FRL 2021-2025: IRELAND

National Forestry Accounting Plan

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Preface

The National Forest Accounting Plan has been developed to meet the requirements of Article 8 (4) of *"Regulation (EU) 2018/841 of the European Parliament and of the Council of 30 May 2018 on the inclusion of greenhouse gas emissions and removals from land use, land use change and forestry in the 2030 climate and energy framework, and amending Regulation (EU) No 525/2013 and Decision No 529/2013/EU*" and sets out the forest reference level (FRL), relating to the accounting of emissions and removals resulting from managed forest land ("land use reported as forest land remaining forest land") during the period 2021 to 2025, and the methodology employed in its construction. The document was prepared in line with the "Criteria and guidance for determining forest reference level" and "Elements of the national forestry accounting plan" sub-sections of Annex IV of the Regulation.

Article 2 (3) provides the definition of the FRL as

> 'forest reference level' means an estimate, expressed in tonnes of CO_2 equivalent per year, of the average annual net emissions or removals resulting from managed forest land within the territory of a Member State in the periods from 2021 to 2025 and from 2026 to 2030, based on the criteria set out in this Regulation;

Article 8 (5) requires that

> The forest reference level shall be based on the continuation of sustainable forest management practice, as documented in the period from 2000 to 2009 with regard to dynamic age-related forest characteristics in national forests, using the best available data.
>
> Forest reference levels as determined in accordance with the first subparagraph shall take account of the future impact of dynamic age-related forest characteristics in order not to unduly constrain forest management intensity as a core element of sustainable forest management practice, with the aim of maintaining or strengthening long-term carbon sinks.

In line with Article 8 (3), this document will be submitted to the European Commission by 31st December 2018 for the FRL period 2021 to 2025 containing the elements listed in Section B of Annex IV and made public online. Following Article 6, the European Commission, in consultation with experts appointed by the Member States, shall undertake a technical assessment of the national forestry accounting plan during 2019. The European Commission will also consult stakeholders and civil society and the results of the technical assessment will be published. Subject to the technical assessment and any subsequent revisions, the FRL for 2021 to 2025 shall be adopted by delegated act by 31st October 2020. An additional FRL will be developed for the 2026-2030 accounting period and submitted by 30th June 2023.

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Chapter 1: General Introduction

1.1 Description of FRL

Forest definition

The definition of forest is the same as that adopted for the LULUCF chapter of the National Inventory Report to the UNFCCC and Ireland's National Forest Inventory. Forest land has a minimum area of 0.1 hectare, a minimum width of 20 m, trees higher than 5 m and a canopy cover of more than 20 per cent within the forest boundary, or trees able to reach these thresholds *in situ*. This is consistent with the forest definition contained in decision 16/CMP.1. The following attributes are also relevant to the definition:

- A tree is a woody perennial of a species forming a single main stem or several stems, and having a definitive crown;
- A forest includes windbreaks, shelterbelts and corridors of trees with an area of more than 0.1 ha and minimum width of 20 m;
- Forest is determined both by the presence of trees/stumps and the absence of other predominant land-uses. Areas under re-establishment (following clearfell) that have not yet reached but are expected to reach a canopy cover of 20 per cent and a minimum tree height of 5 m are included, as are temporarily un-stocked areas, resulting from human intervention, which are expected to be restocked;
- The forest area is determined by the forest boundary. The term forest boundary is defined by any man-made boundary enclosing the forest area or, in the absence of such boundary feature, the boundary of the forest is determined by extending out 1 m from the position of the pith-line of the outermost trees (NFI, 2007a);
- The forest area includes forest roads and other open areas on forest land; forest in national parks, nature reserves and other protected areas such as those of specific scientific, historical, cultural or spiritual interest;
- The forest area excludes tree stands in agricultural production systems, for example in fruit plantations and Christmas tree plantations since these generally do not reach 5m in height;
- The term forest also includes trees in urban parks and gardens, provided these areas satisfy the forest definition.
- Semi-natural forests. There are no unmanaged, natural forests in Ireland. The NFI defines semi-natural forest as native woodlands generally established by natural regeneration, i.e. greater than 80% of the tree species regenerated naturally. Native and non-native tree species are included. This forest land may not be managed in accordance with a formal or an informal plan applied regularly over a sufficiently long period (5 years or more). However, all semi-natural forests are managed for biodiversity, public amenity and pest or disease control. Semi-natural forests are classified as special areas of conservation (SAC) under the National Parks and Wildlife Service (NPWS), and these areas cannot be converted to plantations forests. However, plantation forests can be converted to semi natural forests

under the native woodland scheme (NWS) by either managing the forest to enable regeneration of native woodland species or by planting native trees to regenerate to a native woodland. These changes are tracked by the NFI.

The forest definition is applied in the NFI when land cover and use is determined (see NIR 2007). The classification of forest roads, open forest areas within forest boundaries are undertaken at the plot level based on established permanent sample plots established under the NFI.

Forest management

Ireland considers that all areas meeting the forest definition are managed through forestry operations (timber resource utilisation) or for other reasons such as conservation, control of invasive species, pests or diseases. Therefore, activities under managed forest land (MFL) include all areas which meet the forest definition.

The FRL area

The FRL area will include all forest lands established before 1990 and afforested land which will transition to the FRL area following a transition period of 30 years (see section 3.3.3 for justification). Ireland has a unique forest age class structure due to large legacy afforestation events in the 1950s and again since the late 1980s due to the introduction of an afforestation grant and premium scheme. Forest cover has increased from less than 1% in 1900 to over 11% by 2017. Most of the forest land is managed as plantation forestry with silvicultural management system which have not changed much since the 1970s (see section 2.3.1).

1.2 Adherence to criteria and guidance for establishing a FRL

The criteria and guidance for establishment of a FRL are set out in annex IV section A of the EU LULUCF regulation. The table below cross-references sections in this document which address adherence to the criteria as set out in Annex IV with specific reference to paragraphs under section A.

Table 1: Summary and cross-reference to text addressing specific criteria as set out in section A of Annex IV of the EU LULUCF Regulation

Section A Paragraph	Description	Reference in this document	Comment
a)	Balance between emissions and removals and enhancement of forest sinks in the second half of this century	Section 2.3.1	Policy is to continue afforestation to mid-century and overall target of reaching 18% cover, promote SFM, and regulate felling and deforestation.
b)	Presence of C excluded from accounting	See definition of harvest section 3.2.2.	This is explicitly done by construction of a FRL. Also see definition of harvest pg 9 for comments on windfall credits.
c)	Robust accounting system	See definition of harvest section 3.2.2.	This is explicitly done by construction of a FRL in adherence to the criteria set out in annex IV and in line with methodology outlined in the NIR

d)	Harvested wood products	HWP model description section 3.3 Table 21 section 4.2.	See first order decay model and adoption of IPCC methodology. Methodology follows Annex Comparison of HWP based on instantaneous oxidation and first order decay model
e)	Energy use ratio 2000-2009	Table 6 section 3.3. and Table 21 section 4.2	Application of a constant sawnwood and wood - based panels (WBP) ratio based on 2000-2009 FAO/Eurostat data
f)	Conservation of biodiversity and sustainability	See sustainability ratios section 3.2.2 Section 2.3.1	The preamble of the LULUCF Regulation (recital 16) refers to the principles of sustainable forest management as adopted in the Ministerial Conferences on the Protection of Forests in Europe ('Forest Europe'). The future levels of harvest are demonstrated to be below volume increment (i.e. ratios<1) which is a proxy for sustainable wood production (Forest Europe indicator 3.1). Demonstration of consistency in sustainable practice over FRL period. Documented management practices stem primarily from NFI plots in land managed by Coillte, the state forestry company, which attained FSC certification in 2002. Thus, documented management practices stem primarily from SFM Certified forests. Forest service policy at least 30% broadleaf cover and other measures aimed at the conservation and enhancement of biodiversity
g)	Consistency with national projection EU 523/2013	Section 4.1.2	Forest management area projections are different but similar trends are observed
h)	Consistent with greenhouse gas inventories and relevant historical data and shall be based on transparent, complete, consistent, comparable and accurate information	Section 4.1.2	The current methodology (CARBWARE) has some methodological deficiencies which are now addressed by using CBM (see model framework). National reporting will move to use of CBM in 2019. Use of best available data from NFI and CBM help to meet TACCC principles.

Chapter 2: Preamble for forest reference level

2.1 Pools and gases

Projected estimates include the following pools and gases in line with Annex I of the Regulation and NIR methodology:

i. Above and below ground biomass; gases CO_2, N_2O (biomass burning) and CH_4 (biomass burning). Emissions from fires were projected to be equivalent to the background level for natural disturbances as defined in the annex V of the EU LULUCF decision and 2/CMP7 (see NIR, Duffy et al., 2017).
ii. Semi-natural forests areas are included in the MFL category since all forests are deemed to be managed.
iii. Deadwood (all dead matter with min diameter of 7cm); gases CO_2, N_2O and CH_4 (forest fires)
iv. Litter (diameter <7cm); gases CO_2, N_2O and CH_4 (forest fires)
v. Soils; gases CO_2, as calculated for NIR (Duffy et al., 2017). An emission factor of 0.59 t C ha^{-1} yr^{-1} for 50 years of the first rotation is applied to peat soils using the same methodologies outlined in the NIR and NFI. Additional emissions include dissolved organic carbon loss from organic soils (0.31 t C ha^{-1}), based on the IPCC Wetlands Supplement (2013).
vi. Mineral soil carbon stock changes (CSCs) are estimated using the CBM model
vii. HWP using a first order decay model production approach; gases CO_2
viii. N_2O emissions from fertiliser application are reported under Agriculture and are not included in LULUCF projections.
ix. N_2O and CH_4 emissions due to drainage of forest lands planted before 1990 are included using the same methodology described in IPCC GPG 2006 and the Wetlands Supplement (see Ch. 6 of the NIR 2017). The relative areas of drained mineral, organic N poor and organic N rich soils is assumed to be constant after the last national forest inventory in 2006. This is consistent with approaches used in the UNFCCC reporting submissions.
x. CO_2 emissions from lime and urea application are reported under agriculture as outlined in the 2006 IPCC GPG.
xi. Losses of C from deforested mineral soils located on settlement and other lands are based on an assumption that 20% of soil organic carbon SOC is lost over a period of 20 years (see Duffy et al., 2017). N_2O losses from mineralisation as a result of soil C loss are based on the default method described in the IPCC GPG 2006 (also see Duffy et al., 2017).

2.2 Demonstration of consistency between C pools in the FRL

The transfer of C pools within the category due to disturbance are controlled by defined disturbance matrices in the modelling framework CBM (see appendix B). Other transfers of CSC and associated areas occur when land converted to forest land (L-FL) are transferred to forest land remaining forest land (FL-FL, see section 3.3.3). Forest management practice results in the thinning of plantations from an age of 15 years and the earliest clearfells occur at 27 years. This means that remaining harvest wood product (HWP) stocks, from historical harvest in the L-FL category before the transition years to FL-FL (i.e. 2021-2030), are transferred to the FL-FL HWP pool to ensure consistent transfer and adherence to the mass balance principle (see section 3.3.3).

2.3 Description of forest policies

2.3.1 Description of forests and forest management and adopted national policies

National policy and legislative framework

An updated and renewed strategic policy framework for the future development of the forest sector in Ireland was published by the Department of Agriculture, Food and the Marine and launched in mid-2014. The strategic goal of *Forests, products and people – Ireland's forest policy – a renewed vision*[1] is to develop an internationally competitive and sustainable forest sector that provides a full range of economic, environmental and social benefits to society and which accords with the Forest Europe definition of sustainable forest management. The renewed strategy, which represents a consensus view among a wide range of forest sector stakeholders, foresees expansion of the forest area (from 11% currently to 18% by mid-century), in order to provide for increased and sustained levels of wood production, environmental benefits, including climate change mitigation in the continued sustainable management of the national forest resource, including integration of detailed environmental considerations, and cost effective mobilisation of the forest resource. The DAFM has developed both an Irish National Forest Standard and Code of Best Forest Practice – Ireland to guide sustainable forest management at the national level. This is complimented by the Forestry Standards Manual (2015) that provides guidance on the operational requirements of the various support schemes, such as the Afforestation Scheme, in line with SFM.

New forest legislation was enacted in 2014. The Forestry Act 2014[2] and related Forestry Regulations 2017 (SI No 191 of 2017) aim to make further and better provision in relation to forests and forestry and to provide for the development and promotion of forestry in a manner that maximises the economic, environmental and social value of forests within the principles of sustainable forest management. The Act confers power on the Minister for Agriculture, Food and the Marine to make regulations for the effective management of the forest sector, to make further provision for giving effect to acts of the institutions of the European Union by regulation made by that Minister in respect of forestry and forestry-related activities, to repeal the Forestry Act 1946, to amend the Wildlife Act 1976, to amend the Agriculture Appeals Act 2001, to amend the Environment (Miscellaneous Provisions) Act 2011 and to provide for related matters. This includes the continuation of a licencing system for tree felling which ensures that the forest estate and long-term carbon stock can be maintained. Licences are also required for afforestation, road construction and aerial fertilisation. Where relevant, applications may be forwarded to other relevant public bodies including the National Parks and Wildlife Service.

The licencing system for a range of forest management activities conveys power upon the DAFM and provides the basis for ensuring that forest practices are aligned with other environmental policies. In relation to afforestation, the DAFM has recently combined a series of existing environmental guidelines into a single document entitled "Environmental Requirements for Afforestation". In combination with the document "Land types for Afforestation", and related industry training, these

[1] www.agriculture.gov.ie/forestservice/forestservicegeneralinformation/forestpolicyreviewforestsproductsandpeople

[2] http://www.irishstatutebook.ie/pdf/2014/en.act.2014.0031.pdf

requirements seek to ensure that afforestation is undertaken in a sustainable manner. To increase the biodiversity value of afforestation the DAFM encourages greater diversity in new forests through requirements to include a biodiversity enhancement area in 15% of the grant aided area and a minimum broadleaf area of 15%. The DAFM has also recently published “Forests and Water” setting out how the DAFM and the forest sector will help to achieve the objectives of the River Basin Management Plan for Ireland 2018-2021. The “Felling and Reforestation Policy Document” (DAFM, 2017) outlines how the DAFM regulates harvesting.

Under European and national legislation, the DAFM is required to apply an appropriate assessment procedure to applications for consent, grant approval and licensing for various forestry activities, to evaluate the project within the context of any potentially relevant Special Areas of Conservation (SACs) or Special Protection Areas (SPAs). This procedure involves an initial screening, and if required, an appropriate assessment. Initial screening is carried out to determine if there is a possibility of the project, individually or in combination with other plans or projects, having a significant effect on an SAC or SPA. Screening takes places as part of the normal evaluation of the application by the DAFM, typically based on the submitted application form and maps. In cases where the screening identifies that there is a possibility of the project having an effect on a Natura site, the applicant is required to submit a Natura Impact Statement (NIS). The NIS examines the nature of the possible impact and sets out proposed mitigation measures. On receipt of this document, the DAFM undertakes an appropriate assessment, before arriving at a decision regarding consent, grant approval or licensing. Specific plans have been, or are being, developed for a number of protected species including Freshwater Pearl Mussel and Hen Harrier.

Over half of Irish forest estate has attained SFM certification from the FSC and/or PEFC. The FRL is primarily composed of forests managed by Coillte, an Irish commercial semi-state company, which has dual SFM certification. It attained FSC and PEFC certification in 2002 and 2012 respectively. Certification is less common in the private estate and generally limited to a small number of large owners. The DAFM has recently funded a pilot programme to establish a template for group certification amongst private forest owners to encourage and facilitate greater engagement amongst smaller owners.

Annex IV A(a) of the Regulation requires the FRL to be “consistent with the goal of achieving a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century”. This is reflected in the continuation of sustainable management practices, including afforestation, that are guided by an effective regulatory environment and forest policy guided by the principles of SFM. Ireland’s forest policy will contribute to the conservation and enhancement of sinks primarily in three ways; continued afforestation until at least mid-century, avoided deforestation through regulation, and ensuring forest management is undertaken in a sustainable fashion. In addition, the role of harvested wood products, including innovative wood based products in the bioeconomy, in the substitution of more energy intensive materials plays an important role in reducing anthropogenic emissions.

Afforestation

Over 300,000 ha have been afforested in Ireland since 1990. The majority of the land afforested has been privately-owned agricultural land. Afforestation continues to be incentivised by the State through establishment grants and annual premiums (for maintenance purposes and to reflect income foregone by landowners during the early growing years of the new forest). The Forestry Programmes running from 2006-2013 and 2014 - 2020 have been State funded. Prior to that, the Programme was co-funded by the State and the European Union. Participation in afforestation schemes is voluntary: the decision to plant resting solely with the landowner. Technical, environmental and economic criteria are used by the DAFM, in collaboration with the environmental authorities, to determine the eligibility of candidate sites for afforestation.

Approval for a new Forestry Programme for the period 2014-2020 was attained in 2014/2015. This includes the continuation of afforestation grants and premiums for a range of forest species and forest types, as well as the introduction of new measures including forestry for fibre, agro-forestry, knowledge transfer and innovation actions. Improved financial support for the provision of forest roads to mobilise wood supply from thinnings was also introduced. In addition, in order to incentivise more land owners to afforest a single rate of premium was introduced, thereby removing the differential which existed between farmer and non-farmer designations. The Programme set targets for the establishment of an additional 43,000 ha of new forests, mostly on private lands, and the building of almost 700 km of new roads over the six years. A mid-term review of the Programme was published in 2018. This review resulted in an increase in support levels with larger increases for broadleaf species and an increase in the support for road construction. In addition, some new measures were introduced including a support for continuous cover forestry. The Forestry Programme is designed to impact positively on employment, rural communities and to provide a range of environmental benefits; including climate change mitigation and adaptation. All of these outcomes are set to be delivered in line with the stated strategic goal of *Forests, products and people*.

Deforestation

The Forestry Act 2014 and SI No 191 of 2017 provide the statutory legislation for the issuing of felling licences, restrictions on the felling or removal of tress, imposition of replanting obligations and environmental requirements. The permanent removal of trees and forests where a felling licence is required under the Forestry Act 2014 may be considered under exceptional circumstances on a case by case basis as outlined in the Felling and Reforestation Policy document. Landowners can apply not to replant after felling through the licencing system and may be required to afforest an alternative piece of land depending, in part, on the proposed alternative use. Felling without replanting may also be licenced, for example if the continuation of forest cover does not align with the conservation goals of an SAC or SPA. Outside of the licencing system forest cover is monitored by DAFM, other regulatory bodies and during the National Forest Inventory.

Forest management

All forests in Ireland are managed, and most, except for some broadleaf forests, are managed using plantation forestry management systems. The potential for high levels of forest productivity depending on site and species choices has been a defining element of the development of Irish forestry. In an analysis of the economics of Irish forestry, Gray (1963) noted that rotations in Ireland might range from less than forty years to as much as eighty. Due to similar climate, site conditions and species, Irish practices traditionally followed the British Forest Commission (BFC) yield tables (Edwards and Christie, 1981), when they became available, involving thinning at marginal thinning intensity and clearfell at a rotation age equivalent to maximum mean annual increment (MMAI). In the late 1970s rotation ages were adjusted (shortened) to provide a more commercially viable cashflow for the sector, referred to as commercial rotations (Forest and Wildlife Service, 1976). These amounted to a recommendation to fell Sitka spruce (*Picea sitchensis* (Bong.) Carr.) at MMAI less 20% and lodgepole pine (*Pinus contorta* (Doug.)) at MMAI less 30% and were included in Ireland's Code of Best Forest Practice (Forest Service, 2000). In 1990, Coillte Teoranta (1990), the Irish Forestry Board, published a forest operations manual for its forest managers that included the recommended rotations, thinning practices and possible reasons for deviations from standard practices (Appendix A). These rotations are considered to be close to the financial optimum, depending on discount rate and timber prices, and have been employed in economic analysis of afforestation in the past in Ireland (e.g. Clinch, 1999; Bacon and Associates, 2004). They can also be seen in research work conducted during the 2000 to 2009 period. For example, Ni Dhubhain et al. (2006) refer to public forests typically being harvested at 80% of MMAI and that private spruce forests may be harvested around 30 years of age due to higher productivity levels. Risk of windthrow is one of the defining features of forest management in Ireland and often influences the rotation age and decision to thin individual stands. First thinning is recommended at an age and intensity which does not reduce long term productivity (referred to as marginal intensity and typically 70% of yield class) as described in the Irish Thinning Protocol (FDA, 2007). Age and intensity are largely derived from the BFC yield models although the decision to thin is influenced by wind risk and operational factors (see Appendix A).

