# Annex: Summary of methods

## General overview of carbon pools included in the case studies and the summary of methods

**Table 1:** Overview of carbon pools and activities addressed in each case study. An ‘x’ indicates that the pool is included.

| | | Spain | Czech Republic | Ireland |
|---|---|---|---|---|
| Pools | Living biomass | X | X | X |
| | Litter | | Assumed 0 difference between runs | |
| | Soil | X | Assumed 0 difference between runs | X |
| | Biomass burning through wildfire or other disturbance | X | Not occuring | Not occuring |
| | Harvested wood products | X | X | X |
| Activities | Afforestation | X | n.o. | X |
| | Forest management | X | X | X |
| | Deforestation | Not estimated | Not estimated | Not estimated. |
| Substitution | Materials* | X | X | X |
| | Energy | X | Not estimated | Not estimated. |

* includes fossil fuel substitution effects through combustion of wood processing residues

Emissions were estimated using empirical growth models with data from forest inventories, methods from IPCC (IPCC 2014), national greenhouse gas inventory reports and literature. The methods and data are summarized in Table 2 and described in detail in the sections below.

**Table 2:** Summary of methods used in each case study.

| | | Spain | Czech Republic | Ireland |
|---|---|---|---|---|
| Pools | Living biomass | Empirical growth models (Trasobares & Pukkala 2004; Trasobares et al. 2004a; Trasobares et al. 2004b) | EFISCEN 4.1 (Sallnäs 1990; European Forest Institute 2016; Verkerk et al. 2016) using data from forest management plans | EFISCEN 4.1 (Sallnäs 1990; European Forest Institute 2016; Verkerk et al. 2016) using data from NFI 2012 (Department of Food Agriculture and the Marine 2012) |
| | Soil | Decomposition of stumps and roots (Melin 2014) | - | Emission factor for organic soils (Byrne & Farrell 2005; Duffy et al. 2017) |
| | Biomass burning | Empirical fire models (González et al. 2006; González et al. 2007) | - | - |
| | Harvested wood products | IPCC Tier 2 approach (Rüter 2011; IPCC 2014) with default half-life times of 35, 25 and 2 years for sawnwood, wood-based panels and paper and paperboard, resp. | IPCC Tier 2 approach (Rüter 2011; IPCC 2014) with default half-life times of 35, 25 and 2 years for sawnwood, wood-based panels and paper and paperboard, resp. | IPCC Tier 2 approach (Rüter 2011; Duffy et al. 2017) with default half-life times of 35, 25 and 2 years for sawnwood, wood-based panels and paper and paperboard, resp. |
| Substitution | Materials | Average material displacement factor of 2.1 ton C / ton C (Sathre & O'Connor 2010) | | |
| | Energy | Energy displacement factor | - | - |

## Case study: Spain

**Living biomass**
A simulation period of 50 years, starting in 2015 up to 2065, was considered. The simulation of scenarios was applied to all forested land in Catalonia, represented by the 4,589 plots measured during the 2014–2016 period (The 4th Spanish national forest inventory (NFI) of Catalonia). The plots of the NFI are assumed to represent the tree species composition and structural variability to be found on the 1,6 mil. ha of forested land in Catalonia.

For simulating the development of the 4,589 plots representing the initial state in 2015 the SCENARIO simulator (© 2001–2017 Timo Pukkala) was used (Trasobares 2007). This is a forestry scenario model that utilises the NFI-plots or other similar plots as input data. The program allows the user to make long-term forecasts on the development of the forest resource according to optional management alternatives. This gives the planner the possibility to analyse the overall development of the forest resource and the long-term consequences of policy alternatives. The simulation of stand development was based on individual-tree models (diameter growth, height growth, survival and recruitment models, for each species) (Trasobares & Pukkala 2004; Trasobares et al. 2004a; Trasobares et al. 2004b) and fire damage models fitted using the Spanish NFI data (González et al. 2006; González et al. 2007). Biomass was estimated using expansion factors from (Ruiz-Peinado et al. 2011; Ruiz-Peinado Gertrudix et al. 2012). Simulation period of 50 years (2015-2065) was organized in 3 sub-periods, 2 initial sub-periods of 15 years and a final one of 20 years. Silviculture treatments were simulated in the middle of each sub-period. We simulated all the NFI plots both under a no-management scenario and under a defined set of management prescriptions. After simulations were implemented, the results (representing 421,800 ha per NFI combined simulation) were extrapolated to the whole area of Catalonia, aiming to adjust the simulation to 1.6 million ha, and the scenario defined cutting levels.

