]
- Mineral soil
- Yield class 24
- Thinned
- Rotation of 38 years

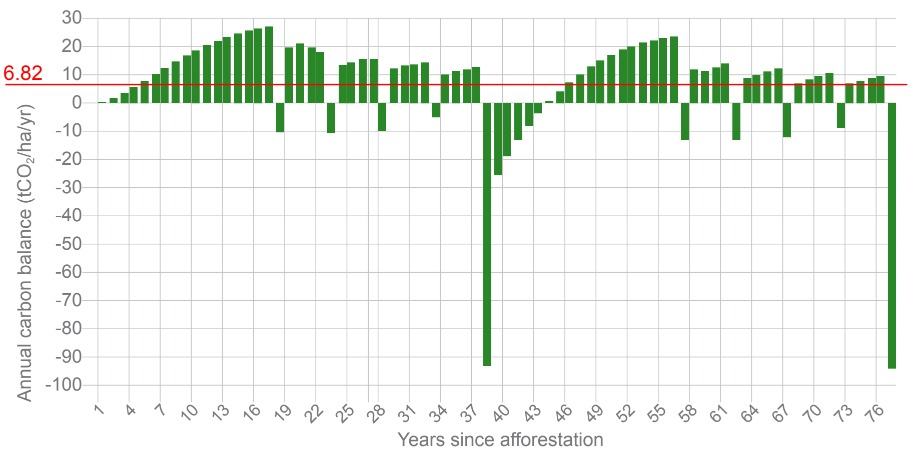

Figure 3: *Carbon sequestration from 70% spruce (by area), 15% broadleaf species and 15% area retained for biodiversity enhancement on a mineral soil. The red line indicates the mean cumulative sequestration over two rotations.*

■ Mean annual CO_2 sequestration	6.8 t CO_2 - eq. $ha^{-1}yr^{-1}$
■ Sequestration potential (CAP)	357 t CO_2 - eq. ha^{-1}

[3] The Forest Biodiversity Guidelines require that in plantations greater than 10 hectares, areas of biodiversity enhancement (ABE's) should comprise up to 15% of the area (Forestry Standards and Procedures Manual 2015).

Example 3: Agroforestry (GPC 11). A silvo-pastoral system combining trees with livestock grazing, e.g. sheep.

- Fast growing broadleaf species, e.g. sycamore
- Initial stocking of 400 trees, reduced to 70 over a rotation
- Mineral soil
- Thinned
- Rotation of 75 years
- Sheep stocking rate of 12 head per hectare

Figure 4: *Carbon sequestration from agroforestry – Fast growing broadleaves e.g. sycamore in a mineral soil combined with grazing for sheep between rows of trees (12 ewes per hectare). The red line indicates the mean cumulative sequestration over two rotations.*

■ Forest/tree-based sequestration	2.86 t CO_2 - eq. $ha^{-1}yr^{-1}$
■ (Less) Agricultural emissions	2.03 t CO_2 - eq. $ha^{-1}yr^{-1}$
■ Net (mean sequestration rate)	0.83 t CO_2 - eq. $ha^{-1}yr^{-1}$
■ Sequestration potential (CAP)	187.4 t CO_2 - eq. ha^{-1}

Future development of the Forest Carbon Tool

The objective of this first iteration of the Forest Carbon Tool is to provide information on the capacity of forests to sequester carbon and particularly, to provide insights for users on the comparative merits of different forest planting options. The tool is not intended to provide definitive or absolute data on any particular forest or for processes related to forest carbon valuation or potential trading platforms. Although the methods presented provide a good basis for forest *ex-ante* estimations for carbon trading platforms, additional elements such as system baselines, leakage, permanence and additionality eligibility criteria and extensive verification would be required to ensure materiality of traded carbon credits.

There is also an ongoing need to further develop knowledge on the impact of a range of factors such as forest types, species choices, rotation lengths and management approaches on sequestration potential. To this end, it is anticipated that updates and enhancements can be incorporated into future iterations of the Forest Carbon Tool as new data and research outputs become available. A current area of focus and further analysis is the significant effect of soil type on forest carbon balances.

Finally, it is also important to emphasise that carbon sequestration is one of a range of important ecosystem services provided by sustainably managed forests. These include timber production, water quality protection, social amenity, landscape and biodiversity enhancement. Factors such as landowner's objectives, tree species choices and forest management approaches are central to determining the specific mix of services that farm forests can provide.

References

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