Timber production forecasts have been derived from the 1976 recommendations and standard thinning practice while accounting for operational and other factors and employing available software, including GIS when available (Gallagher and O'Carroll, 2001; Phillips, 2011; Phillips et al., 2006). In addition, Irish dynamic yield models were developed (Broad and Lynch, 2006) and the BFC developed new models for high yield classes, these developments offer greater insight into forest volume developments over time. In 2008/9 the all-Ireland timber roundwood forecast project (Phillips, 2011) provided revised silvicultural rules to reflect accessibility to land and suitability for thinning. These rules now form the basis for most timber forecasting and management plans, which are specific for species and productivity classes, in Ireland.

Ensuring implementation of sustainable best forest practice on the ground and at site level is an important element of Ireland's overall approach towards sustainable forest management aimed at protection of the existing and future forest resource. The Forest Service Inspectorate of the DAFM oversees forestry activities to ensure that management is carried out according to environmental and silvicultural procedures. As previously described, a comprehensive range of mandatory environmental guidelines and other requirements are in place to this end. A forest owner wishing to apply for a felling licence is required to specify on the felling licence application and accompanying map the reforestation objective(s) they are proposing to pursue for the next rotation. This helps to ensure that sustainable management is maintained for the next rotation. The DAFM may also change or enlarge setbacks around water and other features to minimise any potential negative impact from reforestation.

Harvested wood products

The forest roads grant aid scheme encourages owners to create access in their forests for thinning and other management activities. This can support the mobilisation of small-sized, early thinnings for board manufacture, energy and other uses. A broadleaf tending and thinning grant is also in place. These interventions concentrate growth on the better quality remaining trees and bring forward the production of larger roundwood logs, suitable for sawnwood production and long-lived products. Woodflow data and product use is provided in the annual COFORD woodflow publication[3], which includes figures provided to the UNECE and FAO in the Joint Forest Sector Questionnaire. Over one third of the annual harvest in 2016 was used for energy generation with the balance being used for board manufacture, and sawnwood and stake production. A renewable energy feed-in tariff scheme which provides for co-firing and combined heat and power using biomass was operated by the Department of Communications, Climate Action and the Environment but was closed to new applicants in 2015. The DCCAE is currently designing a Support Scheme for Renewable Heat and a Renewable Electricity Support Scheme. A carbon tax on gas and liquid fossil fuels was introduced in 2010 and was extended to coal and peat in 2013 and increased in 2014. Wood fuels are not subject to the tax. The Department of Agriculture, Food and the Marine provides grant aid support to a number of not-for-profit bodies to promote the efficient use wood fuels and wood products. It engages with the National Standards Authority of Ireland in the development of wood product standards and structural recommendations and funds research and development projects on Irish timber characteristics and innovative wood products.

2.3.2 Description of future harvests under different policy scenarios

Future harvest rates are primarily influenced by silvicultural practices. Policies such as the renewable energy scheme and bio-energy incentive would only influence the allocation of HWP between timber products and biomass for energy. With the expansion of private ownership and the maturing of the private estate, landowners are increasingly seeking information on thinning and felling practices. The DAFM has published an online tool for landowners to investigate how different felling ages may influence the financial return from their forest. Teagasc, the agriculture and food development authority of Ireland, also employs a valuation tool to communicate how harvesting activities can influence financial return. Both of these tools employ the standard silvicultural practices as previously described. Although alternative silvicultural practices are relatively uncommon in Ireland, the DAFM is piloting a support to assist in the conversion of single-storey forests managed using a clearfell system to a continuous cover system. In Ireland, forecasts of future rates of harvest are derived using standard silvicultural rules (Figure 1).

[3] http://www.coford.ie/media/coford/content/publications/2016/00795CCNWoodflowPP48Web070318.pdf

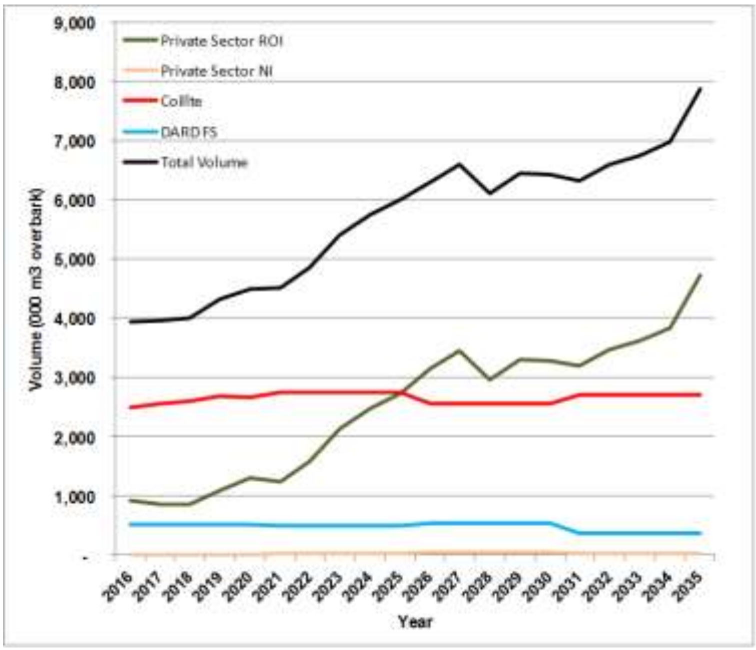


Figure 1 Forecast of roundwood production (net realisable volume) on the island of Ireland to 2035 (Phillips et al., 2016)

Chapter 3: Description of modelling approaches

3.1 General description of approach

Ireland has constructed a FRL based on the CBM-CFS3 modelling framework (Kull et al., 2009). Description of forest management practice (FMP) for the reference period (RP) 2000-2009 was obtained using the 'best available' NFI inventory data (2006-2012) and silvicultural guidelines adopted and used before and during that time period (Figure 2). There are no available, reliable statistical data on forest structure or FMP before the completion of the first NFI in 2006. Therefore, Ireland has adopted to reproduce the greenhouse gas inventory (GHGI), validate and re-calibrate the model based on a time period 2006-2017. Once the validation versus GHGI and re-calibration was complete, the projection of the FRL was run from 2010. For the projection period 2010 to 2016, the state of the forest was initiated using the 2006 NFI data and GHG fluxes were simulated using historical harvest (2006-2016). This was done to ensure consistency with the historical GHGI. The state of the forest before the commitment period (2021-2030) was defined using the latest National Forest Inventory (NFI, 2017). The projection from 2017 onwards was done using the defined management practice for 2000-2009 (see section 3.2.2).

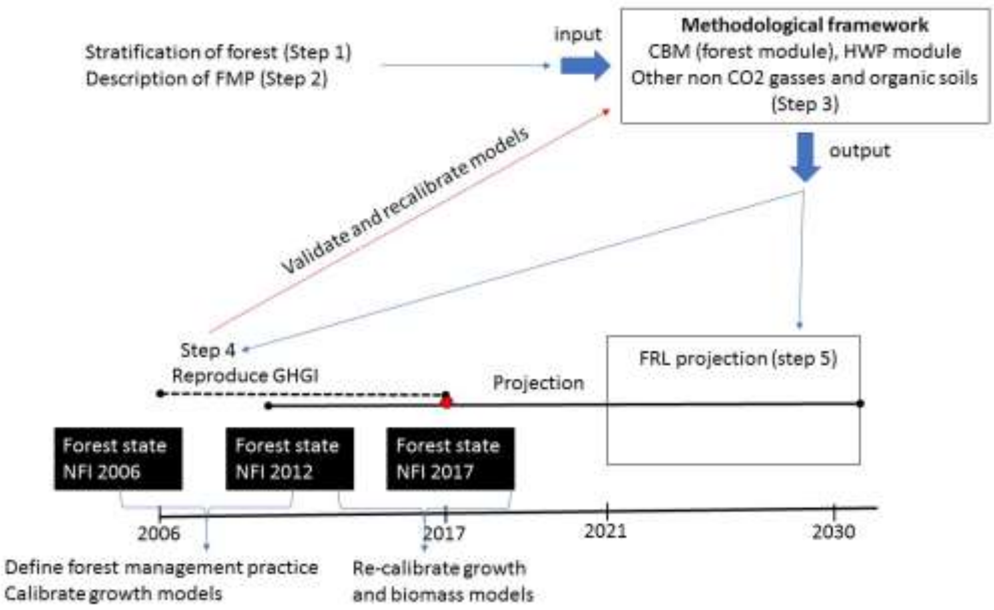


Figure 2 A general flow diagram of approach used to develop FRL showing steps identified in the technical guidance

The areas included in the FRL include forest land remaining forests (FL_FL) and lands converted to forests (L_FL) that transition after a period of 30 years. This is justified by demonstrating that the steady state transition period of C pools for Irish forest ecosystem is different to the IPCC default of 20 years. The FRL age class structure is dynamic since there are transitions from L-FL into FL_FL and removals of lands due to deforestation. Deforestation areas are based on the average deforestation rate over the period 2000-2016. Area subject to fires (i.e. natural disturbances) are based on the background level for the period 2000-2016. Harvest rates are based on documented silvicultural practices calibrated on the observed practices from the NFI with an assumed constant harvest ratio for energy use.

3.2 Description of data sources used for estimating FRL

3.2.1 Stratification of managed forest area

Activity data

Ireland uses the IPPC approach 3 method for tracking geographically explicit land use change to and from forest land as stipulated in para. 4 of article 18 of the EU LULUCF regulation. This is based on a combination of NFI data, collected since 2006 and a national afforestation grant GIS database (see Duffy et al., 2017 for full descriptions). The NFI also provides information on forest cover, species, soils and mensuration information that can be used to define productivity classes and for defining growth and harvest parameters in the FRL model (i.e. defining the state of the forest). The first national forest inventory was completed in 2006 followed by 2 subsequent inventory cycles completed in 2012 and 2017. The NFI data is the main activity information used for stratification of forest areas and the documentation of sustainable forest management practices but other factors such as management differences and model requirements were also considered.

Other data sources for modelling and stratification include:

- The afforestation premiums and grant scheme geodatabase (iFORIS), for deriving afforestation rates and the establishment year of individual forest parcels since 1990 (see NIR, 2017).
- Biomass equations used for deriving CBM parameters were based on National research information (see NIR, 2017).
- Harvest rates historical (NFI) and future the timber forecast 2011-2028 and 2017-2035.
- FAO/Eurostat harvest stats for deriving the allocation of timber to semi-finished products which in turn were employed to generate "a constant ratio between solid and energy use of forest biomass".
- The GROWFOR model for deriving the site indices from NFI data (Broad and Lynch, 2006).
- Tree volume equations (Black, 2016).
- Emission factors for organic soils, fires and drainage (NIR, 2017)
- Soil types, species, area, area of drained soils and all forest characteristics (NFI 2006-2017).

Stratification considerations

Current management

The stratification of the forest management area is based on species cohorts and productivity classes to reflect the different forest management practices in Ireland (see Tables 2 and 3). These management practices apply to both private and state forests, so an ownership stratum is not required.

Model and sampling considerations

Consideration of the modelling requirements to be used in the FRL also influenced the stratification of areas. It was necessary to group some species into groups (cohorts) and productivity index ranges to ensure that sufficient data was available to construct biomass volume curves and volume increment curves based on data from the NFI (see methodology below). The NFI provides information on the forest estate at a plot sample grid resolution of 2 km^2, which equated to ca 1700-1900 plots over the period 2006-2017. The number of NFI plots imposes a limitation on the number of strata that could be derived for projection, so stratification was limited to species/productivity strata. As a relatively small island with a temperate oceanic climate, Ireland does not have multiple distinct climatic zones making these two variables the most meaningful for stratifying the estate. The species cohort strata were also defined to ensure that no new strata can be created in the future (i.e. the strata structure should not change over time). The species strata selected are consistent with those used in national greenhouse gas inventories (GHGI), but some species groups have been generalised due to data limitation constraints during growth and biomass model development (see Section 3.3.4).

The final stratification includes:

i. Species cohorts by area including open areas and temporally unstocked lands as separate strata (Table 2)
ii. The abundant conifer species cohorts Spruce and Pine were further stratified into productivity classes to reflect different growth rates, thinning interventions and rotation ages.
iii. Species cohorts and productivity classes were then grouped in to 5-year age-class bins, which was used for the initialisation state for all modelling exercises.
iv. For afforestation areas
    a. Area were further stratified into afforestation year, so that 30-year transitions from land converted to forest land to forest land remaining forest land can be simulated in the FRL
    b. additional soil type strata were used because soil type effects the changes in SOC following afforestation.

Table 2: A stratification summary of species cohorts and productivity index classes of FM areas in 2016

Description of FMP	**Code**	**Area (ha)**	**Mean volume ha^{-1}**
Conifer mixtures (more than 25% of conifer or broadleaf)	CBmix	19333.1	245.5
Conifer broadleaf mixtures (less than 75% of dominant conifer spp)	Cmix	21514.8	186.9
Fast growing broadleaves (birch, ash, alder, sycamore etc)	FGB	94241.1	155.0
Slow growing broadleaves (oak, beech etc)	SGB	20423.9	178.8
Open areas within forest boundaries e.g. roads	forest open area	27635.6	
Other conifers (except Pine or Spruce)	OC	14969.4	270.9
Pine (Lodgepole, Scots pine and others) with a site index of 4-12m*	Pine4-12	14605.8	144.3
Pine (Lodgepole, Scots pine and others) based on a site index of 12-20m*	Pine12-20	28060.2	299.5
Spruce (Sitka spruce or Norway spruce) based on a site index of 4-12m**	Spruce4-12	37150.9	227.1
Spruce (Sitka spruce or Norway spruce) based on a site index of 13-16m**	Spruce13-16	36423.7	331.8
Spruce (Sitka spruce or Norway spruce) based on a site index of 17-20m**	Spruce17-20	44726.6	356.3
Spruce (Sitka spruce or Norway spruce) based on a site index of 20-24m**	Spruce20-24	63696.0	426.3
Spruce (Sitka spruce or Norway spruce) based on a site index of 24-30m**	Spruce24-30	14242.2	404.2
Clearfelled areas yet to be replanted	temporarily unstocked	10908.9	
		447932.9	

*Site index (top height at 30 years) based on Lodgepole pine; ** site index (top height at 30 years) based on Sitka spruce (Broad and Lynch, 2006)

3.2.2 Definition of sustainable forest management practice for FRL

Section 2.3.1 provides a more general background to forest management practices in Ireland before and during the 2000 to 2009 period. Sustainable forest management practices, which determine the level of harvest in the FRL period (para. 5 of Article 8 of the EU LULUCF regulation), were based on the best available data, which reflect practices in 2000-2009, as documented in the following sources:

i. **NFI 2006 and 2012**. These are the first two national forest inventories carried out in Ireland and the primary source of information on management practices. This is considered as the best available data to represent the period 2000-2009 as it objectively captures actual practices across a sample designed to represent the forest estate.
ii. **Management guidelines before and during the RP,** which were modified from the British Forestry Commission yield tables in the late 1970s (Forest and Wildlife Service, 1976; Code of Best Forest Practice – Ireland, 2000; Irish Thinning Protocol, 2007)
iii. **Silvicultural rules adopted in the 2011-2028 timber forecast** (Phillips, 2011), which is based on management practice for the period <u>prior to 2010</u>. This was used for FMRL submission under 2CMP/6. The same silvicultural rules are used in the most recent timber forecast 2016-2035.
iv. **Harvest rules derived from the 2016-2035 timber forecast** (Phillips et al., 2016). This provided an initial harvest target which was recalibrated against the NFI 2006-2009 data.
v. **FAO/Eurostat dat**a. This was used to confirm the level of historic roundwood harvest

Approach

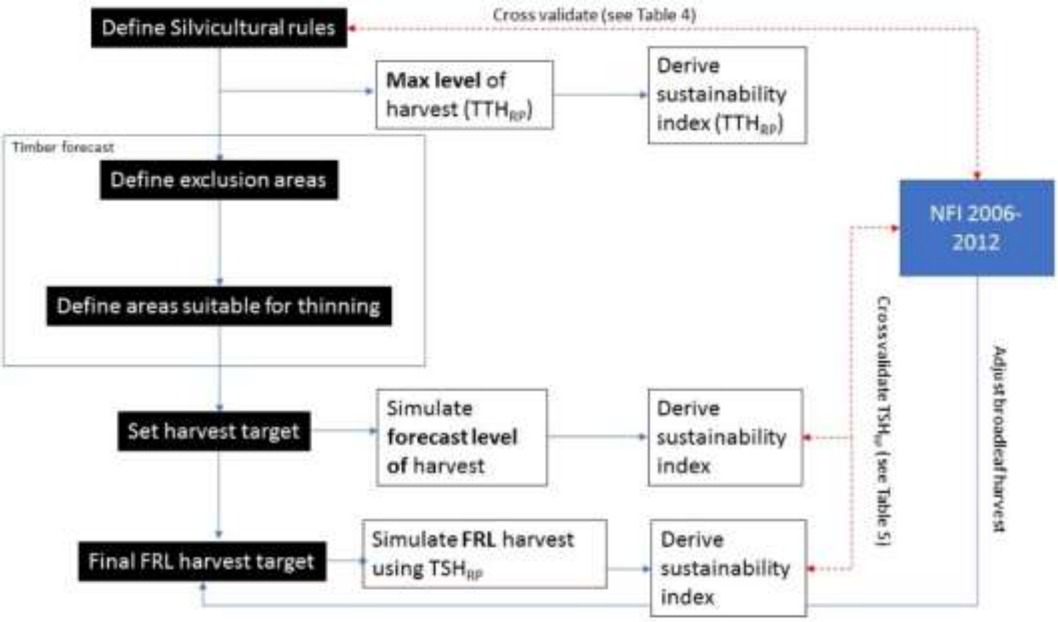


Figure 3 A workflow diagram showing how the silvicultural rules and FRL harvest was determined using a modified approach based on section 2.2.8 of the FRL Technical guidelines

Definition and validation of silvicultural rules

Silvicultural rules were assigned to species cohort-productivity class strata (see step 1) based on documented management guidelines as described above (Table 3). These silvicultural rules are also broadly described in the "Code of Best Forest Practice – Ireland" (page 138, Forest Service, 2000) which was published as a description of forestry operations and the manner in which they should be carried out to ensure the implementation of sustainable forest management, as agreed at the Third Ministerial Conference on the Protection of Forests in Europe in 1998.

Table 3: Yield class values, minimum clearfell (CF) and thinning (TH) age for corresponding site index categories.

Species	Site index category	YC Range	CF age	Thin min age
Spruce	4-12	6-13	50	NA
	12-16	14-18	39	22
	17-20	19-21	34	20
	20-24	22-25	31	18
	24-30	26-30	27	15
Pine	4-12	4-10	46	NA
	12-20	11-14	30	15
SGB			65	25
FGB			38	15
Cmix			40	15
CBmix			40	15
OC			40	15

Silvicultural rules shown in Table 3 were derived from the 2011-2028 timber forecast, which was carried out in 2009-2010 using relevant data available prior to that period and expert judgement (Phillips, 2011). The thinning practices are also reflected in the Irish Thinning Protocol published during the RP (FDA, 2007). These rules are similar to the ones used in the current timber forecast (2016-2035 (Phillips et al., 2016, see appendix A) and would reflect the management of forests for the period 2000-2009 as described previously. However, in order to comply with the requirements, set out in Article 8 para. 5 of the LULUCF regulation, a comparison of the harvest rules with observed clear fell ages and sustainability indices from the 2006-2012 NFI was carried out (Table 4 and 5).

Table 4. Validation of clearfell age assumptions using the best available inventory data (NFI 2006-2012). Note that the 2006 NFI was the first national forest inventory in Ireland.