The management prescription used to simulate the Baseline scenario (current management practices in the region maintained) considered a threshold basal area of 25 $m^2$/ha for management taking place and the following thinning distribution and intensity for diameter classes (DC): DC10: 0%; DC20: 10%; DC30: 30%; DC40: 50%; DC50: 70%. For the CSF scenario (choosing higher threshold basal areas to trigger cuttings and always leaving a share of large retention trees), 2 main cases were considered: (1) stands dominated by *Pinus halepensis* or *Quercus ilex*, related to high fire risk; (2) all the other forest types. For CSF (1) a threshold basal area of 28 $m^2$/ha and the following thinning distribution and intensity was used: DC10: 30%; DC20: 30%; DC30: 0%; DC40: 5%; DC50: 20%. For CSF (2) a threshold basal area of 35 $m^2$/ha and the following thinning distribution and intensity was used: DC10: 0%; DC20: 0%; DC30: 30%; DC40: 50%; DC50: 70%. Figure 1 shows the evolution of a *Pinus sylvestris* stand under the CSF scenario.

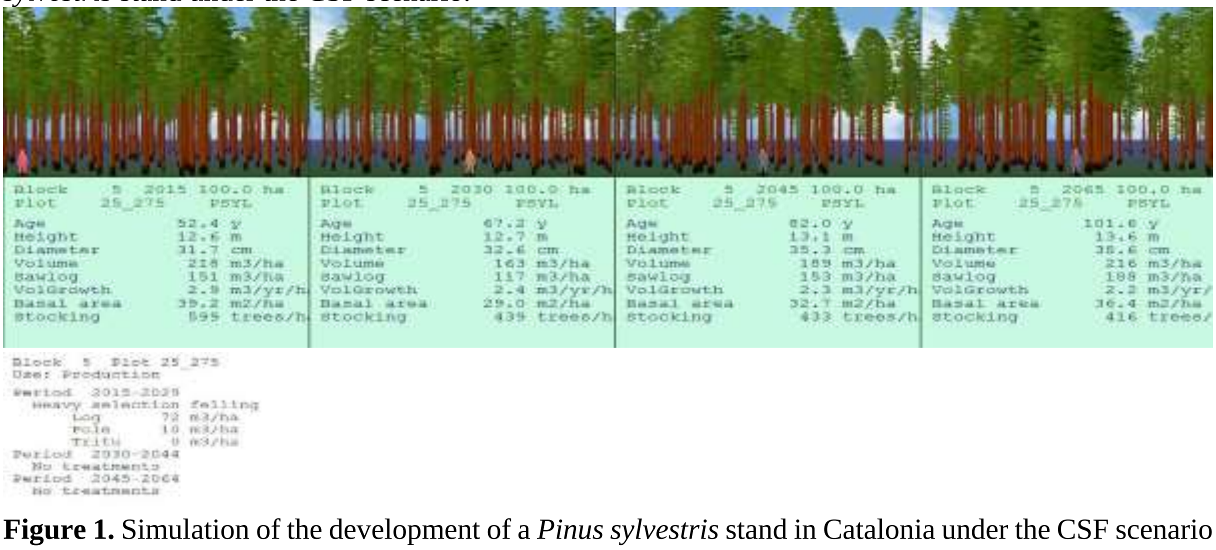


**Figure 1.** Simulation of the development of a *Pinus sylvestris* stand in Catalonia under the CSF scenario (period 2015-2065) using the SCENARIO system.

**Biomass burning**

In the simulations, the way the damage model interacts with the growth models is the following: at each step of the growth simulation, the simulator estimates the probability of fire occurrence (Pocurr), using the model of González et al. (González et al. 2006), and creates a random number that, when compared with Pocurr, results in a simulated fire if it is found to be a lower number. If no fire is simulated the forest follows its normal development according to the growth models. If a fire is simulated in any step of the simulation, the proportion of dead trees is estimated using the model of González et al. (González et al. 2007). Using the proportion of dead trees and its diameter a survival model is applied, and the dead trees are selected and removed (Fig. 2). In this way the dead trees will be removed from the living biomass pool for the next step of the simulation, affecting the amount to be harvested during the scenario period.

