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Projecting the EU forest carbon net emissions in line with the "continuation of forest management": the JRC method

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Contents

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Abstract

In July 2016, the Commission adopted a legal proposal (COM(2016) 479) for the inclusion of Land Use, Land Use Change and Forestry (LULUCF) in the EU 2030 energy and climate targets. In this proposal, greenhouse gas (GHG) emissions and removals from Managed Forest Land in EU Member States will be accounted using the concept of Forest Reference Level (FRL), for the compliance period 2021 to 2030. The FRL is a country-specific projected baseline of future forest emissions and removals, against which the actual reported emissions and removals will be compared for accounting purposes at the time of compliance.

According to the legal proposal, FRLs will be estimated based on the concept of the "continuation of current forest management practice and intensity", as documented in a historical Reference Period (RP). This approach aims to promote an active forest management while ensuring that all the emissions and removals associated with changes in forest policies are fully reflected in the accounting in a transparent and credible way.

This technical report illustrates the method, as applied by the JRC, to trial projections of forest GHG emissions and removals in line with the proposal, and presents key results aggregated at EU level.

1 Introduction

In July 2016, the Commission adopted a legal proposal (COM(2016) 479) for the inclusion of Land Use, Land Use Change and Forestry (LULUCF) in the EU 2030 energy and climate targets. In this proposal, greenhouse gas (GHG) emissions and removals from Managed Forest Land in EU Member States will be accounted using the concept of Forest Reference Level, for the period 2021 to 2030. The **Forest Reference Level (FRL) is a country-specific projected baseline of future forest emissions and removals, against which the actual reported emissions and removals will be compared for accounting purposes** (i.e. during the Compliance Period 2021-2030). According to the proposal, the FRLs will be estimated based on the concept of "**continuation of current forest management practice and intensity**", as documented in a historical Reference Period (RP)[1].

1.1 Why Forest Reference Levels?

Forest carbon accounting is complex. It is different from other sectors since forests are simultaneously a source and a sink of CO_2. It can be hard to disentangle the background natural exchanges of CO_2 between forests and atmosphere from those that are due to human activity. There are also "legacy effects", which means that cutting or planting trees many years in the past still have effects into the future.

In this context, the concept of "Reference Level" has been widely seen – by both the scientific community (e.g. Bottcher et al. 2008) and by the negotiators one (e.g. Grassi et al. 2010) - as a possible pragmatic way to address in the accounting the complex issue of separating recent anthropogenic effects (i.e. recent mitigation efforts) from other effects. As a result, under the 2nd Commitment Period of the Kyoto Protocol (KP CP2, 2013-2020) forests are accounted against projected "Forest Management Reference Level" (FMRL).

The FMRL submitted by EU Member States under the KP, and the new FRL in the Commission's proposal (described in detail in this report), both include consideration of the natural age-related forestry dynamics (based on documented country information). The main difference between the KP FMRL and the Commission's proposed FRL is the way they deal with the impact of "current" policies. Under the KP most Member States included *assumptions* on the *future impact* of policies adopted by the end of 2009, and this led to a significant increase in harvest being factored in the FMRL. Subsequent analyses, e.g. during a public hearing at the European Parliament[2] and in an open letter from key representatives of the scientific community[3], highlighted that incorporating policy-related harvest increases in the FRL may pose risks to environmental integrity[4].

By contrast, the Commission's FRL only considers the *observed* impacts of *current* policies on management practice and intensity during the historical reference period, and then projects that same practices and intensity forward (see sections 1.2 and 2).

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[1] Note that "current" means "documented during the Reference Period (RP)". While the legislative proposal suggests 1990-2009 as RP, other periods are currently being discussed. To inform the ongoing discussion, the quantitative impact of different RPs on FRLs are illustrated in section 3 of this document.