Species group	Site index	Forecast (CF age)	NFI (CF age)	95 % CI	
Spruce	4-12	50	40.8	31.3	50.3
	12-16	39	41.2	36.4	46.0
	17-20	34	36.3	28.0	44.5
	20-24	30	30.7	23.7	37.7
	24-30	27	24.0	21.0	27.0
Pine	4-12	46	42.7	34.4	50.9
	12-20	30	31.5	26.0	37.0
FGB		38	42.5	36.0	49.0
Cmix		40	34.3	27.0	41.6
Cbmix		40	37.4	34.1	40.7
OC		40	40.1	32.7	47.5

The results presented in Table 4 confirm that the assumption of clearfell age is consistent with the defined forest management practice for the RP, based on the data collected in the period 2006 to 2012, the first two cycles of Ireland's NFI. These rotation ages are slightly lower than the commercial rotation ages specified in the Forest and Wildlife Service Operational Directive (Forest and Wildlife Service, 1976), however, they accurately reflect management practice for the period 2000-2009 as shown in (Table 4). The exact details of thinning intensities and carbon transfers associated with harvests and disturbance events are defined in disturbance matrices in Appendix B.

Areas excluded from harvest activities

Areas managed for biodiversity and specific Natura 2000 areas were excluded from the annual harvest to represent management objectives under SFM and operational practice. Area reductions (unproductive area) to allow for planting setback from streams or boundaries, un-stocked areas, roads are included in the analysis as a separate stratum (see Table 2) as determined by the NFI (NFI, 2006). These areas are excluded before the decision rules outlined in Appendix A are applied. The temporally un-stocked areas are assumed to be replanted within a minimum of 2 years after clear-felling.

Definition of level of harvest

Harvests from the maximum theoretical harvest over the reference period were derived using the silvicultural rules (rotation age and thinning rules) developed during the national timber forecast project competed in early 2010 (Phillips, 2011). These are the same silvicultural rules observed in the reference period (RP) 2006-2012 NFI (Table 4). Once the initial level of harvest was determined, adjustments to the target harvest was made using statistical harvest and increment obtained from the 2006-2012 NFI (see Figure 3, 4 and Table 5 below).

The initial level of harvest (i.e. forecast harvest, see Figure 3) is defined using the harvest rules and other factors such as accessibility of land. Adjustments for accessibility and suitability for thinning is based on a spatial decision support system developed during the timber forecast (See Appendix A). Employing these data is vital to represent actual management practices as CBM is not spatially explicit and so could not generate harvesting outcomes that reflect the same level of accuracy or range of management outcomes. In keeping with sustainable management, the harvest also took account of lower harvesting levels within environmentally sensitive areas as noted above. A similar approach was adopted for the FMRL submission because this reflected management practices before 2010. This approach would result in no windfall credits because the accounted amount is only depended on the level of harvest relative to the FRML or the FRL. The 2018 NIR submission clearly shows that reported emission/removals for FM land in Ireland is identical to the FMRL following technical correction except for small differences in the level of harvest. Hence, this demonstrates that the methodology is in line the TACCC principles and, in particular, accurately reflects the continuation of documented sustainable forest management practices

The initial level of harvest as defined in the timber forecast was then cross validated against the NFI to see if the level of harvest reflects management practice over the reference period (TSH_{RP}). Sustainability index is a useful way of assessing the level of harvest relative to the timber biomass increment. When the CBM model (see descriptions in methodology) for forest management areas were run using the silvicultural rules without any target volume constraints, the sustainability ratio was ca 1. However, the sustainability index for the 2017-2035 timber forecast target volume simulation was 0.54-0.6 (see forecast target, Figure 4). This clearly shows that the level of harvest for the timber forecast is well below the total timber available for harvest (potential harvest).

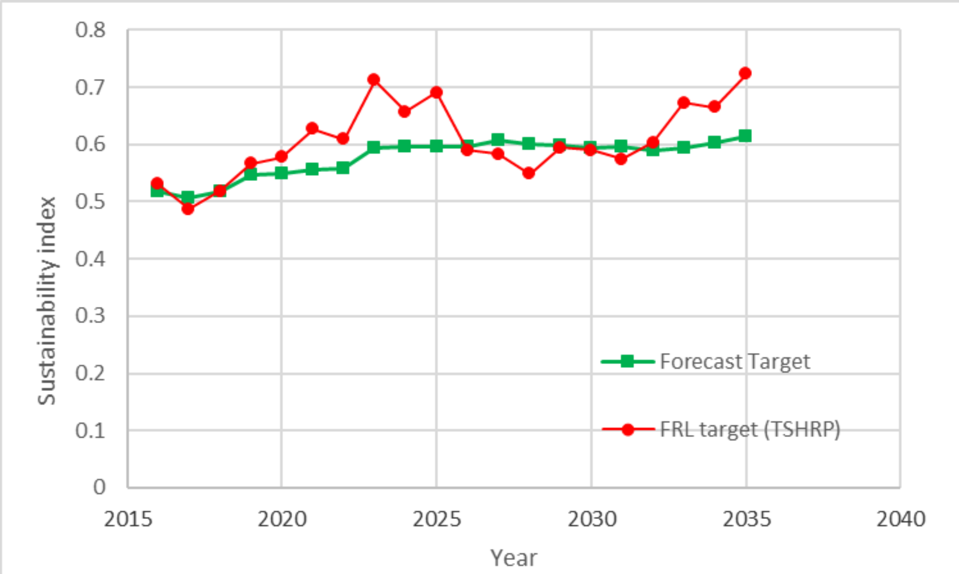


Figure 4 The Sustainability index (harvest/net growth) for FM lands based on: a) The timber forecast harvest and b) the adjusted harvest of FM land used for construction of the FRL (FRL target corrected using the statistical level of harvest over the RP, TSHRP)

Adjustment of timber forecast level of harvest using TSH_{RP}

Comparison of sustainability indices were also used to validate the level of harvest used in the timber forecasts to see if it reflects the level of harvest during the period 2006-2009 (Table 5, Figure 3). This can be used to compare the level of harvest from the forecast and what actually occurs, based on the NFI (i.e. TSH_{RP} see figure 3 and section 2.28 of FRL Technical Guidelines). The number of plots subject to thinning or harvest in the NFI for the RP period is limited, so stratification of species cohorts was reduced to 3 strata to reduce sample error.

Table 5. Comparison of sustainability indices (and 95% confidence interval in parenthesis) from the 2006-2012 NFI and those obtained from the CBM simulation using the timber forecast target volume for FM areas.

	Forecast target	**NFI 2006-2012 (TSH_{RP})**
Spruce	0.77 (0.68-0.85)	0.69 (0.64-0.74)
Other conifers	0.50 (0.42-0.59)	0.51 (0.48-0.54)
Broadleaves	0.09 (0.05-0.12)	0.24 (0.18-0.30)

Broadleaf forests are generally managed less intensively than conifers in Ireland. NFI statistics show that the sustainability ratio for broadleaves is only 0.16 (based on total stem volumes, NFI 2006-2012). The corresponding biomass sustainability ratio (harvested stem biomass/ total biomass increment before harvest) is 0.24 (Table 5). For the Coillte estate, which is the largest land owner, broadleaves are excluded from the timber forecast. The forecast harvest for the private estate was assumed to be 1m^3 per ha^{-1} yr^{-1} (Phillips et al., 2016). If maintained this would underestimate the harvesting rates in broadleaf forests.

Based on the comparisons of sustainability indices for the NFI and CBM simulation using the silvicultural rules and the forecast target volumes, it is clear that the broadleaf harvest is underestimated in the timber forecast by a factor or 2.66. Based on this comparison, the level of harvest for the FGB and SGB category was conservatively doubled, resulting in a sustainability index of 0.18 which is within the confidence interval for broadleaves in the NFI. The adjusted target sustainability index increased as a result of this adjustment (see FRL (TSH_{RP}) Target Figure 3). This helps to ensure a more accurate reflection of management practices but given the areas involved the overall impact will be minor.

The final level of harvest used in the FRL is outlined under the CBM calibration section (Figure 10). The consistency of the application of the sustainability ratio in the FRL target, versus the NFI, demonstrates that there is consistent application of sustainable practice over the FRL time series (see Article 8(5) of EU LULUCF regulation).

3.3 Detailed description of modelling framework used for FRL

The modelling framework uses two basic data types to describe variations in forest and HWP pool CSCs:

- Fixed data for the CP
    - Silvicultural rules and rotation ages
    - Area of annual fires and deforestation
    - Annual level of harvest for each year is fixed, but this changes from year to year depending on age class dynamics.
    - All emission factors, biomass constants and growth function coefficient are fixed.
    - The ratio of timber harvest to semi-finished HWP
    - Climate variables are fixed (i.e. temperature dependent decay functions are based on a long term mean temperatures)
- Dynamic CP
    - Age class structure within defined species strata-i.e. state of the forest
    - Area of managed forest and afforestation i.e. transiting forests
    - Level of harvest within each species strata
    - Growth is age dependent
    - Interannual variation in level of harvest as defined by the thinning g and clearfell thresholds.

3.3.1 Forest Carbon

Ireland currently uses a single tree growth model (CARBWARE) for C reporting and projections, such as the setting of the FMRL under 2CMP/7 and for the EC decision 529 submission. However, Ireland has been collaborating with the EU JRC (ISPRA) to use the CBM-CFS3 (Canadian Forest Service Carbon Budget Model) model for future reporting and forecasting. Previous work carried out in 2012 indicated good agreement for biomass and dead organic matter (DOM) carbon (C) stock changes (CSCs) for AR areas, but there were large differences in the simulation outputs for FM areas (Pilli, unpublished data). Detailed analysis of model outputs and assumption used for both the CBM and CARBWARE model showed that the differences between model outputs for FM land were due to:

i. Use of generic biomass to volume conversion equations in CBM, compared to country specifically derived biomass equations used in CARBWARE.
ii. CBM input data was based on stratification of NFI data into age species class matrices on a 10-year bin class. In contrast, CARBWARE is a single tree model that operated at the plot level (no post NFI stratification).
iii. CARBWARE does not have a regeneration or tree ingrowth sub-model, so long simulations, without recalibration with NFI data, may lead to large underestimations in biomass CSCs.
iv. DOM CSCs in CBM include C transfers from biomass, litter, deadwood and soil pools. In contrast, CARBWARE only includes litter and deadwood inputs and decay outputs and does not consider fragmentation losses or losses/gains from the slow C pool in soils.
v. CARBWARE does not run an initialisation to equilibrate the DOM pools before the start of a simulation. The initial litter and deadwood pool is based on NFI deadwood pools and a look up value for age-species specific litter stocks. In contrast, CBM runs an initialisation to equilibrate DOM pools. The danger of not doing an equilibration is that DOM CSCs can be overestimated for forest land remaining forest land. However, this is not a concern for CSCs in land converted to forest land because the DOM pools are initially zero.

To address these shortcomings and to provide an improved framework for forest CSC projections, including the generation of the FRL, Ireland has opted to use CBM for all future reporting and forest projections. The main reasons for this are:

i. Harmonisation of approaches using CBM would be comparable with model simulations developed by the JRC and other EU countries. This is done in the spirit of improving comparability and transparency and consistency of method used in national inventories at both the European and International level (see IPCC GPG 2006, EU LULUCF Regulation and Regulation (EU) No 525/2013 EC).
ii. The CBM model includes estimation of CSCs in mineral soils and the treatment of C flows in the DOM is complete. In contrast, CARBWARE does not estimate mineral soil CSCs, does not completely treat all DOM transfers and does not run and initialisation to equilibrate the DOM pools in the model framework. Recent and ongoing research has provided greater insights into changes in soil carbon post afforestation.
iii. The inability of CARBWARE to deal with ingrowth of tree in the NFI means that long term simulations can produce large underestimations of biomass and over estimations of DOM CSCs.
iv. As described later in this section, initial comparisons between CARBWARE and CBM suggest that CBM is a more accurate modelling approach when compared against observed carbon stocks derived from repeated NFIs.

A detailed description of CBM is presented under the CBM calibration section of this document. We also demonstrate consistency between CBM and CARBWARE (National inventory submissions) outside of the shortcomings of CARBWARE as highlighted above. Ireland intends to use CBM for all forest reporting from 2018 onwards.

The selection of the CBM model also ensures the following key elements of the EU LULUCF regulation are adhered to, in addition to the TACCC principles:

i. Use of defined disturbance harvest matrices based on justified rotation and thinning ages ensures that dynamic age-related characteristics of the forest do not remain fixed throughout the CP, meaning that the age structure of the forest is modelled to develop over time. This allows to "not unduly constrain forest management intensity as a core element of sustainable forest management practice" (Article 8(5)).
ii. The application of a target harvest level based on a calibrated sustainability ratio derived from the first two NFIs ensures "continuation of sustainable forest management practice" (Article 8(5)).
iii. The "state of the forest" for the FRL (see FRL Technical Guidance for definition) is defined using the species-age strata from the NFI 2017 (i.e. "best available data"). The FRL Technical Guidelines recommend using NFI data up to 2010 or to explain the use of later data. Ireland is employing the latest NFI data as earlier data is not considered to be consistent with Article 8(5) of the LULUCF regulation because the state of the forest in 2010 will not reflect the state of the forest prior to the commencement of the CP. Therefore, the state of the forest that reflects dynamic age class characteristics is best defined using data closest to the initiation of the CP ("best available data" (see Article 8(5)) age class of the FRL). If 2010 data is used, and there are subsequent NFI data prior to 2021, a technical correction should be completed to comply with conditions set out in Article 8(5) as described in section 2.5.4.3 of the Technical Guidance.
iv. The state of the DOM pool at initiation of the simulation (i.e. CBM initiation of the DOM pool) also better defined using the state of the forest in 2017.

3.3.2 HWP

In line with Article 9 and Annex V of the Regulation, the HWP model is based on the product half-life decay model as outlined in the 2013 IPCC supplementary guidelines under the Kyoto protocol. In order to establish a basis for the inclusion of emissions from harvested wood products (HWP) arising from harvests, it is first necessary to estimate the annual production of HWP arising from domestic harvest using FAO statistics. Firewood, wood for energy, wood biomass harvest and harvest from deforestation was assumed to be instantaneously oxidised and were not included in the harvested wood product pool inflows.

Historical HWP inflows

The FAO data has relevant information on production, imports and exports of industrial roundwood[4], for estimation of the fraction used for production from domestic harvest, excluding fuel wood, using equation 1:

$$f_{RWi} = \frac{RW_{Pi} - RW_{EXi}}{RW_{Pi} + RW_{IMi} - RW_{EXi}} \qquad (1)$$

[4] FAO Definition: All roundwood except wood fuel. In production statistics, it is an aggregate comprising sawlogs and veneer logs; pulpwood, round and split; and other industrial roundwood. It is reported in cubic metres solid volume underbark (i.e. excluding bark).

Where:

f_{RWi} = share of industrial roundwood for the domestic production of HWP originating from domestic forests in year *i*.

RW_{Pi} = production of industrial roundwood in year *i*, m^3 yr^{-1}

RW_{IMi} = import of industrial roundwood in year *i*, m^3 yr^{-1}

RW_{EXi} = export of industrial roundwood in year *i*, m^3 yr^{-1}

The f_{RWi} was applied to the industrial round wood fraction to derive sawnwood and wood-based panels (WBP) production from domestic harvest only. No paper is currently being produced from wood fibre in Ireland. Historical paper production from Clondalkin paper mills from 1961 to 1982 was obtained from FAO commodity data. No corrections were required for imported pulpwood or roundwood for paper production since this was all derived from domestic harvest.

Projected HWP inflows

Ireland cannot disaggregate historical HWP inflows for forest land remaining forest land for the period 2000-2009. The GHGI common reporting format for Convention reporting of HWP inflows is based on all forest areas, so there is no historical distinction of HWP inflow for the L-FL and FL-FL categories. Therefore, it is not possible to directly follow the technical guidance sections 2.5.3 and 2.5.6 (see Forsell et al., 2018). The ratio of harvest used for energy production before (from 2017 onwards) and over the FRL period (2021-2030) was based on the average energy use ratio of harvested timber (all forest categories excluding deforestation) for the period 2000-2009 (f_{energy}, see Table 6). The allocation of timber harvest to semi-finished products was based on the average allocations for the period 2000-2009 (Table 6) as stipulated in paragraph e, section A of Annex IV of the EU LULUCF Regulation. To estimate the share of energy, sawnwood, WBP and paper inflows from future harvest (i.e. total roundwood production excl. deforestation), the ratio of the historical inflow from domestic production (for a given semi-finished product) over the roundwood harvest value (f_{TRWi}) for the years (i) 2000-2009 (see table 6 below) was employed. The rationale for this is that:

i. Most of the harvest will occur in the MFL category so the ratio of harvest for energy use based on the total roundwood harvest excluding deforestation is the best available data to calculate HWP inflow for the projection
ii. The approach we use is similar to that recommended by the technical guidance sections 2.5.3 and 2.5.6 (Forsell et al., 2018).
iii. The ratio of semi-finished products to total roundwood production is indicative of the energy use ratio of harvested timber from all forests (f_{energy}, see Table 6).
iv. The ratio of sawnwood ($f_{sawnwood}$) or WBP (f_{WBP}) from domestic production over the total roundwood harvest is indicative of the allocation of harvested timber into HWP semi-finished products over the reference period 2000-2009. In addition, since these ratios inherently include the constant energy ratio, the application of the ratios for future HWP inflows would be consistent with the criteria set out under paragraph e, section A of the Annex IV to the EU LULUCF Regulation.
v. The allocation of harvested timber to sawnwood or WBP would simply be a product of the ratio and amount of harvest from managed forest in a given year during the FRL accounting period (eq. 2 and 3):

SW_{DPi} = roundwood harvest$_i$ x $f_{sawnwood(i)}$ in year *i* (2)

WBP_{DPi} = roundwood harvest$_i$ x $f_{WBP(i)}$ in year *i* (3)

It should be noted that a technical correction to the HWP FRL will be applied when actual allocations to sawnwood and WBP are known for the periods 2017-2020. However, the fixed ratio as indicated in table 6 will be applied to the FRL for the periods 2021-2030 based on the 2000-2009 share as specified in the EU LULUCF regulation.

Table 6: Derived energy (f_{energy}), sawnwood ($f_{sawnwood}$) and WBP (f_{WBP}) ratio from historical FAO data for allocation of harvested wood to HWP semi-finished products for the FRL projection.

Year	**Total roundwood harvest (m3)**	**a) Total roundwood harvest excl. deforestation (m3)**	**b) Industrial roundwood (m3)**	**c) f_{RWi}**	**d) Sawnwood from domestic harvest excl. deforestation (m3)**	**e) Wood based panels from domestic harvest, excl. deforestation (m3)**	**f) $f_{sawnwoodi}$ *(=d/a)***	**g) f_{WBP} *(=e/a)***	**$f_{energyi}$ *(=1-f-g)***
2000	3008451	2840383	2586600	0.96	804891	675251	0.283	0.238	0.479
2001	2836000	2667932	2423000	0.96	835192	662836	0.313	0.248	0.439
2002	2910710	2742642	2612100	0.946	728635	623847	0.266	0.227	0.507
2003	3000000	2831932	2653200	0.934	886513	734575	0.313	0.259	0.428
2004	2846490	2678422	2542489	0.922	814488	729596	0.304	0.272	0.424
2005	2942000	2773932	2629000	0.908	868835	748996	0.313	0.270	0.417
2006	2967778	2031349	2655000	0.919	687911	589189	0.339	0.290	0.371
2007	2980823	2563667	2678000	0.9	846594	746767	0.330	0.291	0.378
2008	2226000	1993260	2144000	0.853	532260	586479	0.267	0.294	0.439
2009	2582980	2360718	2261796	0.912	644937	594108	0.273	0.252	0.475
2010	2879795	2768575	2436975	0.947	731414	717766	0.264	0.259	0.477
2011	2899000	2784041	2440783	0.954	726243	701943	0.261	0.252	0.487
2012	2838462	2737212	2375654	0.916	715888	644570	0.262	0.235	0.503
2013	3028713	3014788	2542253	0.899	741236	664612	0.246	0.220	0.534
2014	3114084	3081975	2624729	0.902	817857	697548	0.265	0.226	0.508
2015	3198787	3168321	2707888	0.894	809425	687536	0.255	0.217	0.528
2016	3148401	3129809	2824834	0.906	895309	701515	0.286	0.224	0.490
Mean value 2000-2009		2548424	2518519	0.921	765026	669164	0.300	0.264	0.436

Allocation of HWP in forest sub-categories

The inflow of HWP associated with land converted to forests and forest management areas is based on the share of harvest coming from harvest in the CBM simulation. For the historical HWP inflows and HWP stock the allocation of HWP to FM activities were estimated using the following equation:

$$f_{j,i} = \frac{Harvest_{j,i}}{Harvest_{total,i}} \quad (4)$$

Where,

$f_{j,i}$= share of harvest originating from the particular forest category *j* in year *i*.

j = activity *FM* in year *i*.