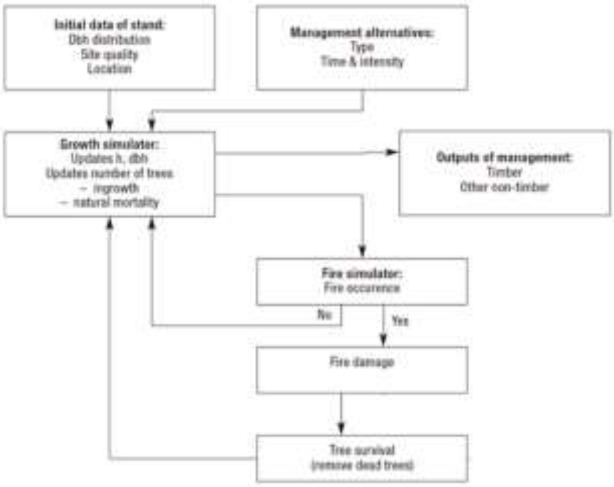


**Figure 2.** Scheme showing how fire risk was integrated on the simulation of each NFI plot.

**Soil**

Variation in soil carbon for the scenarios only considered the impact of leaving stumps and roots from harvested trees. From an amount of dry matter on roots and stumps estimated from the past harvesting levels, we estimated the amount of dry matter on each simulation step by identifying which portion of the biomass on dead trees remained on the ground after harvest, and applied a time dependent decomposition rate (Melin 2014). Although the decomposition rate was obtained from boreal conditions, due to the absence of adequate models for Mediterranean conditions, after discussion with experts, the model was found to be suitable, as the trade-offs between increased temperature and reduced soil humidity should balance the results.

**Harvested wood products**

The historical harvesting levels and distribution of final products for the period 2010-2015 were obtained from internal reports from the Forest Sciences and Technology Centre of Catalonia (CTFC). As the amount of harvested timber increased steadily over this period, we chose the year 2015 to accommodate the harvesting levels for the baseline scenario at year 2015, allowing as well some increase on the amount of timber harvested over the simulation period to reflect the current trend to continue into the future. The distribution of products for the baseline scenario was also derived from the historic data, and maintained over the whole simulation period (Table 3).

In the case of the CSF scenario, the increase in actively managed forest area, the amount of timber to be harvested, and the new distribution of timber products was set after discussion with experts from the regional forest administration.

**Table 3.** Distribution of harvested timber to the initial transformation process, and from those initial processes to final products.

| Baseline | Initial processes % | Final products in % over the initial process: Fuelwood | Energy biomass | Paper | Packaging | Poles | Construction | Boards |
|---|---|---|---|---|---|---|---|---|
| Saw | 40 | 0 | 40 | 10 | 50 | 0 | 0 | 0 |
| Pole | 5 | 0 | 0 | 0 | 0 | 100 | 0 | 0 |
| Particle | 25 | 0 | 90 | 10 | 0 | 0 | 0 | 0 |
| Fuelwood | 30 | 100 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 100 | | | | | | | |

| CSF | Initial processes % | Final products in % over the initial process: Fuelwood | Energy biomass | Paper | Packaging | Poles | Construction | Boards |
|---|---|---|---|---|---|---|---|---|
| Saw | 40 | 0 | 20 | 10 | 30 | 0 | 20 | 20 |
| Pole | 5 | 0 | 0 | 0 | 0 | 100 | 0 | 0 |
| Particle | 35 | 0 | 50 | 10 | 0 | 0 | 0 | 40 |
| Fuelwood | 20 | 100 | 0 | 0 | 0 | 0 | 0 | 0 |

**Substitution**

The material substitution effects have been estimated based on a meta-analysis of 21 studies that cover a wide range of wood product types, materials substituted and geographic regions (Sathre & O'Connor 2010). The study estimated displacement factors in which all the GHG impacts of the wood products chain are allocated to the final product; the displacement factors include emissions from forest management, harvest, transport and processing, as well as avoided emissions due to material and fossil substitution. The study found material displacement factors ranging from -2.3 to 15 ton C per ton C, with most displacement factors lying in the range of 1.0 to 3.0 ton C per ton C. An average displacement factor of 2.1 ton C per ton C was estimated and we used this displacement factors as a basis to assess the benefits of CSF in all three case studies.

We reduced this substitution factor to 1.4 to account for energy that is no longer produced from wood due to the assumed changes in wood allocation. We calculated the substitution for both scenarios separately and used the difference as the additional substitution effect of the CSF scenario. We applied the displacement factor of 0.7 for wood-based energy (Ruter et al. 2016).