[2] http://forest.jrc.ec.europa.eu/activities/lulucf/presentations/

[3] http://www.euractiv.com/section/climate-environment/opinion/forest-accounting-rules-put-eus-climate-credibility-at-risk/

[4] When an anticipated (assumed) policy-driven increase of harvest is included the FRL, its impact on the atmosphere is not accounted against the FRL. This may lead to an unbalance accounting across sectors, as the substitution effects of this policy-driven extra harvest are already fully credited in other GHG sectors. Note that, from an atmospheric perspective, the reduction in the forest sink associated to the inclusion of policy assumptions in the FRL leads to more CO_2 remaining in the atmosphere and is thus effectively equivalent to a net increase in emissions.

1.2 The key principles behind the Forest Reference Level based on the continuation of current forest management

The key principle behind the FRL based on "continuation of current forest management practice and intensity" is that **future GHG accounts for Managed Forest Land (MFL[5]) in the Compliance Period (CP) should reflect the impact of *changes* in management practice and intensity[6] relative to the Reference Period (RP).**

The aim of this FRL approach is to make the accounting of the forest sector comparable to the accounting in any other GHG sector (which reflects the impact of policy/management changes relative to a base year), **while acknowledging its special country-specific characteristics**. In this way, "one tonne of carbon" will be treated as "one tonne of carbon" across GHG sectors.

To this aim, the methodology to project FRLs presented in this report:

(a) **Fully includes the country-specific natural forestry dynamics** (e.g., legacy effects related to forest age-class structure). This is done by combining the continuation of "current forest management practice and intensity", as documented in the historical RP, with the expected changes in forest characteristics (e.g. biomass available for wood supply, net increment) as induced by age-related dynamics after the RP[7]. For example, as time passes and a forest becomes older, the net increment *may* decline and increased harvest volumes *may* be needed to continue the "current" management practice and intensity. These dynamics (reduced increment and increased absolute harvest volumes) will likely lead to a reduced sink, but since it is embedded in the FRL it will not be accounted as a 'debit'. It is important to note that with "intensity of management" we do NOT mean the absolute harvest volumes (which are NOT kept constant in the projections) but the ratio between observed harvest volumes and the "biomass available for wood supply" (see section 2.4.2 for details).

(b) **Does *not* include the impact that existing (or currently planned) policies**[8], market processes or forest owners' behaviour may have on *future* forest management practice and intensity. However, the proposed FRL will inherently reflect the observed impact of policies already implemented during the RP.

It is important to note that the Commission's proposal does NOT limit future harvest volumes. On the contrary, the Commission's approach aims to promote an active forest management and an intelligent use of wood – in line with the 'climate smart forestry' concept[9] - while ensuring that all the emissions and removals associated with changes in forest policies are fully reflected in the accounting in a transparent and credible way.

[5] Managed Forest Land (MFL) corresponds to "forest land remaining forest land" under UNFCCC reporting.

[6] Example of changes in forest management practices and intensity include (but are not limited to): shortening rotation lengths, increasing thinning intensity, conversion from conifers to broadleaves, conversion from coppice to high forests, changing the forest function, etc.

[7] Keeping unchanged the forest management practice and intensity documented in the RP.

[8] For example, policies may already be in place that will mean a change in harvest intensity in the future, such as policies to increase the amount of biomass going into the bioeconomy (including bioenergy).

[9] http://www.efi.int/portal/policy_advice/thinkforest/past_events/roundtable/

1.3 Aim of this technical report

This technical report illustrates the method as applied by the JRC to develop projections in line with the "continuation of current forest management" concept, and presents key results obtained at EU level using the Carbon Budget Model (CBM).

This report does not provide technical guidance on how to set a FRL. Rather, the purpose is to illustrate a possible conceptual framework to facilitate the construction of the EU Member States' FRLs, and to provide technical details on a *possible way* to implement it. Other methods to construct a FRL may be developed in line with the "continuation of current forest management practice and intensity" concept.