The final inflow of domestically produced sawnwood in a given forest activity (*j*) in year *i*, for example, is then calculated as:

$$SW_{j,i} = SW_{DPi} \times f_{j,i} \quad (5)$$

Conversion factors for HWP products

Table 7: Conversion factors used for default HWP categories.

HWP categories	**Density**	**Carbon fraction**	**C conversion factor (per air dry density)**
	[Mg m^{-3}]		[Mg C m^{-3}]
Sawnwood	0.458	0.5	0.229
Wood-based panels	0.595	0.454	0.269
			Mg C Mg^{-1}
Paper and paperboard	0.9		0.386
Source IPCC GPG 2013			

Emissions from the historic and projected HWP C pool

Forestry production and trade data from 1961-2016 from FAO, projected HWP inflows (see above) and historical growth for timber utilisation (see below) were used to estimate harvested wood product (HWP) emissions/removals in Ireland for 1900-2030 using a model based on IPCC 2006 Guidelines; i.e. the Pingoud and Wagner 2006 model:

$$C_{i+1} = e^{-k} \times C_i + \left[\frac{(1-e^{-k})}{k}\right] \times Inflow_i \quad (6)$$

$$\Delta C_i = C_{i+1} - C_i \quad (7)$$

Where:

i = year

C_i = the carbon stock in the particular HWP category from a particular forest activity at the beginning of year *i*, Gg C

k = decay constant of first-order decay for HWP category given in units yr^{-1} (*k* = ln(2)/HL, where HL is half-life of the HWP pool in years (see below).

$Inflow_i$ = the inflow to the particular HWP category (HWP_j) during year *i*, Gg C yr^{-1}

ΔC_i = carbon stock change of the HWP category during year i, Gg C yr^{-1}

Historic consumption rates from 1900-1960, using a growth rate of 1.15% y^{-1}, were used to estimate emissions from products entering the system prior to 1961, as outlined in IPCC Guidelines for National Greenhouse Gas Inventories 2006[5]. Default half-lives of two years for paper, 25 years for wood-based panels, and 35 years for sawnwood were used to estimate emissions resulting from products coming out of use.

3.3.3 Simulation of transitions

To deal with the requirement to simulate 30-year transitions (see justification in sections below) between AR land and FM land areas in CBM the following factors had to be considered:

i. The CBM requirement for different simulations (FM and AR with successive exclusion of afforestation year in the AR category). For example, in 2021 all areas afforested in 1990 with the associated C stock in forests are transferred to FM lands etc. (Figure 3).
ii. The share of harvest scheduled for AR land transitioned to managed forest land (MFL) lands is carried over to the FM disturbance event table for harvest simulation between the period 2021-2030.
iii. The existing HWP stock from harvests occurring on AR lands prior to the transition to MFL lands is carried over and included in the decaying HWP pool in MFL. If this is not done the HWP emissions due to decay will be underestimated (Figure 5).

The diagram below shows the workflow to simulate land use transitions and associated CSC between land converted to forest land and forest land remaining forest land based on a 30-year transition.

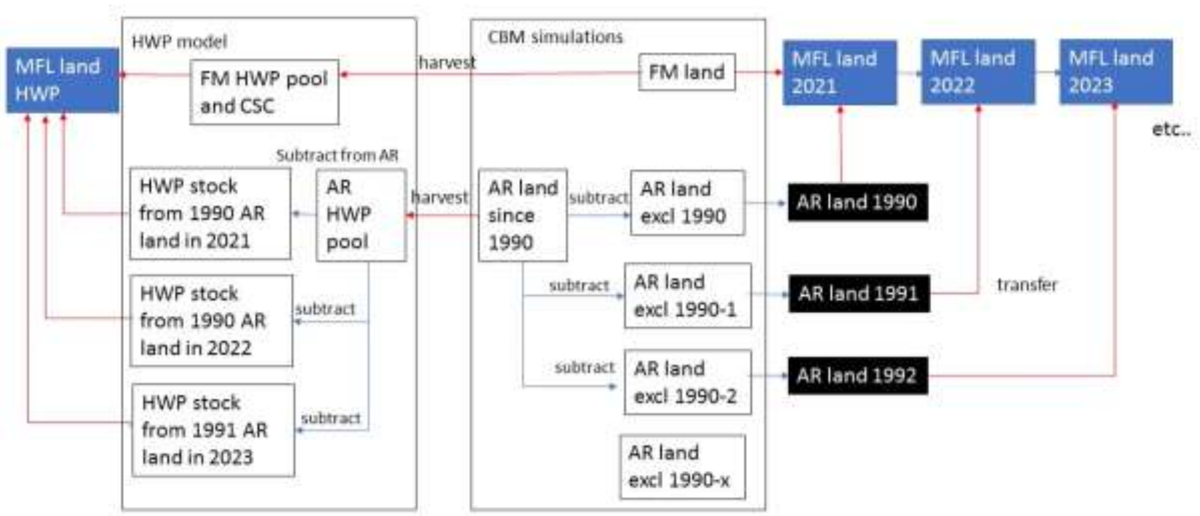


Figure 5 The workflow to simulate land use transitions and associated CSC between land converted to forest land and forest land remaining forest land based on a 30-year transition.

In order to simulate the transitions in CBM, the CSC in AR forests had to be simulated 11 times, once with all AR land and harvests since 1990 and then successive runs where one years' activity data, starting with lands planted in 1990, is removed from the initiation state (e.g. AR land excl. 1990, in Figure 5 above). The difference between all AR lands and AR land excluding 1990 afforestation then

[5] IPCC Guidelines for National Greenhouse Gas Inventories 2006 Chapter 12, pg 17-19.

reflects the areas and CSCs for all forest afforested in 1990 in the year 2021. These areas and C stocks are transferred to the MFL category together with areas and C stocks for FM lands. The procedure is repeated for the entire time series.

For HWP, the harvest originating in AR lands planted since 1990 are transferred to the HWP module for AR lands (i.e. AR HWP pool in Figure 3). However, the decaying HWP stock for lands undergoing transitions also need to be transferred to the HWP pool in MFL together with the FM HWP pool. For example, in 2021, the remaining HWP pool for harvests taken from forests afforested in 1990 is transferred to the decaying HWP in the MFL category (Figure 5). This means that the HWP pool in MFL increases due to transferred between categories and due to scheduled harvest in the MFL category.

Justification for using a 30-year transition period

According to paragraph 2 of article 6 of the EU LULUCF regulation "a Member State may change the categorisation of transitioning land from land converted to forest land to forest land remaining forest land, 30 years after the date of that conversion, **if duly justified based on the IPCC Guidelines**". The 2006 IPCC guidelines for AFOLU (vol 4, Ch 2) outlines that the rationale for use of the 20-year interval is taken as a default length of transition period for carbon stock changes following land-use change. However, the IPCC guidelines state that the actual length of transition period depends on "natural and ecological circumstances of a particular country or region and may differ from 20 years" (see ch4 of AFOLU GPG). The C dynamics in soils, litter and biomass following transition to forest land may take significantly longer than 20 or 30 years. In Ireland's case, the transition period for biomass to reach steady state may occur within a 20-30 year period for fast growing species (Figure 7 below). However, the steady state for litter, deadwood and soils may be considerably longer over 100 years. Evidence for these transition periods come from two different modelling frameworks i.e. CBM and YASSO (figure 6 and 7). Calibration of the YASSO model using Irish inventory information and additional GIS variables (Black et al., 2014) showed that the transition period of for SOC to reach steady state over a range of mineral soils varies for 30-70 years (Figure 6).

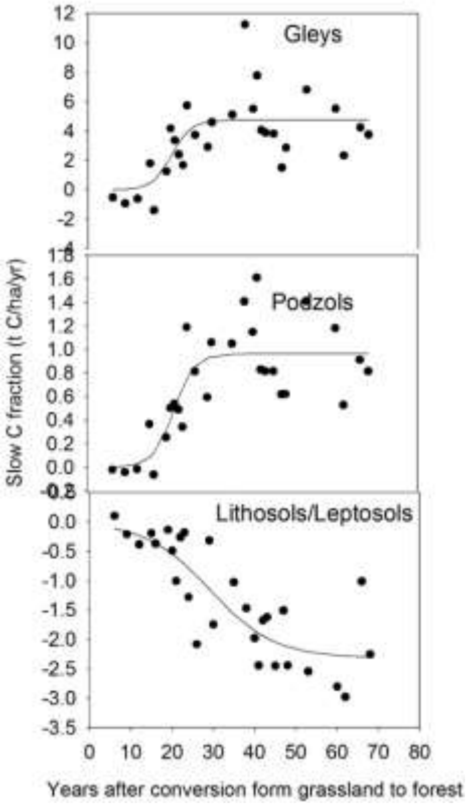


Figure 6 Simulated changes in SOC stocks in the 3 major mineral soil types undergoing transition from grasslands to forests based on a YASSO model calibrated for Irish conditions.

These results are consistent with CBM outputs, which shows that mineral SOC stock do not reach steady state within the 1st rotation of a typical conifer forest (ca. 50 years for Sitka spruce S.I. 16, Figure 6. Steady state for litter and deadwood transitions appear to be 35-40 years for the same forest type (Figure 7).

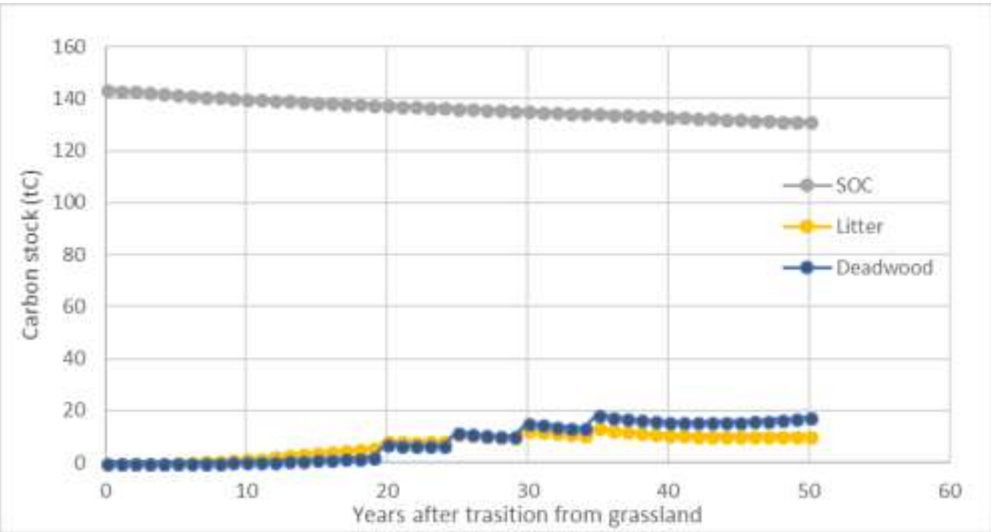


Figure 7 CBM simulations shows CSCs in soils, Deadwood and litter for a typical conifer plantation (Sitka spruce SI 16 growing on Luvisol soil) following conversion from grasslands

We demonstrate that the ecological circumstances for the transition period for SOC, litter and deadwood pools are longer than 30 years. Based on the IPCC guidelines, we justify using a transition period which is more than 20 or 30 years. However, since the EU LULUCF regulation does not allow transition periods longer than 30 years, we will adopt the 30-year transition period for accounting lands converted to forest land. The FRL will include land converted to forest lands after a transition period of 30 years. For example, for the year 2021, forest land remaining forest land will include C stock changes in all pool (biomass, litter deadwood, soils and HWP) from land afforested in 1990.

3.3.4 Calibration of CBM

In 2017-2018, Ireland set up a comprehensive CBM modelling framework and created a country specific archive database index (AIDB) for model simulation of forest CSCs based on National Forest Inventory (NFI) data to define the initiation state and growth characteristics. The stratification of NFI data and development of model initialisation, disturbance and transition assumptions facilitated the refinement of the previous work done on CBM in 2012. Particular improvements included:

i. refinement of species strata to reflect forest management over the period 2000-2009 specific to Ireland.
ii. a higher resolution of age class bins from 10 to 5 years to define the initial state of the forest and allow finer control of disturbance matrices and growth increment.
iii. development of country specific volume to biomass equations and biomass allocation equations for the defined species and productivity class strata
iv. refinement of the current annual increment (CAI) and standing volume curves for the new species-age class matrix.

For a description of CBM and use of the AIDB database please refer to Kurz et al. (2009) and Kull et al. (2016).

3.3.4.1 Stratification of NFI data

The initial state of the forest area is defined in the “Inventory” table in the AIDB for CBM simulations. This uses the stratification as defined in step 1 of this methodology section (pp. 4-6). For afforested lands the inventory species-age class matrix is expanded to include 4 major soils groups and previous land use prior to forest conversion (i.e. non-forest soils). Analysis of recent data show that conversion from forest land occur on grasslands and managed wetlands.

3.3.4.2 Species specific biomass to volume conversion factors

CBM uses merchantable stem volume (stump to 7cm diameter) from the NFI plot data as primary input for the determination of biomass components (Figure 8, Boudewyn et al., 2007). Single tree merchantable volumes and biomass values for different components (merchantable, non-merchantable, sapling, foliage, branches, stemwood, bark etc.) were derived based on NFI DBH and H country specific equations for different species (NFI, 2001, Duffy et al, 2017, Tobin et al., 2007). Single tree estimates were scaled up to the stand level (per ha) for each species cohort using NFI stratified plot expansion factors and the area of the NFI plot (0.05ha, see NFI, 2017). Species cohort were further simplified into 5 strata (see Table 8) due to insufficient data to solve equation parameters for all strata identified in Table 2. The FGB and SGB strata were also combined to solve eq 8, 9 and 10 because there was insufficient data to solve the parameters. Parameters for the FGB/SGB biomass equations were used to define biomass components for the CBmix and Cmix strata, OC model parameters were used for the Cmix stratum biomass components. The CBM default

C fraction of 0.5 was used to convert biomass to C. These biomass equations are specified in the AIDB tables during model calibration.

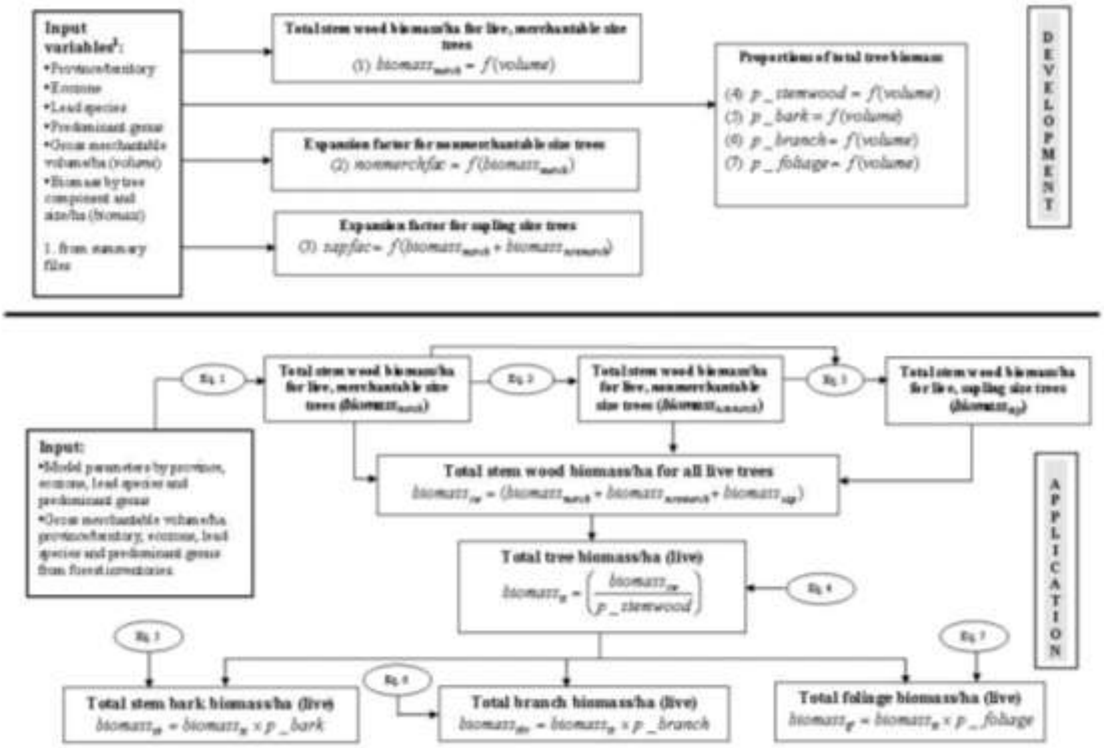


Figure 8 Summary flow chart of development and application of biomass component functions in CBM, taken from Boudewyn (2007). Note that eq. references in the diagram do not match the text below, but the equation names do.

Biomass equations

Merchantable stem biomass (*bm*, t ha^{-1}), which excludes stumps, tops and non-merchantable trees, to volume (v, m^{3}ha^{-1}), equation:

$$bm = a \times v^b \quad (8)$$

Table 8: Parameters for Eq 8.

Cohort	a	b	Vol limit (m3/ha)	Min limit (m3/ha)	RMSE
Spruce	1.583	0.764	1020	3.6	10.4
Pine	0.974	0.899	1120	2.1	17.7
Other conifers	1.406	0.799	950	5.42	11.7
***Fast growing broadleaves (FGB)**	0.384	1.150	650	4.2	42.5
***Slow growing broadleaves (SGB)**	0.384	1.150	650	4.2	42.5

* The FGB and SGB strata were combined to solve the parameters because there was insufficient data to solve the parameters for the individual stratum

A large component of young forests do not contain merchantable timber but still may have a considerable stem biomass that is nonmerchantable (*bn*). The *nonmerchfactor* corrects for this based on the following:

$$nonmerchfactor(f) = k + a \times bm^{b} \quad (9)$$

$nonmerchfactor = \frac{bnm}{bm}$, where *bnm=bn+bm*

Table 9: Parameters for Eq 9.

Cohort	k	a	b	*f* bnlimit	Min limit f	RMSE
Spruce	0.863	0.597	-0.302	3.4	1	0.08
Pine	0.723	1.728	-0.363	4.5	1	0.17
Other conifers	0.906	1.304	-0.536	2.1	1	0.06
***FGB**	0.471	49.165	-0.942	7.2	1.05	32
***SGB**	0.471	49.165	-0.942	7.2	1.05	32

*The FGB and SGB strata were combined to solve the parameters because there was insufficient data to solve the parameters for the individual stratum

Saplings also do not contain timber (DBH >0cm) but still may have a biomass value (bs). The *saplingfactor* corrects for this based on the following:

$$saplingfactor(f) = k + a \times bnm^{b} \quad (10)$$

$saplingfactor = \frac{bsnm}{bnm}$, where $bsnm = bs + bnm$

Table 10: Parameters for Eq 10.