## Case study: Czech Republic

The following section provides details on how emissions and removals have been estimated for each pool. The assumptions applied in the Baseline and CSF scenario are described in section 4.3 of the study and are not repeated here. The simulation scenarios for the Czech Republic were computed using the European Forest Information SCENario Model *(*EFISCEN) version 4.1 (Sallnäs 1990; European Forest Institute 2016; Verkerk et al. 2016). The source data used for the simulations was obtained from the database of forest management plans (FMP) administered by the Forest Management Institute, Brandys n. Labem, Czech Republic. The data assembled for this exercise is for the year 2011 (April 2012), and it is based on the Czech typological system which is codified in the Czech Forestry Act (No. 83/1996 Coll.). The Czech forestry differentiates 27 sets of management stands (according to altitude and site/soil properties) and accordingly prescribed management regimes. We assume a start year of 2010 and all simulations were performed until 2100.

**Living biomass, soil and harvested wood products**
The living biomass was taken directly from the outputs of the EFISCEN model. We did not include an estimate of soil carbon effects. The difference between the scenarios was estimated to be very small, while the uncertainty is large.

Harvested wood products were calculated using the same methodology as in the national system, reported in the Czech NIR (Raši et al. 2015; Krtkova et al. 2017). The methods follow the Tier 2 approach as described in the 2013 IPCC KP Supplement (IPCC 2014). It uses FAOSTAT data on industrial roundwood and wood pulp production, export and imports and production of sawnwood, wood-based panels and paper and paperboard, starting 1961 to estimate inflows to the HWP pool. To estimate prior inflows (1900-1960), data from 1960 are extrapolated to 1900, assuming that historic consumption increased by 1.15% annually from 1900 to 1960 (estimated HWP growth rate in Europe). Default half-life times of 35, 25 and 2 years are assumed to estimate the decay of sawnwood, wood-based panels and paper and paperboard, resp. (IPCC 2014; Duffy et al. 2017).Time series of harvested wood products were extended until 2100. The period 2011-2015 was taken as a basis, and a constant export quantity until 2100 was assumed. Domestic production per HWP category over time differed between the scenarios due to different allocation factors for vulnerable and stable forests to these categories (see Table 4). Imports were adjusted accordingly to arrive at constant export quantities.

**Table 4.** Allocation of harvested roundwood to different product shares. After allocation to sawnwood a sawing conversion efficiency of 60% was assumed based on UNECE conversion factors. The saw losses are allocated to panels and energy.

| | Beech | Oak | Pine | Spruce planned fellings | Spruce sanitary fellings | Other |
|---|---|---|---|---|---|---|
| paper | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0 |
| panels | 0.1 | 0.1 | 0.2 | 0.1 | 0.1 | 0.2 |
| sawnwood | 0.4 | 0.4 | **0.6** | **0.7** | **0.6** | 0.2 |
| (firewood) | **0.4** | **0.4** | 0.1 | 0.1 | 0.2 | 0.6 |

**Substitution**

Substitution effects were calculated for long-term products produced from sawnwood and we assumed that 60% of the wood would actually end up in long-term products. A displacement factor of 2.1 equivalent $CO_2$ emission reduction per dry ton of wood product was used for construction wood and wood-based panels (Sathre & O'Connor 2010). We reduced this substitution factor to 1.4 to account for energy that is no longer produced from wood due to the assumed changes in wood allocation. We calculated the substitution for both scenarios separately and used the difference as the additional substitution effect of the CSF scenario.

# Case study: Republic of Ireland

The benefits of CSF were estimated for Ireland, focusing on fluxes from the main carbon pools (living biomass, soil and harvested wood products) and substitution of emission-intensive materials. Emissions from other pools or activities have not been estimated as these historically have been relatively small (CRF tables), or would not lead to differences between the two scenarios.

The following section provide details on how emissions and removals have been estimated for each pool. The assumptions applied in the Baseline and CSF scenarios are described in section 5.3 of the study and are not repeated here.

**Living biomass**
The development of the pools of living biomass have been estimated with the European Forest Information SCENario Model (EFISCEN) model version 4.1 (Sallnäs 1990; European Forest Institute 2016; Verkerk et al. 2016). EFISCEN is a large-scale forest model that projects forest resource development. The model uses national forest inventory data as a main source of input to describe the current structure and composition of European forest resources. Based on this information, the model can project the development of forest resources, as affected by growth, management actions (e.g., tree species selection, thinning, final fellings) and changes in forest area.

The data used in EFISCEN are described in Table 5. The reference year for the projections for Ireland is 2012. The total simulation period was 50 years, i.e. simulations were carried out until the year 2062.