Specifically, this document includes:

- Section 2: A step-by-step description of the method followed by the JRC to project emissions and removals from MFL, in line with the principles in section 1.2, tested in all EU countries (except Malta and Cyprus). These steps are summarized in Box 1.
- Section 3: The key results of the JRC forest carbon modelling, in terms of expected future forest harvest, net increment and sink levels, aggregated at EU level.

2 The JRC method to project the continuation of current forest management

The following sections illustrate, in simple sequential steps, how the JRC projected emissions and removals from Managed Forest Land (MFL) are calculated in line with the principles described in section 1.2.

Projections were carried out for each Member State (except Malta and Cyprus, due to lack of adequate data). The information on forest characteristics and on forest management during the RP for each country is mostly based on Annex 2b of Pilli et al. (2016a).

First, the total area of MFL was divided into different strata (section 2.1) and the forest management practices occurred during the RP have been described and documented for each stratum (2.2). Since these steps entirely depend on national circumstances and data availability, additional general considerations are provided, including examples of different criteria that could be followed.

Second, the evolution of MFL area after the RP was determined (2.3).

Third, from the end of the RP onwards, the carbon stock changes in MFL were calculated for all the forest carbon pools based on the "continuation of management practice and intensity" as observed in the RP (2.4). Essentially, for each stratum identified above, we combined the expected *age-related* evolution of forest characteristics (e.g., biomass available for wood supply, increment) *after* the RP with the type and intensity of management documented *during* the RP. An "ex-post calibration" was carried out to ensure consistency of model results with the historical data reported by GHG inventories (2.4.6). The method applied by the JRC to project the Harvested Wood Products carbon pool (HWP) is also included (2.5). All the steps above are summarised in Box 1.

While the methodological approach applied by JRC is presented, alternative options are occasionally discussed.

2.1 Stratification of the Managed Forest Land area in the Reference Period

The vast majority of the forest area in the EU is managed through a wide range of forest management approaches[10] (Duncker et al., 2012). These vary among and within countries, and are characterized by specific objectives and supporting practices that depend on: (i) predetermined (and largely un-modifiable) conditions, such as the climate and bio-geophysical site conditions; (ii) the functions assigned by the society to a certain forest area, and (iii) the specific economic and market circumstances.

Applying the concept of "continuing management practices and intensity" requires subdivision of the MFL of each country into **strata** (whose areas should be quantified and assumed constant from the RP onwards, except for possible changes in total MFL area after the RP described in section 3.3), based on national circumstances and data availability.

Possible reasons for stratification may include:

- Main **management objective**: different objectives (e.g. wood production, soil and watershed protection, biodiversity conservation, recreation, agro-forestry, etc.) are associated to different management practices.

[10] Note that the terminology used here (e.g., forest type, management type, management system) is that which is used by JRC when preforming model runs, but other terminology may be of course used to stratify and characterize forest management.

- **Forest type** (referring to species composition, e.g., pure spruce forests, mixed forests, etc.), **management type** (referring to the preferred regeneration system, e.g., high forest or coppice) and **management system** (even-aged or uneven-aged): all these categories have different management practices associated with them, such as rotation ages, thinning intensities and timing, etc.
- **Climate / soil type / fertility class / administrative zonation**: marked differences in climate, soil type or fertility may result in different management practices.

There is no minimum or recommended number of forest strata, but each stratum should be associated to a common set of documented management practices representative of the RP (see section 2.2).

The JRC used various combination of the stratification criteria listed above, depending on data available for each country. More information can be found in the Annex 2b of Pilli et al. (2016a).

2.2 Documentation of the management practices for each strata in the Reference Period

Within each stratum identified according to the approach above, forest management practices can be described through a set of operations, including, for example, the use of artificial or natural regeneration, the species planted, the type of soil preparation, the schedule and intensity of thinnings and final cut (see Duncker et al., 2012). Among these operations, the most relevant ones are end-of-rotation cuttings (e.g., clearcut, partial cutting), thinnings, or exclusion of any harvest operation on natural reserves. Each of these is generally applied to a specific combination of forest type, management type and management system. For example, an even-aged conifer high forest with artificial regeneration, whose main function is timber production, may require a clearcut, while an uneven-aged mixed forest requires certain partial or selective cutting.