Cohort	k	a	b	*f bs*limit	RMSE
Spruce	1.0091	0.4289	-0.869	1.6	0.02
Pine	0.9922	0.6071	-0.9240	1.9	0.004
Other conifers	0.9922	0.6071	-0.9240	1.8	0.004
***FGB**	0.9912	100	-1.9745	1.8	0.014
***SGB**	0.9912	100	-1.9745	1.8	0.014

*The FGB and SGB strata were combined to solve the parameters because there was insufficient data to solve the parameters for the individual stratum

Biomass proportion equations

Models to predict the proportional division of total biomass to stemwood, bark, branches and foliage are derived from NFI tree and plot information and biomass algorithms (NIR, 2017) using a multinomial modelling approach. Total aboveground biomass ($Biomass_{ag}$) can be derived from $Biomass_{swt}$ (bm + nonmerchfactor + saplingfactor), and an expansion factor p_stemwood derived from standing merchantable volume (v, m^3 ha^{-1}), based on eq 11:

$$Biomass_{ag} = \frac{Biomass_{swt}}{p_{stemwood}} \tag{11}$$

and

$$p_{stemwood} = \frac{1}{1+e^{a1+a2\times v+a3\times lv}+e^{b1+b2\times v+b3\times lv}+e^{c1+c2\times v+c3\times lv}} \tag{11a}$$

Where *lv* is the natural log of volume plus 5, ln(v+5)

The other above ground biomass components (foliage, branch and bark) are estimated using the same proportional equations parameters as shown above, but on a proportional basis so that the total biomass equals the sum of proportions.

Bark biomass (*Biomassbk*) is estimated as follows:

$$Biomass_{bk} = Biomass_{ag} \times p_{bark} \tag{12}$$

$$p_{bark} = \frac{e^{a1+a2\times v+a3\times lv}}{1+e^{a1+a2\times v+a3\times lv}+e^{b1+b2\times v+b3\times lv}+e^{c1+c2\times v+c3\times lv}} \tag{12a}$$

Branch biomass (*Biomassbr*) is estimated as follows:

$$Biomass_{br} = Biomass_{ag} \times p_{branch} \tag{13}$$

$$p_{branch} = \frac{e^{b1+b2\times v+b3\times lv}}{1+e^{a1+a2\times v+a3\times lv}+e^{b1+b2\times v+b3\times lv}+e^{c1+c2\times v+c3\times lv}} \tag{13a}$$

Foliage biomass (*Biomassfl*) is estimated as follows:

$$Biomass_{fl} = Biomass_{ag} \times p_{bark} \tag{14}$$

$$p_{foliage} = \frac{e^{c1+c2\times v+c3\times lv}}{1+e^{a1+a2\times v+a3\times lv}+e^{b1+b2\times v+b3\times lv}+e^{c1+c2\times v+c3\times lv}} \tag{14a}$$

Table 11: Parameters for all biomass fractions. The fractions for FGB and SGB were taken directly from Boudewyn (2007).

Cohort		**1**	**2**	**3**	***Vol* limit**	**RMSE**	
Spruce	a	-1.07341	0.00011	-0.17291	771	Stemwood	0.04
	b	1.06544	0.00027	-0.43841		Bark	0.01
	c	0.65877	0.00028	-0.41110		Branch	0.03
						Foliage	0.02
Pine	a	-2.18146	-0.00004	0.00825	891	Stemwood	0.07
	b	-1.96692	-0.00003	0.01106		Bark	0.11
	c	-1.68418	0.00007	-0.10473		Branch	0.06
						Foliage	0.06
Other conifers	a	-0.94047	0.00015	-0.18072	910	Stemwood	0.08

	b	1.150062	0.00031	-0.50674		Bark	0.11
	c	0.89950	0.00037	-0.57301		Branch	0.04
						Foliage	0.09
FGB	a	-1.6458	0.00002	-0.02892	599	Stemwood	0.09
	b	-0.67447	-0.00034	-0.1204		Bark	0.01
	c	-0.83940	-0.00120	-0.25447		Branch	0.03
						Foliage	0.02
SGB	a	-2.23522	-0.00055	0.00469	1099	Stemwood	0.14
	b	-1.38733	-0.00014	0.04913		Bark	0.06
	c	-2.38719	-0.00063	-0.15867		Branch	0.07
						Foliage	0.12

Belowground biomass was calculated using equations and parameters defined by Li et al. (2003).

3.3.4.3 Growth and standing volume curves for species strata

Current annual increment (CAI) curves for the species cohort strata were parametrised using merchantable volume (under bark) data from the 2012-2017 NFI cycles (Table 12). A modified Chapman-Richards growth function was used:

$$CAI = a \times exp^{-b \times age} \times 1 - exp^{(-b \times age)^{c-1}} \quad (15)$$

Table 12: Solved parameters for CAI of different species cohorts

		Parameter	
Cohort	**a**	**b**	**c**
CBmix	69.654	0.027	2.922
Cmix	114.533	0.032	3.670
FGB	85.532	0.071	5.001
OC	155.663	0.036	4.217
Pine4-12	149.682	0.033	6.821
Pine12-20	147.517	0.038	4.525
SGB	47.157	0.022	3.057
Spruce4-12	142.815	0.034	6.509
Spruce13-16	330.124	0.038	5.604
Spruce17-20	292.059	0.057	5.783
Spruce20-24	393.734	0.075	6.525
Spruce24-30	628.315	0.111	9.029

CBM also uses standing volume curves during the model initialisation of DOM pools under forest management. Standing volume curves were derived for the same cohorts using a standing volume Chapman-Richards function based on the NFI 2017 data (Table 13):

$$CAI = a \times 1 - exp^{(-b \times age)^{c}} \quad (16)$$

Table 13: Solved parameters for standing volume of different species cohorts

		Parameter	
Cohort	**a**	**b**	**c**
CBmix	367.393	0.037	1.784
Cmix	330.955	0.053	2.488
FGB	631.321	0.003	0.814
OC	890.057	0.004	0.790
Pine4-12	215.211	0.078	5.214
Pine12-20	384.23	0.081	5.784
SGB	324.666	0.046	3.532
Spruce4-12	270.545	0.094	21.86
Spruce13-16	555.356	0.053	5.247
Spruce17-20	763.412	0.063	5.439
Spruce20-24	536.339	0.156	15.956
Spruce24-30	560.118	0.174	13.467

The standing volume and CAI curve values are specified in the AIDB to control stand volume increment. Importantly, CAI is derived from the 2017 NFI for the FRL so this reflects the current state (i.e. age class structure, growth and mortality) of managed forests. Use of most recent data to define the initialisation state of the forest prior to simulation of projected CSCs will factor out any age class legacy effects as required under paragraph 5 of article 8 of the EU LULUCF Regulation.

3.3.4.4 Disturbance matrices

CBM simulates disturbances based on user defined input matrices (Kurz et al., 2009). These matrices define the timing and intensity of disturbances by species/productivity strata (referred to as classifiers in CBM).

Afforestation

The afforestation disturbance matrix defines the annual area of species/productivity and soil type classes that are afforested every year since 1990 (Figure 9). Assumptions of future afforestation rates are consistent with Ireland’s Decision 529/2013 submission in 2015 although the rates will not impact on the FRL as these forests will not be transitioning during the compliance period. The afforestation legacy will have a large influence on harvest rates on both AR and FM due to the 30-year transition and harvest from thinning forests as young as 15 years in some cases (see silvicultural rules Table 4 and final target harvest Figure 11 below).

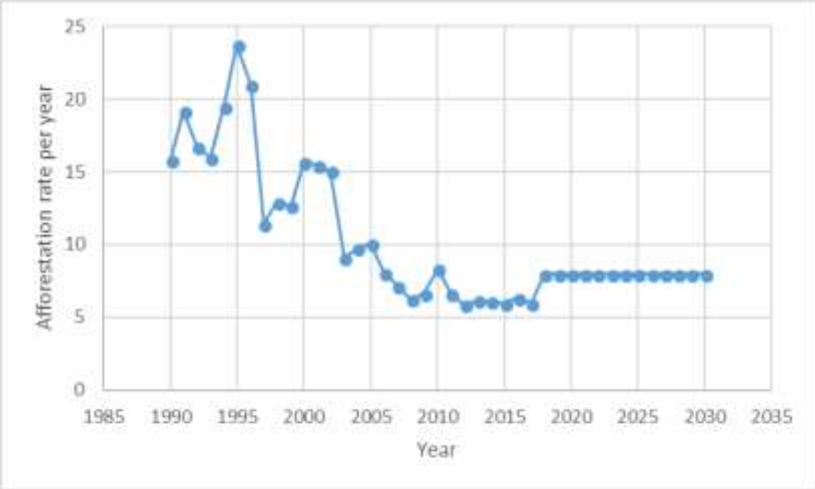


Figure 9 Historical and future afforestation rates

The total afforestation area is derived from NFI and the IFORIS (afforestation grant GIS database) and the proportion of species/soil strata are derived from NFI plot data (Table 14). The stratification of soil types was based on available SOC data in the national soil database (Black et al., 2014 and SOLUM project). Generalised soil types were grouped in to WRB groups, which have similar SOC values. For example, all brown earths were grouped into the Cambisol group.

Table 14: A summary of species/soil matrix area showing the percentage of areas for each species soil strata based on the NFI 2017.

	Soil strata (% of total area 2017)					
Species strata	**Peat (Organic & Organo-mineral)**	**Cambisols**	**Gleysols**	**Luvisols**	**Podzolic**	**Grand Total**
CBmix	1.5	1.0	2.2	0.0	0.0	4.8
Cmix	7.1	0.6	3.4	0.0	0.3	11.3
FGB	2.2	0.4	2.9	0.2	0.2	5.9
OC	0.9	0.3	1.1	0.0	0.5	2.8
Pine12-20	4.8	0.4	0.0	0.6	0.0	5.9
Pine4-12	2.2	0.0	0.0	0.0	0.0	2.2
SGB	0.0	0.1	1.1	0.0	0.0	1.2
Spruce 13-16	4.4	0.0	0.2	0.2	0.2	5.0
Spruce 17-20	9.7	0.8	1.9	0.4	0.3	13.0
Spruce 24-30	7.5	1.6	9.3	0.0	2.0	20.3
Spruce 4-12	4.9	0.1	0.2	0.0	0.2	5.4
Spruce20-24	12.3	0.7	7.4	0.7	0.9	22.1
Grand Total	57.6	6.2	29.6	2.1	4.5	100.0

CBM uses a non-forest SOC value for initialising the slow C pool value in the DOM model. However, the peat (organic soil emissions) component is not currently modelled in CBM so these emissions are applied after the CBM simulations, as done under current reporting methodology (Duffy et al., 2017). The non-forest mineral SOC value is a function of the mean soil value for a soil stratum on the previous land use. For Ireland, all afforestation of mineral soils occurs on managed or semi natural grasslands. Managed grassland included cropland pasture transitions (seer Duffy et al., 2017). The applied SOC values for grassland cambisol, gleysol, luvisols and podzols are 92, 87, 76 and 77 tC per ha, respectively.

Fires

Emission from fires would be accounted for under the natural disturbances provision (see Annex IV of the EU LULUCF Regulation). Therefore, future annual emissions from fires for the period 2017-2030 are assumed to be equivalent to the mean value (after all outliers are removed) between 2001-2016, using the natural disturbance provisions (Annex VI of EU LULUCF regulation, see Table 15). This is equivalent to an area of 169ha and 81 ha per year for FM and AR lands respectively (Table 15). The legacy effect of forest fires on age class distribution and CSCs in FL-FL need to be included in the FRL. This is done by simulating fire disturbance events based on an annual disturbance of 169 or 91 ha per year for the 2 forest categories in CBM (Table 15). This simulates the C stock changes in the biomass and DOM due to fire, but emissions to the atmosphere from fires are estimated using the same method used in the GHGI submissions (see Duffy et al., 2017)

It should be noted that the natural disturbance provision is based on the period 2001-2020, so a technical correction will be applied when actual fire areas are known up to 2020 and new background values are calculated for the 2001-2020 time series.

Table 15: Preliminary calculation of the background and margin values for FM and AR (2001-2016) using guidelines provided in Annex VI of the EU LULUCF Regulation.

		Gg CO_2 eq. for FM					
Background/ margin	I step	II step	III step	IV step	V step	VI step	**Eq. Area**
Arithmetic mean	86	73	65	55	47	**49**	**169**
standard deviation	76	59	50	37	21	18	
background+margin	237	190	165	130	89	85	
		Gg CO2 eq. for AR					
Background/ margin	I step	II step	III step	IV step	V step	VI step	**Eq. Area**
Arithmetic mean	11.36	13.75	13.75	13.75	13.75	**13.75**	**81**
standard deviation	16.71	7.69	7.69	7.69	7.69	7.69	
background+margin	44.78	29.12	29.12	29.12	29.12	29.12	

Fire emissions of L_FL transitioning to FL_FL for the period 2020-2030 was based on the background and margin (Fire(b+m) for AR land (29.12Gg CO_2, see table 15), but this was adjusted based on the proportion of L-FL areas transitioning to FL_FL (L-FLtrans) over the total AR area (ARarea)in a particular year (i):

$$Fire\ emission(i) = Fire_{(b+m)} \times \frac{L\text{−}FL_{trans(i)}}{AR_{area(i)}} \qquad 16.$$

Deforestation

Future deforestation rates were derived for the average deforestation rate (933 ha per year) over the period 2000-2016 as published in the GHGI (Duffy et al (2017). NFI 2006-2012 data shows that the age of forest prior to deforestation varies from 13 to 80 years, where standing volume can vary from 4 to 278 m^3/ha. Based on NFI data 2006-2012, It is assumed that deforestation events are random with no clear species, age and standing volume trend. Therefore, deforestation events scheduled in the CBM disturbance matrix are set up to randomly clearfell and not replant for any of the species cohorts. Timber from harvest due to deforestation is not included in HWP inflows. All deforestation emissions or removals are not included in the FRL.

A technical correction will be applied when know deforestation rates for the period 2017-2020 are published or if better activity data becomes available. However, the deforestation rate of the FRL period will be fixed at 933 ha per year.

Thinning and clearfells

The harvest disturbance matrix defined the timing and intensity of harvest interventions in CBM. This is controlled by the silvicultural rules and target harvest for each species stratum. If a target harvest is not defined the model harvests all available timber based on only the silvicultural rules.

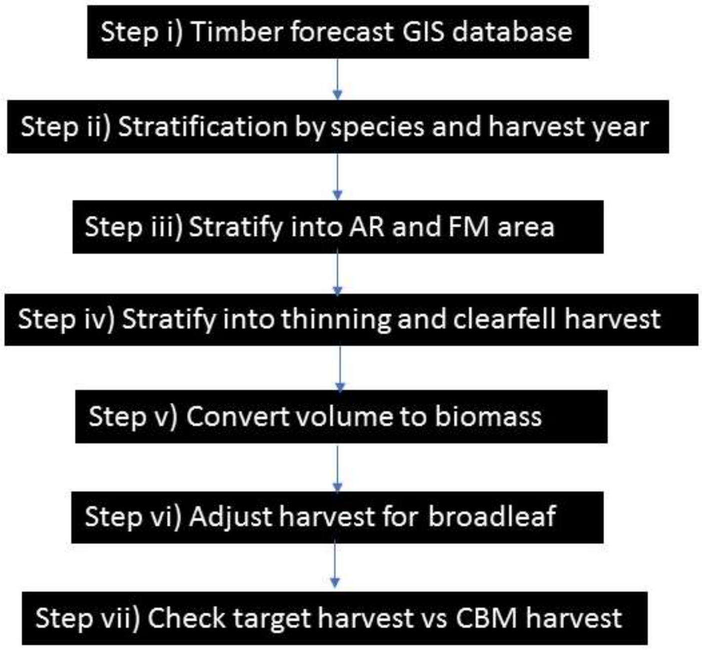


Figure 10 A workflow diagram showing how the final target harvest was derived (see related text for a detailed description)

Derivation of the final FRL target harvest is done in the following way (also see workflow diagram Figure 10:

i. Prescribed thinning and clearfells are spatially defined according to silvicultural rules and the available harvest volumes for each harvest year, from 2016-2035, in the timber forecast.
ii. The GIS forecast database contains forest parcel attributes which are used to stratify the harvest events by harvest year and by the same species strata used for CBM (see Table 2).
iii. Forest parcel attributes related to year of planting and whether forests are afforested or reforested allow the stratification into the AR and FM categories by harvest year.

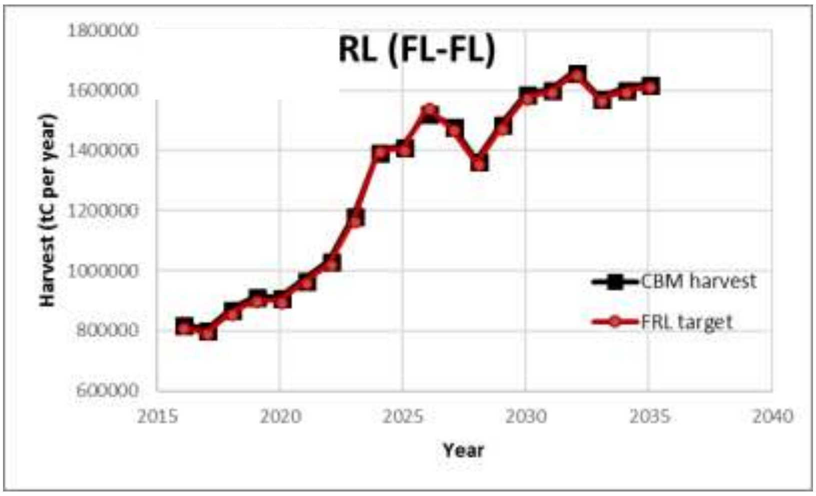
iv. Volumes are then re-stratified into harvest from thinning and clearfell within each species strata and for each harvest year.
v. Volumes are converted to biomass using the volume to biomass function for each species strata (see Tables 8 and 9).
vi. Timber forecast harvests are corrected for broadleaf harvest using the sustainability ratio validation with the NFI (see Figure 3 and Table 5).
vii. The target harvest is then calibrated against the actual harvest obtained from the different CBM simulations (see Figure 10).

FRL target level of harvest

The final FRL target level of harvest (Figure 11) is based on the adjusted timber forecast harvest 2017-2035 (see Figure 3 and Table 5). The harvest increases from 0.8 M tC per year in 2017 to over 1.6M tC by 2035 in MFL (top panel, Figure 11) is due to 2 major factors:

i. An increase in the area of forest under pre-1990 forests (FM lands) becoming available for clearfell and thinning as governed by the silvicultural rules. This harvest in these areas increase 1.1 m tC by 2023 (middle panel, Figure 10), followed by a steady decline in harvest as the age class distribution becomes younger and less timber is available for harvest (i.e. a left shift).
ii. The areas available for harvest in L_FL (AR land in Figure 9) increased significantly in 2025 due to the large availability of timber for clearfell in productive Sitka spruce stands that were afforested 27-34 years prior to 2025. The subsequent increase in harvest is due to the increase availability of timber for clearfell from afforested lands since 1990 (see Figures 9 and 11).

Once the target harvest was established, CBM simulates harvest for species strata using the silvicultural rules. Figure 11 also shows the agreement between the target harvest and the actual harvest obtained in the CBM simulations.



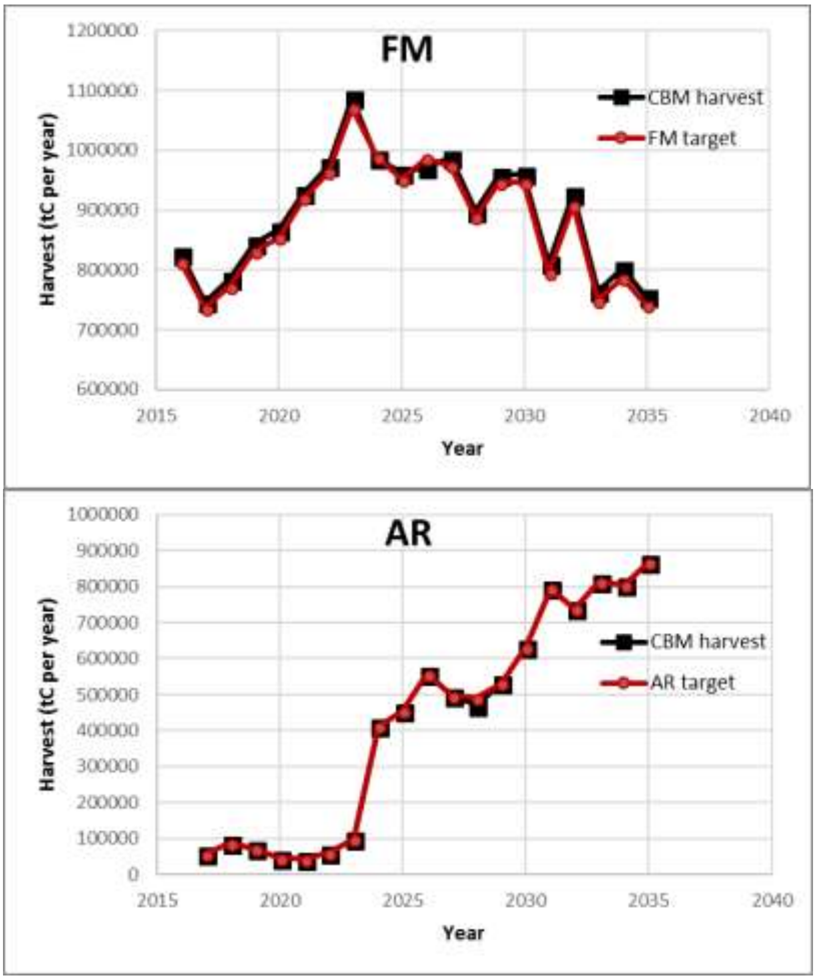


Figure 11 The actual harvest obtained in the CBM simulation (CBM harvest) versus the target harvests as defined in the disturbance events for model simulations. Note the level of harvest for the FRL (MFL) include harvests from lands converted to forest land (AR) which are older than 30 years old and older, (i.e. harvest in transitioning lands, L-FL) and managed forest land, as defined under the Kyoto protocol (FM).