**Table 5.** Overview of datasets used in EFISCEN in the case study for the Republic of Ireland.

| Data | Description |
|---|---|
| **National forest inventory** | • NFI 2012 (Department of Food Agriculture and the Marine 2012) |
| **Management parameters** | • Common rotation lengths (Department of Food Agriculture and the Marine)<br>• Species selection (Department of Food Agriculture and the Marine 2015) |
| **Basic wood densities** | • Species-specific wood density (t dry matter/$m^3$ fresh volume) (IPCC 2003) |
| **Biomass distribution factors** | • Age-dependent, species-specific biomass distribution functions (Bartelink 1997; Levy et al. 2004) |

**Soil**
The methods described in the Irish national greenhouse gas inventory report (Duffy et al. 2017) were applied to estimate future emissions from organic soils and organo-mineral soils. Irish soils can be classified into three major groups; mineral, peat (organic) and peaty/mineral (organo-mineral) soils. In accordance with the NIR, soil emissions are only estimated for organic and organo-mineral soils, as Irish mineral soils have been estimated not to represent a carbon source. Duffy et al. (2017) use an emission factor of 0.59 t C/ha/yr to estimate on-site emissions from first rotation forests on drained organic soils up to 50 years of age. This emission factor is based on a study by Byrne and Farrell (2005) who demonstrated that organic soils are not a source following successive rotations. For organo-mineral soils, the same emission factor is used, but a correction is made based on soil depth (Duffy et al. 2017). For the period 2011-2015, this correction reduced the emission factor on average by 56% for forests remaining forests and 52% for land converted to forest. These reduction factors were assumed to remain constant throughout the simulation period. In addition to on-site emissions, an off-site emission factor of 0.31 t C/ha/yr is applied to all drained organic and organo-mineral soils (Duffy et al. 2017) throughout the simulation period.

For forest remaining forest, the average share of first rotation forests younger than 50 years decreased from 40% to 34% and this trend was linearly extrapolated. As a result, it was estimated that by 2037, there would be no first rotation forests any more. The same approach was applied for forests on organo-mineral soils.

Emissions from afforestation on drained organic or organo-mineral soils were estimated using the abovementioned emission factor. Once afforested sites exceed 50 years of age, no on-site emissions were assumed, e.g. forests established in 1990 were assumed to have no on-site emissions any more after 2040, etc. The off-site emission factor of 0.31 ton C/ha/yr was applied to all drained organic and organo-mineral soils (Duffy et al. 2017) throughout the simulation period.

The approach applied here is not dynamically linked with the estimations for living biomass; changes in forest management that affect litter production do not affect the development of the soil carbon balance.

**Harvested wood products**

The methods described in the Irish NIR (Duffy et al. 2017) were followed to estimate future emissions from Harvested Wood Products. The methods follow the Tier 2 approach in the 2013 IPCC KP Supplement (IPCC 2014). This approach uses FAOSTAT data on industrial roundwood and wood pulp production, export and imports and production of sawnwood, wood-based panels and paper and paperboard, starting 1961 to estimate inflows to the HWP pool. To estimate prior inflows (1900-1960), data from 1960 are extrapolated to 1900, assuming that historic consumption increased by 1.15% annually from 1900 to 1960. Default half-life times of 35, 25 and 2 years are assumed to estimate the decay of sawnwood, wood-based panels and paper and paperboard, respectively (IPCC 2014; Duffy et al. 2017).

The projected, future inflow was calculated by means of the annual growth rates of the projected harvest of Ireland as compared to 2012 (cf. Rüter 2011). In the Baseline scenario, the same growth rates were assumed for all three semi-finished products (i.e. sawnwood, wood-based panels and paper and paperboard). Based on existing wood flows in Ireland (Knaggs & O'Driscoll 2016), the additionally harvested wood in the CSF scenario was allocated to produce construction wood (26%). The rest of the harvested wood (including sawmill residues) is used to produce wood-based panels (48%), energy in combined heat and power plants (25%) or is allocated to other uses (1%).

**Substitution**

Substitution effects were only estimated for wood harvested in addition to the wood harvested already in the Baseline scenario, i.e. no substitution effects are assumed for wood that would be harvested without CSF measures. A displacement factor of 2.1 equivalent $CO_2$ emission reduction per ton of $CO_2$ in wood product was used for construction wood and wood-based panels (Sathre & O'Connor 2010). As these displacement factors attribute all the GHG impacts of the wood products chain to the final product (e.g. including energy produced from wood processing residues), the factor was only applied to construction materials (sawlogs and wood-based panels; 49% of the total additionally harvested roundwood).

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