3.3.4.5 Disturbance transfers and turnover parameters

Biomass turnover and litter transfers

CBM simulates mortality and litter fall to represent transfers of C from biomass to other DOM pools resulting from tree, foliage, branch, and root mortality (Kurtz et al., 2009). The table in Appendix B shows the country specific turnover rates and transfer rates specified in the AIDB (tblEcoBoundaryDeault) database of CBM (see table I of appendix B). Inputs into and emissions from the DOM pool generally increase as mortality or harvests increase (see section 4.1.1). The CBM model transfers C between nine different pools within the DOM pool, which turn over C at various rates depending on how labile the C is in each pool (Kurtz et al., 2009).

Decay dynamics

Decomposition for DOM pools are modelled using a temperature-dependent decay rate that determines the amount of organic matter that decomposes in a DOM pool. This is the only climate depended relationship used in CBM. The annual mean temperature for all regions in Ireland is set to 7.5 deg C in the 'tblClimateDefault' table in the AIDB of CBM. CBM uses proportions to determine the amount of C in the decayed material that is released to the atmosphere or transferred to the more stable slow DOM pools. The default decay rates and transfer proportions are specified in the 'tblDOMParamtersDefault' table in the AIDB based on values published by Kurz et al. (2009).

Disturbance matrices

Disturbance (harvest, fire, deforestation etc.) impacts are defined using matrix that describes the proportion of C transferred between pools, as fluxes to the atmosphere, and as transfers to the DOM pools or the timber sector. These are specific for each disturbance type and defined in the 'tblDMValuesLookup'table in the AIDB (Tables II, III, IV, V and VI of appendix B).

Chapter 4: The FRL

4.1 Consistency between FRL and GHGI

4.1.1 Validation of CBM with previous GHGI

The Irish greenhouse gas inventory (GHGI) does not currently include 20-year transitions under convention reporting of forest land (Duffy et al., 2017). The lands are reported using the same format under convention and KP reporting to ensure comparability and consistency and because of a lack of historical data to construct time series transitions between land use categories. Therefore, comparisons were done for AR and FM forest categories without transitions. Once the CBM model was calibrated, separate validations were run for FM and AR forest areas and outputs were compared to the official GHGI outputs 2006-2017 (IE_NIR_2018). This calibration is done for transparency and to demonstrate that the methods used to develop the FRL (i.e. CBM) are consistent and comparable to those (i.e. CARBWARE) used for UNFCCC submissions, the previous FMRL and submissions under EC decision 525/2013 (see para, g and h in Annex IV of the EU LULUCF regulation). The FRL estimates for all other pools except for biomass, and DOM are done using identical methods to those used in the UNFCCC submissions. These include HWP CSCs, emissions from drained organic soils, N_2O emissions from N mineralisation and GHG emissions for fires. However, it is important to note that the CBM approach has been developed for reporting purposes and will be employed in the NIR ensuring consistency between reporting and accounting methodologies.

4.1.1.1 AR validation

AR land will represent a larger proportion of areas in the forest land remaining forest land (FL-FL) under the FRL because of high afforestation rates since 1990 and the application of the 30-year transition rule (para. 2 Article 6 of the EU LULUCF regulation). Therefore, it is important to also validate CBM outputs for AR lands.

Set up of CBM

The 2017 NFI data and IFORIS data (afforestation grants and premiums data set) was used to define age class and species matrices for afforestation transitions for 1990-2016 (i.e. the afforestation transition matrix). The actual level of harvest in AR lands since 2007, as derived from the 2006-2017 NFI data, was used to set the level of harvest in the disturbance matrix. Current annual increment and stand volume curves were recalibrated for the 2006-2017 period using the 2006 and 2012 NFI data.

A QC control check on the simulated level of harvest in CBM and the level of harvest as reported in the 2018 NIR for AR lands for the period 2007-2016 and the afforestation productive areas (excluding open area) for the period 1990-2016 confirmed that CBM was adequately set up for validation (Figure 12).

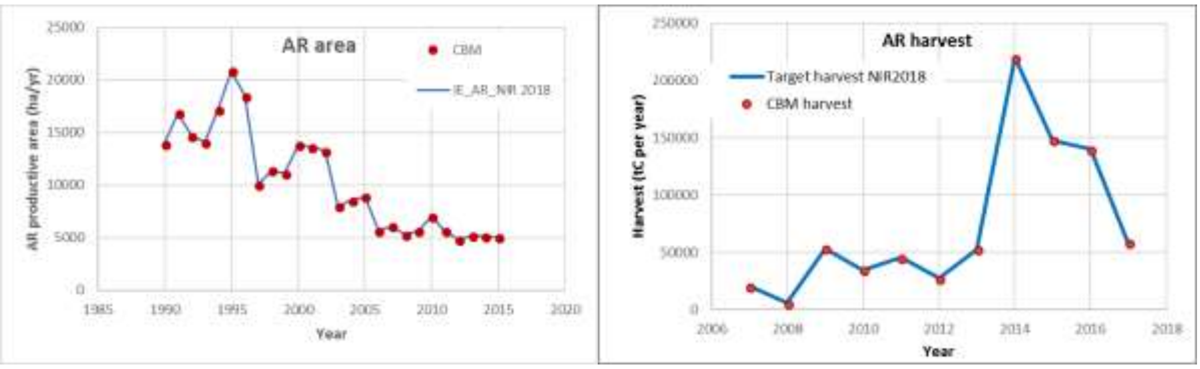


Figure 12 A comparison of the afforestation rate (left panel) or target harvest for AR lands (right panel) over the period 1990-2016, as reported in the NIR (2018), and the simulated harvest by CBM

4.1.1.2 FM validation

Set up of CBM

The 2006 NFI was used to define age class and species matrices for forest land in 2006. The actual level of harvest, derived from the 2006-2017 NFI data, was used to set the level of harvest in the disturbance matrix. Current annual increment and stand volume curves were recalibrated for the 2006-2017 period using the 2006 and 2012 NFI data.

A QC control check on the simulated level of harvest in CBM and the level of harvest as reported in the 2018 NIR for FM 2006-2016 confirmed that CBM was adequately set up for validation (Figure 13).

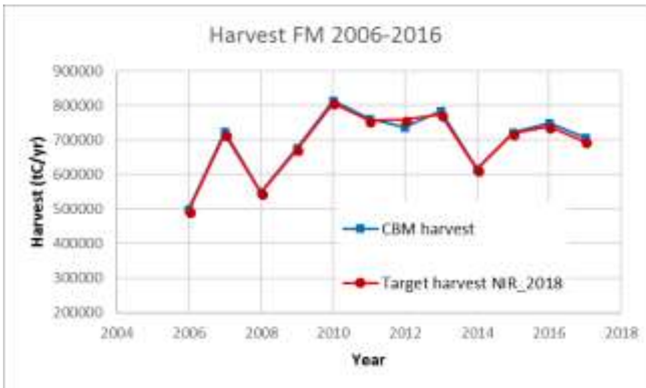


Figure 13 A comparison of the target harvest for FM lands over the period 2006-2016, as reported in the NIR (2018), and the simulated harvest by CBM.

4.1.2 Comparisons with UNFCCC submissions

For comparison with CARBWARE outputs of FM and AR data submitted to the UNFCCC (NIR, 2018), total GHG emissions for all pools (see section 2.1) and CSCs in the biomass (aboveground and belowground biomass), litter and deadwood pools were compared. CBM includes estimates of mineral soil CSCs, but this was not compared since CARBWARE does not estimate emissions/removals from this pool. Comparisons of level or trends for emissions from organic soils, fires, CH_4 or N_2O emissions due to drainage and HWP CSCs were not considered because the same methodology is applied to calculate these emissions/removals.

Comparison of CBM and CARBWARE outputs for AR land showed good agreement (Figures 14, 15 and table 16 below).

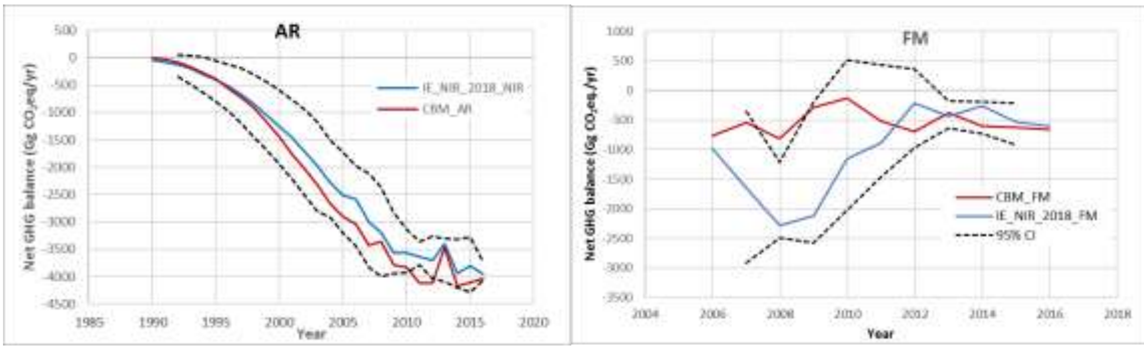


Figure 14 Net GHG removals for all pools and non-CO2 gases for CARBWARE (GHGI, blue symbols) and CBM (red symbols) in the afforestation (AR, left panel) and forest management categories (FM, right panel). The broken lines represent the upper and lower confidence interval of a 5-year (AR) or 3-year (FM) moving average of CARBWARE data over the time series. The CARBWARE outputs are the same as those reported to for the GHGI submission 2018 as reported to the UNFCCC (IE_NIR_2018).

Analysis of AR GHG trends, based on the 95% confidence interval of CARBWARE values, indicate that CBM estimates show consistent trend within the 95% confidence interval in all years, except 2011 and 2012 (Figure 14). Validation statistics (RMSE and t-test) of GHG levels for the entire time series confirm that there is no significant difference in the mean GHG levels for CBM and CARBWARE estimated for AR land for all GHG, biomass, litter and dead wood pools (Table 16).

Table 16: A level comparison of GHG emissions/removals and C pool CSC over the time series for AR and FM strata. The t-test was applied (assuming unequal variance of data) and mean value for CARBWARE and CBM was significantly different when P(T<=t) was >0.05 (see red text). The % RMSE is determined as the RMSE over the mean value for CARBWARE estimates.

	RMSE (Gg)	**P(T<=t) two-tail**
AR validation statistics		
Total GHG	17.2	0.58 n.s
Biomass	14	0.99 n.s
Litter and deadwood	3.2	0.84 n.s
HWP	0.01	0.99 ns
FM validation statistics		
Total GHG	-869.2	**0.06ns**
Biomass	221.3	0.38 n.s
Litter and deadwood	281.8	**4.4E-06**
HWP	0.03	0.98 ns

Although the mean value for CBM and CARBWARE are not significant, the RMSE for biomass over the AR time series was 14.0 Gg (Table 16), it is apparent that the biomass CSCs is slightly higher for CBM (Figure 14). This is possibly due to:

- Differences in the way biomass is estimated (i.e. CBM used biomass-volume functions, CARBWARE derived biomass directly from DBH or tree height)
- CARBWARE adjusts tree mortality in a dynamic way based on single tree functions (Black, 2016), CBM applies a uniform stand mortality rate over time. This may lead to great or lower CSC at different stand aged (see Figure 14).

- CARBWARE tends to under estimate biomass CSC due to the fact that the ingrowth of trees in the NFI plots are not accounted for. However, this factor is only influential when NFI data is used (i.e. from 2006 onwards)

The mean litter and deadwood CSCs for CBM and CARBWARE for AR land is not significant (RMSE = 3.2 Gg, Table 16). However, it appears that CBM litter and deadwood CSCs are more sensitive to harvest disturbances (see years 2007-2016 and CBM trend outlier in 2012, Figure 15). This is probably due to the more complete C flow model for DOM and the fact that CARBWARE does not include fragmentation losses from litter and dead wood. Thus, CBM is likely a more complete and accurate model of DOM.

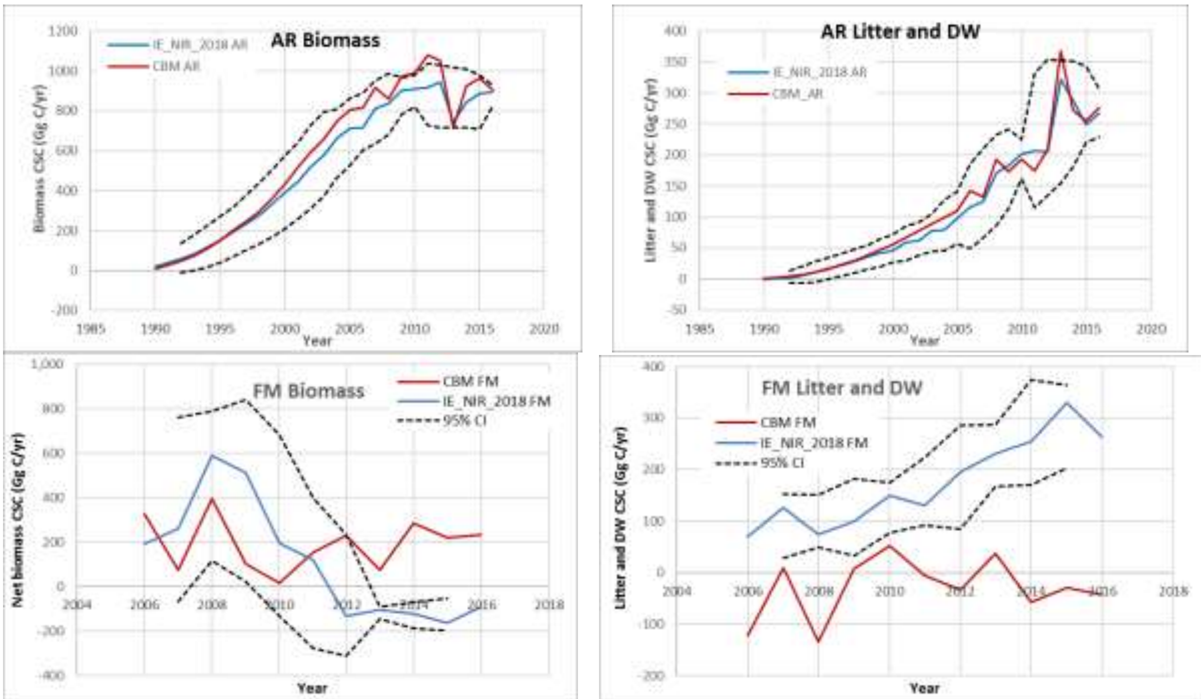


Figure 15 Outputs from CARBWARE (GHGI, blue symbols) and CBM (red symbols) showing historical CSCs in biomass (left panel), litter and deadwood (right panel) in the afforestation (AR, top panel) and forest management categories (FM, bottom panel). The broken lines represent the upper and lower confidence interval of a 5-year (AR) or 3-year (FM) moving average of CARBWARE data over the time series. The larger number of terms for the moving average for AR was used because of the larger dataset. The CARBWARE outputs are the same as those reported to for the GHGI submission 2018 as reported to the UNFCCC (IE_NIR_2018).

Comparison of CSCs for FM lands was only possible for the period 2006-2016 because no NFI were available before 2006. Historical emissions and removals for FM land before 2006 are based on a time series adjustment and extrapolation from 2006 (see Duffy et al., 2017).

Comparison of CARBWARE and CBM means are considered to be significantly different for the deadwood and litter pools (Table 16). However, it appears that the differences in DOM pools estimates are the main reason for the observed differences in the total GHG balance since biomass estimates are not significantly different when CBM and CARBWARE means are compared. The RMSE for biomass, litter and deadwood are quite large (RMSE = 114 and 174 Gg C for biomass and DOM, respectively).

The differences in biomass estimates between the two methods can be associated with numerous factors including:

- The inability of CARBWARE to account for tree ingrowth (see above). This may be manifested by a decline biomass CSC decline for FM areas over time (Figure 14). In contrast CBM does account for ingrowth.
- The different level aggregation (see stratification in model selection) and scale at which biomass CSC are estimated.
- Differences in the application of mortality assumptions for the two different model frameworks.

Analysis of trends for the inventory versus CBM (Figures 13 and 14) suggest that the total GHG balance and biomass trend for CBM are broadly within the 95% CI of the inventory trends. However, there are large discrepancies for litter and deadwood estimates in FM lands (Figure 15). But it is recognised that the CARBWARE model does not properly characterise the DOM CSCs in managed forests due to:

- Inadequate DOM pool equilibration which may lead to an unrealistic change in the DOM trend. This can be seen in the comparison for litter and deadwood for FM lands (Figure 14), where CARBWARE DOM estimates continually increase, regardless of level of harvest (Figure 12 and 13).
- It appears that CBM may better characterise biomass CSCs in response to management. For example, differences in the level of harvest (Figure 12) are better reflected in the biomass and DOM CSC outputs for the CBM model, when compared to those for the CARBWARE model (Figure 15).
- A recent research project (CFORREP) completed under the COFORD funding stream suggest that litter and deadwood emissions are currently underestimated in the CARBWARE model, particularly for land under FM, due to the exclusion of fragmentation losses form the C flow model. Fragmentation could account for over 30% of DOM (Bond-Lamberty and Gower, 2008) that is transferred from litter and deadwood to other C pools not included in the CARBWARE model.
- The CARBWARE model allocates dead roots from harvest or mortality to the deadwood pool, in contrast to CBM, where dead roots are allocated to the soil pools. This may also reflect observed differences when dead wood pools are compared.

4.1.3 Adjustments to the CARBWARE DOM model

The CARBWARE model was re-run to include fragmentation losses of 30% for both the litter and deadwood pools (Figure 15). The fragmentation losses from the deadwood pool were assumed to be transferred to the litter pool in the adjusted CARBWARE model. For the litter pool, fragmentation losses were assumed to be lost to the atmosphere as an emission. This assumption is not correct in theory because fragmentation of litter would be transferred to the soil pool. The CARBWARE DOM model is incomplete as highlighted in section 4.1.2.

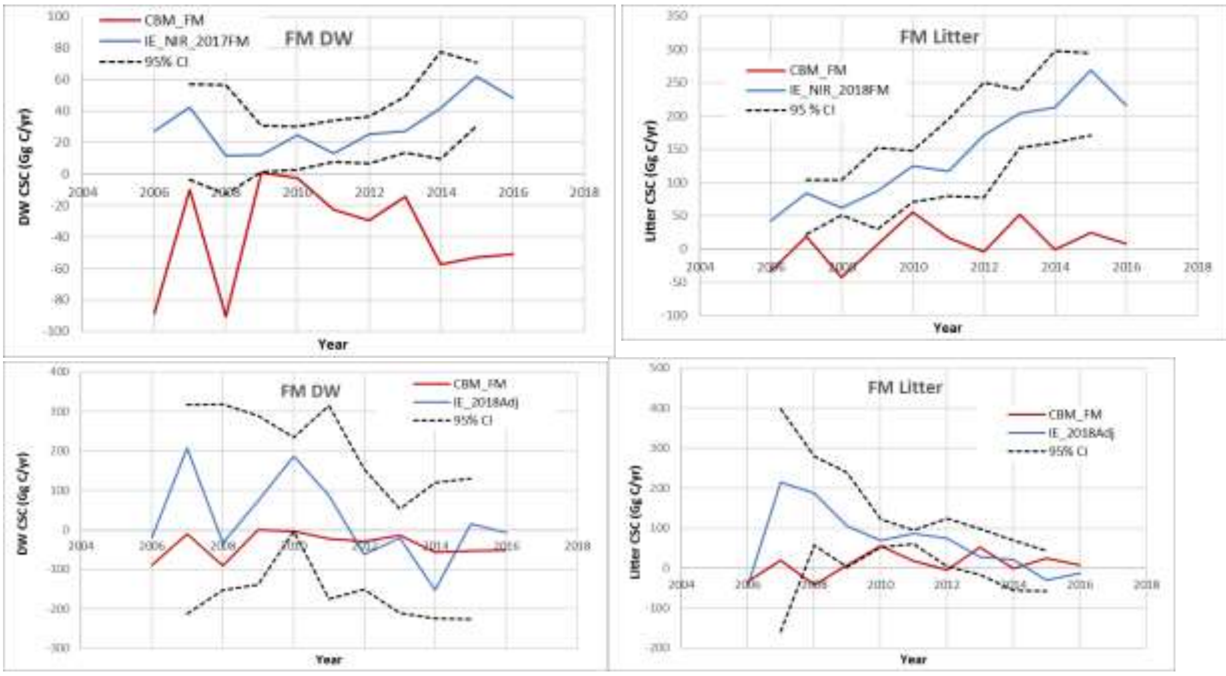


Figure 16 Comparisons of the litter and deadwood (DW) removals/emissions from the CARBWARE (GHGI data) and CBM outputs (top panel) and the adjusted CARBWARE (IE_2018Adj) to include fragmentation losses.

There is better agreement between the mean and level trends for deadwood, when the adjusted CARBWARE was compared with the CBM outputs (Figure 16 bottom panel and Table 17). The results suggest that the CARBWARE model is improved by including fragmentation losses, but the CBM model accounts for other processes which are not included in the CARBWARE model. In addition, the inputs into the litter and deadwood pool from biomass is slightly different due to smaller difference in biomass stock changes. Inputs from harvest were very similar (data not shown).

Table 17: A level comparison of litter and deadwood emissions/removals and C pool CSC over the time series the FM stratum. The t-test was applied (assuming unequal variance of data) and mean value for CARBWARE and CBM was significantly different when P(T<=t) was >0.05 (see red text). The % RMSE is determined as the RMSE over the mean value for CARBWARE estimates.

	RMSE (Gg)	P(T<=t) two-tail
Validation without CARBWARE adjustment		
Litter	154.1	**8.37E-05**
Deadwood	77.1	**1.54E-06**
Validation with CARBWARE adjustment		
Litter	102.4	**0.07n.s**
Deadwood	106.6	**0.08n.s**

4.1.4 Comparisons with NFI data

Comparison of biomass stock change estimates from CARBWARE and CBM versus the stock changes derived from the 2006, 2012 and 2017 NFIs show that the CBM model provides a more accurate assessment of biomass stock changes over time, particularly for the 2012 to 2017 period (Table 18). The lower calculated biomass stock change estimated using CARBWARE is possibly associated with the ingrowth of trees that are not included in the CARBWARE model. In contrast, the CBM model is a stand level model so it does account for ingrowth since these are included in the growth curves for each species cohort.

Table 18: A comparison of mean biomass CSC (Gg C yr^{-1}) obtained from the NFI, CARBWARE and CBM. * Note the NFI values are the total AR and FM areas and these values are adjusted for in growth tree diameters and heights. NFI, CBM and CARBWARE estimates are derived as the average annual biomass CSC for the periods 2006-2011 and 2012-2016.

Source		**2006-2011**		**2012-2017**	
NFI	Total*		1234.8		968.5
CARBWARE	FM	311.2		-121.9	
	AR	848.3		867.4	
	Total		1159.5		745.6
CBM	FM	178.3		209.1	
	AR	939.5		940.7	
	Total		1117.8		1149.8

4.1.5 Conclusion

The criteria and guidance for determining forest reference level outlined in Annex IV A (h) of the Regulation require that

"the reference level shall be consistent with greenhouse gas inventories and relevant historical data and shall be based on transparent, complete, consistent, comparable and accurate information. In particular, the model used to construct the reference level shall be able to reproduce historical data from the National Greenhouse Gas Inventory."

As outlined in this section the modelling approach which Ireland has now adopted for inventory reporting and employed in the generation of the FRL is consistent with the results of past inventories but differs in relation to the specific treatment of some pools. Past treatment of litter and deadwood in particular is less accurate and complete than the current CBM approach as described. Comparisons with historic harvests show high levels of correlation demonstrating that the silvicultural assumptions are accurate.

The aforementioned problems associated with DOM pool estimates using CARBWARE and the better agreement between NFI results and CBM estimations (sections 3.3.1., 4.1.2 and 4.1.3) suggest that CBM would be the best available method to use for development of a FRL and represents an approach that will be "transparent, complete, consistent, comparable and accurate". We consider that CBM estimates should **not be adjusted** (using the overlap method, see section 2.2.4, FRL Technical Guidelines) because these estimates are more robust than those currently used in the GHG inventory. CBM will replace CARBWARE for all GHG reporting and accounting under the Convention and Kyoto protocol in Irelands most recent inventory submission due in April 2019 (NIR, 2019). In addition, a 30-year transition period will be applied in the future to ensure consistency between Convention reporting and reporting obligations under the EU LULUCF Regulation.

It should be noted that, regardless of any differences in methods used to construct the FRL and historic inventories, the use of technical corrections to ensure methodological consistency between accounting and reporting approaches would result in the same outcome and avoid any undue accountable emissions or removals.

4.2. FRL projection 2021-2025

The FRL projection for the period 2017-2025 was initiated using the 2017 NFI inventory data to define the state of the forest. This is consistent with the Guidelines for the FRL (see section 2.5.4.2). However, in order to report a time series from 2010 onwards (see Guideline requirements in section 2.5.4.1), the NFI 2006 was used to define the state of the forest for the projected time series 2010 to 2016 (see Table 19 below).

The final CSC for the MFL area over the time series (Table 19) was derived for the amalgamation of information for forest land planted before 1990 (i.e. FM area Table C1, appendix C) and afforested land transitioning to MFL areas after 30 years (Table C2, appendix C). Comparison of the 3 tables clearly shows how CSC and areas are allocated from the different model simulations and GHG category estimations (also see Figure 5).

The emission/removal trends (excl. HWP) for MFL areas shows a transition from a sink to a source by 2012 -2017 and consistent increases in GHG emissions from 420 Gg in 2018 to 2,161 Gg CO_2 eq. by 2025 (Table 19). These trends are driven by numerous factors:

- A deforestation rate of 933 ha per year, based on the mean rate for 2000-2016, which affects current annual increment.
- An increase in the level of harvest from ca. 3Mm^3 in 2010 to 4.8Mm^3 by 2025 (Table 20). Most of this increase (0.04 to 1.7Mm^3) is due to harvest from afforested land transitioning into MFL over the period (Table 20). The increased harvest rate is consistent with the afforestation legacy going back to the 1950s (see Black et al., 2012) and silvicultural prescriptions applied to the forecast.
- The age class distribution for MFL shows a clear shift towards younger stands for the period, which would also decrease the growth increment (see Black et al., 2012 and Figure 17).
- The increase in fire emissions (the background level, Table 19) from 87 to 97 Gg CO_2 is due the increase share of fire emission from afforested land transitions (see Eq16 and Table C2 appendix C).
- The increase in emissions from organic soils and non-CO_2 emissions due to drainage, associated with an increase in associated afforested land transition area (Table 19 and Table C2, appendix C).

Table 19: The MFL areas and carbon stock changes (excl. HWP) including fires as natural disturbances and other non-CO_2 emissions from drainage of soils

Year	Area	Org. soil Area	Biomass	Litter	Deadwood	Min SOC	Org Soils	Total Forest		Fire	Non-CO2-Drainage	Total
	kha		Stock change tC					Gg C	Gg CO2	Gg CO2 eq	Gg CO2 eq	Gg CO2 eq
2010	374	234	-1991	-35986	-91130	-63050	-98979	-291	1067.499	69.653	111.173	**1248.325**
2011	381	238	137810	17518	-12369	-125358	-100880	-83	305.357	70.795	113.309	**489.461**
2012	388	243	211560	-44827	-93112	-65939	-102758	-95	348.612	71.936	115.418	**535.966**
2013	395	247	57695	5368	-1448	-15369	-104613	-58	214.012	73.061	117.502	**404.575**
2014	402	251	269183	53001	-4957	-22513	-106471	188	-690.222	74.171	119.588	**-496.463**
2015	409	256	205110	15188	-24573	-49483	-108233	38	-139.362	75.282	121.568	**57.488**
2016	415	259	218441	-5752	-31524	-83144	-109884	-12	43.502	76.327	123.422	**243.250**
2017	423	264	133669	66470	-3830	-8782	-111991	76	-276.965	77.294	125.789	**-73.883**
2018	432	270	22475	83283	-39215	-10257	-114464	-58	213.326	78.579	128.566	**420.471**
2019	445	278	-126473	90633	-30128	-10516	-117826	-194	712.476	80.119	132.343	**924.937**
2020	461	288	-193480	78507	-12482	-10645	-122093	-260	954.044	82.278	137.135	**1173.457**
2021	479	300	-156525	94823	1092	-7115	-126915	-195	713.677	87.932	144.024	**945.633**
2022	495	309	-290103	115624	22387	-5681	-132468	-290	1064.217	89.207	149.378	**1302.801**
2023	510	317	-538286	143791	34153	-4805	-136091	-501	1837.874	90.372	154.284	**2082.530**
2024	529	328	-429345	89026	78342	-2594	-141961	-407	1490.617	91.753	159.459	**1741.829**
2025	552	341	-532246	99994	68060	-2027	-151506	-518	1898.322	93.397	169.893	**2161.612**

Table 20: Harvest for MFL for the period 2010-2025, showing the breakdown of harvest from different forest land categories.

Year	Harvest FM (Incl Defor)	Harvest FM (excl. defor)	Harvest (L-FL) transitions	MFL Harvest	Vol. FM (Excl. defor)	Vol. (L-FL) transitions	Total MFL Vol.	Inflow to HWP sawlog	Inflow to HWP WBP
	tC				m3			m3	
2010	732205	704979	34846	739825	2613704	154871	2768575	731414	717766
2011	688871	662596	45506	708102	2581792	202249	2784041	726243	701943
2012	764351	738026	27460	765486	2615168	122044	2737212	715888	644570
2013	787809	784204	17597	801801	2936579	78209	3014788	741236	664612
2014	623644	617279	73368	690647	2755897	326079	3081975	817857	697548
2015	658696	652481	49374	701855	2948883	219439	3168321	809425	687536
2016	753955	749529	46714	796243	2922190	207619	3129809	895309	701515
2017	856337	736093	58228	794321	3014826	258790	3273616	982085	864235
2018	889105	772638	87753	860391	3107516	390012	3497528	1049258	923347
2019	944375	830697	71475	902172	3309042	317665	3626707	1088012	957451
2020	966442	853313	10035	863348	3410401	40125	3450526	1035158	910939
2021	1033740	913929	8934	922863	3671466	35523	3706990	1112097	978645
2022	1085855	958644	53169	1011813	3827772	212563	4040335	1212100	1066648
2023	1196118	1069270	93475	1162745	4256205	370618	4626823	1388047	1221481
2024	1103850	971249	153002	1124251	3868662	605210	4473871	1342161	1181102
2025	1057337	951317	266461	1217778	3790900	1059195	4850095	1455029	1280425

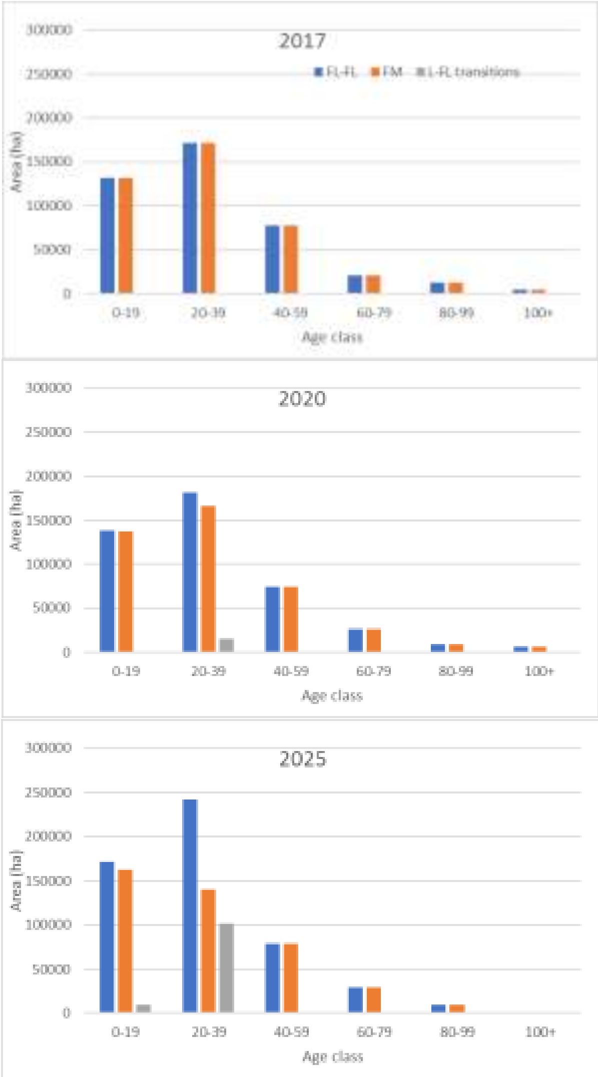


Figure 17 Changes in age class distribution in the different forest categories

Tables 20 and 21 show allocation of harvest from FL_FL areas to the HWP pool. The following information is provided to show that the treatment of HWP allocations is consistent with requirements set out in the LULUCF Regulation.

- Harvest from deforestation is assumed to be immediately oxidized and not included in HWP inflows (see Table 20). In addition, all removals or emissions from deforestation are not included under the MFL category (Table 19) as they will be accounted separately.
- As set out in criterion e) of Annex IV.A of the LULUCF Regulation, for calculating the HWP contribution to the FRL, “a constant ratio between solid and energy use of forest biomass as documented in the period from 2000 to 2009 shall be assumed”. Table 20 shows a constant ratio for sawnwood and WBP, based on the 2000-2009 mean (see Table 6 and 20), is used to estimate HWP inflows (Table 21).
- HWP CSCs are based on a 1st order decay model (see methods). Table 21 shows how inflows and decay fluxes are estimated.

- As set out in Annex IV of the Regulation, the reference level includes C pools of harvested wood products. A comparison between assuming instantaneous oxidation and applying the first-order decay function and half-life values is provided in Table 22.
- To ensure consistent reporting of C pools and within the HWP, decay of HWP C from historical input from transitioning L-FL areas is included in CSC for HWP. This is not specifically outlined in the Regulation or in the Technical guidance, but would be a requirement to ensure that double accounting does not occur between HWP from L-FL and FL-FL.

It should be noted that a lower inflow into HWP for the periods prior to the CP (2010-2016, Table 21) are primarily due to lower historical sawnwood and WBP ratios (Table 6), when compared to the mean value for 2000-2009 (see Table 6 and 21). The HWP stock also increases due to steady increase in harvest (Table 20).

Annual estimated emissions and removals from managed forest land and the average for the period 2021-2025 (FRL) are laid out in Table 22.

Table 21: HWP inflow and stock changes for different HWP categories over the CP 2010-2025. The inclusion of emissions from historical harvest of L-FL lands prior to the transition period (L-FL_{pre30}). The L-FL pre 30 stock change values for the period 2010-2016 are already included (IE) in the HWP estimate for MFL (IE)

Year	Sawnwood inflow tC	WBP inflow tC	Paper inflow tC	Sawnwood stock tC (MFL)	WBP stock tC (MFL)	Paper stock tC (MFL)	Sawnwood Δstock tC	WBP Δstock tC	Paper Δstock tC	L-FLpre30t Δstock tC	Total GgC	Total Δstock M tCO2
2010	161025	185622	NO	3250024	2705669	9.35E-01	97624	112153	-4.E-01	**IE**	209.78	**-769.18**
2011	159715	181335	NO	3344437	2810526	6.61E-01	94413	104858	-3.E-01	**IE**	199.27	**-730.66**
2012	158090	167204	NO	3435390	2898580	4.67E-01	90953	88054	-2.E-01	**IE**	179.01	**-656.36**
2013	168963	177959	NO	3535324	2994832	3.30E-01	99935	96252	-1.E-01	**IE**	196.19	**-719.35**
2014	185358	185706	NO	3649533	3096093	2.34E-01	114209	101261	-1.E-01	**IE**	215.47	**-790.06**
2015	183593	183186	NO	3759755	3192100	1.65E-01	110222	96007	-7.E-02	**IE**	206.23	**-756.17**
2016	203815	187593	NO	3887839	3289828	1.17E-01	128084	97728	-5.E-02	**IE**	225.81	**-827.98**
2017	224897	232479	NO	4034286	3429154	8.26E-02	146447	139325	-3.E-02	1.76	287.54	**-1054.30**
2018	240280	248380	NO	4193092	3580352	5.84E-02	158807	151198	-2.E-02	5.19	315.19	**-1155.70**
2019	249155	257554	NO	4357572	3736464	4.13E-02	164480	156112	-2.E-02	-1.53	317.53	**-1164.29**
2020	237051	245043	NO	4506842	3875966	2.92E-02	149270	139503	-1.E-02	-3.06	282.65	**-1036.38**
2021	254670	263256	NO	4670631	4029617	2.07E-02	163789	153651	-9.E-03	-4.30	308.85	**-1132.45**
2022	277571	286928	NO	4853883	4202415	1.46E-02	183252	172797	-6.E-03	-6.04	343.97	**-1261.22**
2023	317863	328578	NO	5073437	4411565	1.03E-02	219554	209150	-4.E-03	-8.23	412.24	**-1511.54**
2024	307355	317716	NO	5278282	4604283	7.30E-03	204844	192718	-3.E-03	-9.99	377.59	**-1384.49**
2025	333202	344434	NO	5504702	4818082	5.16E-03	226420	213799	-2.E-03	-11.30	417.62	**-1531.29**

Table 22: The FRL and a comparison of total emission/removals assuming instantaneous oxidation and using the 1st order decay model with default decay constants.

Year	MFL incl. HWP 1st order decay	MFL excl. HWP (inst. oxid.)
	kt CO2 eq.	
2021	-186.81	945.63
2022	41.59	1302.80
2023	570.99	2082.53
2024	357.34	1741.83
2025	630.33	2161.61
	Sum	
2021-2025	1413.433	8234.406
	FRL incl. HWP 1st order decay	**FRL excl. HWP (inst. oxid.)**
	Mean	
2021-2025	282.687	1646.881

Appendix A - *Definition of management practices*

THINNING AND ROTATION CLASSIFICATION

OBJECTIVES: To achieve compatibility between HPF's and forecasts of production.

To take on board local management decisions into the forecasting process.

STANDARD TREATMENTS

CLEARFELL: Fell at age of Maximum Mean Annual Increment except for
Sitka spruce - fell at MMAI less 20%
Norway spruce - fell at MMAI less 30%
Lodgepole pine - fell at MMAI less 30%

THINNING: Thin to marginal thinning intensity. First thin at recommended age in management tables +/- 3 years.

DEVIATIONS FROM STANDARD TREATMENTS

CLEARFELL: ***Instability*** - felling in advance of windblow or where crop partially blown and to hold to normal rotation not a viable proposition.

Market Considerations - felling to avail of market opportunity for low Yield Class or poor form crops. Retention of pruned crops to achieve diameter needed.

Other Reasons - disease, seed stand, game development and environmentally sensitive areas.

THINNING: ***Instability*** - where thinning will lead to onset of windblow and a reduced rotation length.

Thin Stage - where crops have gone beyond the age of first thinning and to thin would lead to onset of windblow and reduced rotation.

Access - landlocked crops due to weight restrictions on county roads or long ROW's.

Other Reasons - low yield class and poor form crops where thinning will not enhance the overall profitability of the crop.

Figure 18 Page from Forest Operations Manual (Coillte Teoranta, 1990) – an example of the documentation of management practices from before the reference period.

Management Decisions from Roundwood Forecast

The approach to defining management decisions in the roundwood forecast that was employed as an initial target harvest are presented below.

1. Area

If species = spruce, pine or other conifer and area >=4.0 ha then thin

If species = broadleaves and area >=2.5 ha then thin

2. Yield Class

If species = spruce and YC >=16 then thin

If species = pine and YC >=10 then thin

If species = other conifer and YC >= 12 then thin

If species = broadleaves and YC >= 8 then thin

3. Thin Status

If thin status = thinned and age >= first thin, then continue to thin crop

If thin status = unthinned and age >= thin age + 2 then no thin

If thin status = unthinned and age < thin age +2 then follow rules 2-4

4. Number of Thinnings

If conifer species = spruce, or lodgepole coastal and thin then 3 thinnings on 4 year cycle

If conifer species ≠ spruce, or lodgepole coastal and thin then thin on 4 year cycle[6]

if species = broadleaves and thin then regular thinnings on 4 year cycle

5. Wind Risk, Soil type and Elevation

If Wind Risk =A and soil type = wet mineral / peat and elevation >=100 then no thin

If Wind Risk = B or C. and soil type = wet mineral / peat & elevation >=200 then no thin

[6] As species classed as other conifers use the NS yield model to estimate volume yields, a number of minor species will receive only three thinnings at a reduced thinning intensity rate.

If Wind Risk = D or E and soil = wet mineral / peat and elevation >=300 then no thin

6. Access

If soil = peat and area >= 2.5 and < 11.0 and distance to road >= 50m then no thin

If soil = peat and area >= 11.0 and < 14.0 and distance to road >= 75m then no thin

If soil = peat and area >= 14.0 and < 16.0 and distance to road >= 100m then no thin

If soil = peat and area >= 16.0 and < 19.0 and distance to road >= 125m then no thin

If soil = peat and area >= 19.0 and < 23.0 and distance to road >= 150m then no thin

If soil = peat and area >= 23.0 and < 25.0 and distance to road >= 175m then no thin

If soil = peat and area >= 25.0 and < 28.0 and distance to road >= 200m then no thin

If soil = peat and area >= 28.0 and distance to road >= 225m then no thin

If soil = mineral and area >= 2.5 and < 6.0 and distance to road >= 50m then no thin

If soil = mineral and area >= 6.0 and < 12.0 and distance to road >= 75m then no thin

If soil = mineral and area >= 12.0 and < 14.0 and distance to road >= 100m then no thin

If soil = mineral and area >= 14.0 and < 16.0 and distance to road >= 125m then no thin

If soil = mineral and area >= 16.0 and < 20.0 and distance to road >= 150m then no thin

If soil = mineral and area >= 20.0 and < 22.0 and distance to road >= 175m then no thin

If soil = mineral and area >= 22.0 and < 24.0 and distance to road >= 200m then no thin

If soil = mineral and area >= 24.0 and < 26.0 and distance to road >= 225m then no thin

If soil = mineral and area >= 26.0 and distance to road >= 250m then no thin

Appendix B Turnover rates and CBM disturbance matrices

Table I Biomass turnover and litterfall transfer rates. AG=aboveground, BG=belowground, SW=softwood, HW=hardwood.

CBM pool	**Turnover rates (%C yr^{-1})**	**DOM pool receiving turnover**	**Litterfall transfers (% transferred to DOM pool)**
Merchantable stem (SW,HW)[a]	1	Snag stems	100
Other wood (HW, SW)[b]	4	Snag branches	25
		AG fast	75
Foliage (SW)[c]	15	AG very fast	100
Foliage (HW)[b]	95	AG very fast	100
Fine roots (HW,SW)[d]	64.1	AG very fast	50
		BG very fast	50
Coarse roots (HW,SW)[d]	2	AG fast	50
		BG fast	50

[a] Derived form NFI 2012-2017; [b]Kurz et al. (1992) [c]Tobin et al., 2007; [d] Li et al. (2003)

Table II: The Disturbance matrix for fires showing C transfers and emissions

From \ to	Softwood merch.	Softwood foliage	Softwood others	Softwood sub-merch	Softwood coarse roots	Softwood fine roots	Hardwood merch.	Hardwood foliage	Hardwood others	Hardwood sub-merch	Hardwood coarse roots	Hardwood fine roots	Above Ground Very Fast soil C	Below Ground Very Fast soil C	Above Ground Fast soil C	Below Ground Fast soil C	Medium soil C	Above Ground Slow soil C	Below Ground Slow soil C	Softwood Stem Snag	Softwood Branch Snag	Hardwood Stem Snag	Hardwood Branch Snag	Black C	Peat	Em. CO2	Em. CH4	Em.CO	Em. N2O	Products
Softwood merchantable																				1										
Softwood foliage																										0.90	1.00E-02	0.09		
Softwood others																					0.75					0.23	2.50E-03	0.02		
Softwood sub-merch																					0.75					0.23	2.50E-03	0.02		
Softwood coarse roots															0.5	0.5														
Softwood fine roots													0.309	0.5												0.17	1.91E-03	0.02		
Hardwood merchantable																					1.00									
Hardwood foliage													0.003													0.90	1.0E-02	0.09		
Hardwood others																						0.99				1.0E-06	5.0E-06			
Hardwood sub-merch																										1.4E-05	1.5E-07	1.4E-06		
Hardwood coarse roots															0.5	0.5														
Hardwood fine roots													0.312	0.5												0.17	1.9E-03	0.02		
Above Ground Very Fast soil C													7E-04													0.90	0.01	0.09		
Below Ground Very Fast soil C														1																
Above Ground Fast soil C															0.15											0.76	0.01	0.08		
Below Ground Fast soil C																1														
Medium soil C																	0.323									0.6092	0.00677	0.0609		
Above Ground Slow soil C																		0.617								0.3445	0.00383	0.0344		
Below Ground Slow soil C																			1											
Softwood Stem Snag																	1													
Softwood Branch Snag															1															
Hardwood Stem Snag																	1													
Hardwood Branch Snag															1															
Black C																								1						
Peat																									1					

Table III: The Disturbance matrix for deforestation showing C transfers and emissions

From \ to	Softwood merch.	Softwood foliage	Softwood others	Softwood sub-merch	Softwood coarse roots	Softwood fine roots	Hardwood merch.	Hardwood foliage	Hardwood others	Hardwood sub-merch	Hardwood coarse roots	Hardwood fine roots	Above Ground Very Fast soil C	Below Ground Very Fast soil C	Above Ground Fast soil C	Below Ground Fast soil C	Medium soil C	Above Ground Slow soil C	Below Ground Slow soil C	Softwood Stem Snag	Softwood Branch Snag	Hardwood Stem Snag	Hardwood Branch Snag	Black C	Peat	Em. CO2	Em. CH4	Em.CO	Em. N2O	Products
Softwood merchantable																										0.03				0.97
Softwood foliage																										1.00				
Softwood others																										1.00				
Softwood sub-merch																										1.00				
Softwood coarse roots																										1.00				
Softwood fine roots													0.348	0.348												0.30				
Hardwood merchantable																										0.03				0.97
Hardwood foliage																										1.00				
Hardwood others																										1.00				
Hardwood sub-merch																										1.00				
Hardwood coarse roots																										1.00				
Hardwood fine roots													0.348	0.348												0.30				
Above Ground Very Fast soil C													7E-04													0.99				
Below Ground Very Fast soil C														1																
Above Ground Fast soil C															1															
Below Ground Fast soil C																0.1										0.90				
Medium soil C																	0.87									0.13				
Above Ground Slow soil C																		0.923								0.077				
Below Ground Slow soil C																			1											
Softwood Stem Snag																										1				
Softwood Branch Snag																										1				
Hardwood Stem Snag																										1				
Hardwood Branch Snag																										1				
Black C																								1						
Peat																									1					

Table IV: The Disturbance matrix for thinning (25%) showing C transfers and emissions

From \ to	Softwood merch.	Softwood foliage	Softwood others	Softwood sub-merch	Softwood coarse roots	Softwood fine roots	Hardwood merch.	Hardwood foliage	Hardwood others	Hardwood sub-merch	Hardwood coarse roots	Hardwood fine roots	Above Ground Very Fast soil C	Below Ground Very Fast soil C	Above Ground Fast soil C	Below Ground Fast soil C	Medium soil C	Above Ground Slow soil C	Below Ground Slow soil C	Softwood Stem Snag	Softwood Branch Snag	Hardwood Stem Snag	Hardwood Branch Snag	Black C	Peat	Em. CO2	Em. CH4	Em.CO	Em. N2O	Products
Softwood merchantable	0.75																			0.025										0.23
Softwood foliage		0.75											0.225													0.03				
Softwood others			0.75																	0.25										
Softwood sub-merch				0.75																	0.25									
Softwood coarse roots					0.75										0.125	0.125														
Softwood fine roots						0.75								0.125	0.125															
Hardwood merchantable							0.75													0.025										0.23
Hardwood foliage								0.75					0.25																	
Hardwood others									0.75														0.25							
Hardwood sub-merch										0.75												0.25								
Hardwood coarse roots											0.75				0.125	0.125														
Hardwood fine roots												0.75	0.125	0.125																
Above Ground Very Fast soil C													1																	
Below Ground Very Fast soil C														1																
Above Ground Fast soil C															1															
Below Ground Fast soil C																1														
Medium soil C																	1													
Above Ground Slow soil C																		1												
Below Ground Slow soil C																			1											
Softwood Stem Snag																				1										
Softwood Branch Snag																					1									
Hardwood Stem Snag																						1								
Hardwood Branch Snag																							1							
Black C																								1						
Peat																									1					

Table V: The Disturbance matrix for clearfells showing C transfers and emissions

From \ to	Softwood merch.	Softwood foliage	Softwood others	Softwood sub-merch	Softwood coarse roots	Softwood fine roots	Hardwood merch.	Hardwood foliage	Hardwood others	Hardwood sub-merch	Hardwood coarse roots	Hardwood fine roots	Above Ground Very Fast soil C	Below Ground Very Fast soil C	Above Ground Fast soil C	Below Ground Fast soil C	Medium soil C	Above Ground Slow soil C	Below Ground Slow soil C	Softwood Stem Snag	Softwood Branch Snag	Hardwood Stem Snag	Hardwood Branch Snag	Black C	Peat	Em. CO2	Em. CH4	Em.CO	Em. N2O	Products
Softwood merchantable																				0.03										0.97
Softwood foliage													0.9													0.10				
Softwood others															0.7								0.3							
Softwood sub-merch															0.7								0.3							
Softwood coarse roots															0.5	0.5														
Softwood fine roots													0.5	0.5																
Hardwood merchantable																						0.10								0.90
Hardwood foliage													0.9													0.10				
Hardwood others															0.7								0.3							
Hardwood sub-merch															0.7								0.3							
Hardwood coarse roots															0.5	0.5														
Hardwood fine roots													0.5	0.5																
Above Ground Very Fast soil C													1																	
Below Ground Very Fast soil C														1																
Above Ground Fast soil C															1															
Below Ground Fast soil C																1														
Medium soil C																	1													
Above Ground Slow soil C																		1												
Below Ground Slow soil C																			1											
Softwood Stem Snag																				1										
Softwood Branch Snag																					1									
Hardwood Stem Snag																						1								
Hardwood Branch Snag																							1							
Black C																								1						
Peat																									1					

Table VI: The Disturbance matrix for afforestation showing C transfers and emissions

From \ to	Softwood merch.	Softwood foliage	Softwood others	Softwood sub-merch	Softwood coarse roots	Softwood fine roots	Hardwood merch.	Hardwood foliage	Hardwood others	Hardwood sub-merch	Hardwood coarse roots	Hardwood fine roots	Above Ground Very Fast soil C	Below Ground Very Fast soil C	Above Ground Fast soil C	Below Ground Fast soil C	Medium soil C	Above Ground Slow soil C	Below Ground Slow soil C	Softwood Stem Snag	Softwood Branch Snag	Hardwood Stem Snag	Hardwood Branch Snag	Black C	Peat	Em. CO_2	Em. CH_4	Em.CO	Em. N_2O	Products
Softwood merchantable	1																													
Softwood foliage		1																												
Softwood others			1																											
Softwood sub-merch				1																										
Softwood coarse roots					1																									
Softwood fine roots						1																								
Hardwood merchantable							1																							
Hardwood foliage								1																						
Hardwood others									1																					
Hardwood sub-merch										1																				
Hardwood coarse roots											1																			
Hardwood fine roots												1																		
Above Ground Very Fast soil C													1																	
Below Ground Very Fast soil C														1																
Above Ground Fast soil C															1															
Below Ground Fast soil C																1														
Medium soil C																	1													
Above Ground Slow soil C																		1												
Below Ground Slow soil C																			1											
Softwood Stem Snag																				1										
Softwood Branch Snag																					1									
Hardwood Stem Snag																						1								
Hardwood Branch Snag																							1							
Black C																								1						
Peat																									1					

Appendix C The background data for the FRL timeseries shown in section 4.2

Table C1: Areas and carbon stock changes in forest land planted before 1990 (FM) including fires ad natural disturbances.

Year	Area	Org. soil Area	Biomass	Litter	Deadwood	Min SOC	Org Soils	Total Forest		Fire	Non-CO2-Drainage	Total
	kha		Stock change tC					Gg C	Gg CO2	Gg CO2 eq	Gg CO2 eq	Gg CO2 eq
2020	445	278	-151468	83451	-6652	-9354	-113374	-197.398	723.791	85.068	131.544	940.403
2021	444	279	-277477	86984	-12875	-9617	-112085	-325.070	1191.923	85.068	131.278	1408.269
2022	444	278	-390822	89592	-7028	-9560	-110189	-428.006	1569.354	85.068	131.012	1785.434
2023	443	278	-616694	103699	-8508	-9742	-107773	-639.018	2343.067	85.068	130.746	2558.880
2024	442	277	-458149	35055	15350	-9502	-105796	-523.041	1917.818	85.068	130.480	2133.365
2025	441	276	-430373	13649	-21717	-11015	-103129	-552.586	2026.147	85.068	130.213	2241.428

Table C2: Areas and carbon stock changes in afforested land transitioning to MFL after 30 years.

Year	Area	Org. soil Area	Biomass	Litter	Deadwood	Min SOC	Org Soils	Total Forest		Fire	Non-CO2-Drainage	Total
	kHa		Stock change tC						Gg CO2	Gg CO2 eq.	Gg CO2 eq.	Gg CO2 eq.
2020	15.8	9.9	43931	5170	6097	1350	-7188	49.359	-180.984	1.326	5.591	-174.068
2021	35.0	20.9	120952	7839	13968	2502	-14830	130.431	-478.246	2.864	12.746	-462.635
2022	51.7	30.5	100719	26032	29414	3879	-22279	137.765	-505.137	4.139	18.366	-482.632
2023	67.7	39.7	78409	40091	42661	4937	-28317	137.780	-505.193	5.304	23.538	-476.351
2024	87.1	50.9	28804	53971	62991	6908	-36165	116.509	-427.201	6.686	28.979	-391.536
2025	110.8	64.5	-101873	86346	89777	8988	-48377	34.861	-127.825	8.329	39.680	-79.816

References

Bacon and Associates. 2004. A Review and Appraisal of Ireland's Forestry Development Strategy. Published by the Department of Agriculture and Food.

Black, K., Hendrick, E., Gallagher., G., Farrington, P. 2012. Establishment of Irelands projected reference level for Forest Management for the period 2013-2020 under Article 3.4 of the Kyoto Protocol. *Irish Forestry* 69: 7-32

Black, K, Creamer, R.E., Xenakis G., and Cook, S. 2014. Improving the YASSO forest soil carbon model using spatial data and geostatisitical approaches**.** *Geoderma* 232-234:487-499

Black K. 2016. Description, calibration and validation of the CARBWARE single tree-based stand simulator. Forestry 86(1):55-68 doi: 10.1093/forestry/cpv033

Bond-Lamberty et al., 2008. Decomposition and Fragmentation of Coarse Woody Debris: Re-visiting a Boreal Black Spruce Chronosequence Ecosystems (2008) 11: 831–840

Boudewyn, P. Song, X. Magnussen, S. and Gillis, M.D. 2007.Model-based, volume-to-biomass conversion for forested and vegetated land in Canada.Natural Resources Canada • Canadian Forest Service Pacific Forestry Centre • Victoria, British Columbia Information Report • BC-X-411

Broad, L., Lynch, T. 2006 Growth models for Sitka spruce in Ireland. *Irish For.* **63**, 53-79.

Clinch, J. P. 1999. Economics of Irish Forestry. COFORD, Dublin.

Coillte Teoranta. 1990. Forest Operations Manual…Getting it right first time. Wicklow Press Ltd.

Duffy, B. Hyde, E. Hanley, P. O'Brien and K. Black 2017. National inventory report Greenhouse gas emissions 1990 – 2015 Reported to the united nations Framework convention On climate change, EPA, Dublin

Edwards, P.N., Christie, J.M. 1981 Yield models for forest management. *Forestry Commission Booklet no. 48.* HMSO, London.

FDA (Forest Development association). 2007. Irish Thinning Protocol. - A complete step by step guide to the requirements and implementation of thinning systems in Ireland. Funded by the Forest Service of the Department of Agriculture and Food.

Forest and Wildlife Service (1976) Rotation lengths and thinning regimes for conifers. Operational Directive (1/77) rotation lengths and thinning regimes for conifers. Department of Fisheries, Dublin

Forest Service (2000) Code of Best Forest Practice-Ireland. Department of Marine and Natural Rsources, Dublin.

Forsell N, Korosuo A, Federici S, Gusti M, Rincón-Cristóbal J-J, Rüter S, Sánchez-Jiménez B, Dore C, Brajterman O and Gardiner J. (2018). Guidance on developing and reporting Forest Reference Levels in accordance with Regulation (EU) 2018/841. Available online at: http://europa.eu/!kr79Wm *[Accessed 27.06.2018]*

Gallagher, G. and O'Carroll, J. 2001. Forecast of roundwood production from the forests of Ireland 2001-2015. COFORD, Dublin.

Gray, H.J., 1963. 'The Economics of Irish Forestry," Journal of Statistical and Social Inquiry Society of Ireland, Vol. XXI, Part III.

Ni Dhubhain, A., Magner, D., and Nieuwenhuis, M. 2006. Juvenile wood in Irish grown Sitka spruce and the impact of rotation length. Irish Forestry, 63 1&2.

Phillips, H. (2011). All Ireland Roundwood Production Forecast 2011-2028. Dublin: COFORD.

Phillips et al. (2017). All Ireland Roundwood Production Forecast 2017-2035. Dublin: COFORD.

Kurtz, W.A., Dymond, C.C., White, T.M., Stinson, G., Shaw, C.H., Rampley, G.J., Smyth, C., Simpson, B.N., Neilson, E.T., Trofymow, J.A., Metsaranta, J., and Apps, M.J. 2009. CBM-CFS3: a model of carbon-dynamics in forestry and land- use change implementing IPCC standards. Ecol. Model. 220(4): 480–504. doi 10.1016/j.ecolmodel.2008.10.018.

Li, Z., Kurtz, W.A., Apps, M.J., Beukema, S.J., 2003. Belowground dynamics in the Carbon Budget: recent improvements and implications for the estimation of NPP and NEP. Can. J. For. Res. 33, 126–136.

Kull, S.J.; Morken, S.; Smyth, C.E.; Fellows, M. 2016. Carbon Budget Model of the Canadian Forest Sector (CBM-CFS3): Archive Index Database Table and Parameter Descriptions. Natural Resources Canada, Canadian Forest Service, Northern Forestry Centre, Edmonton, Alberta.

NIR 2017. National inventory report Greenhouse gas emissions 1990 – 2015 Reported to the united nations Framework convention On climate change, EPA, Dublin