Each forest management practice can be defined by a set of **operational criteria**, such as those (not exhaustive) reported in in Table 1. Each criterium may assume one or more quantitative **values** (Table 2). It is important to quantitatively define each management practice so that they can be modelled.

Table 1: Examples of **operational criteria** adopted by forest managers for the application of forest management practices.

Minimum age (rotation): the operation is applied when the forest reaches a minimum age.
Amount of (merchantable) biomass: the operation is applied when total or harvestable biomass reaches a certain level
Minimum Dbh (Diameter at Breast Height): in many cases, this is the main criterium for the timing of end-of-rotation cuttings in uneven-aged forests.
Minimum time interval between two consecutive operations: each operation is applied after a certain amount of years since the previous one (e.g., thinnings).
Increment: the rotation length may be defined as the time when the maximum mean volume annual increment occurs, in order to maximize timber production.
Other criteria may include: basal area, annual cutting area, amount of trees or biomass to retain in the forest, return of investment etc.

Table 2: Example of quantitative **values** defining forest management practices based on the use of "minimum age" as operational criterium. Each management practice is composed by one or more operations, and is applied to a certain stratum, i.e., a combination of forest type (e.g., spruce or beech-dominated forests), management type (e.g., high forests, coppice) and management system (e.g., even-aged or uneven-aged forest). For each operation, the minimum age (or time interval) and the percentage of living biomass removed are reported.

Forest type	**Man. type**	**Man. system**	**Silvicultural operations**					
			Pre-commercial thinning		**Commercial thinning**		**End-of-rotation cutting**	
			Age (yrs.)	**% biomass removed**	**Age (yrs.)**	**% biomass removed**	**Age (yrs.)**	**% biomass removed**
Spruce	High forest	Even-ag	> 20	15 %	> 60	20 %	120 - 140	100% (Clear cut with salvage)
		Unev.-ag					Every 15	20 %
Beech	High forest	Even-ag	> 30	15%	> 120	30 %	> 140	100% (Clear cut with salvage)
		Unev.-ag					Every 15	20 %
	Coppice	Even-ag					Every 30	100% (Clear cut with salvage)
		Unev.-ag					Every 10	30 %

At national levels, countries report also on criteria and indicators for sustainable forest management to Forest Europe (http://foresteurope.org/), according to 34 indicators. These indicators can also provide a guidance to define operational criteria for management during the RP.

Documenting the current forest management practices means taking a "picture" of the main silvicultural practices for each stratum during the RP (i.e. not including *assumed* future *changes* in forest management or function), based on the data available in each country. In other words, the *operational criteria* above and their *values* (or similar indicators) need to be described, taking into account the forestry practices relevant for the RP (e.g., area being actually managed or harvest that actually occurred, as reported by forest management plans or records), but also considering silvicultural textbooks, scientific literature and expert assessment.

Since the documentation of current forest management practices should entirely reflect the country's circumstances, a large degree of flexibility should be applied, as long as (i) the criteria/values (or similar indicators) used are transparently documented and their rationale illustrated, and (ii) the same forest management practices are applied consistently when doing projections (see 2.4).

The main criterium used by the JRC is minimum/rotation age, except in uneven-aged forests where the minimum time interval between two consecutive operations has been applied. More information on the criteria and values used by JRC for the various Member states can be found in the Annex 2b of Pilli et al. (2016a).

2.3 Projection of the evolution of Managed Forest Land area after the Reference Period

The area of Managed Forest Land (MFL) may change in time due to two dynamic processes:

- Land classified as "land converted to forest" reaches the end of the conversion period (default 20 years) and starts being reported as MFL.
- MFL is converted to other land-uses (i.e. deforestation) and starts being reported as "forest land converted to other land-uses".

Since the expected gross expansion of MFL area due to land converted to forest is *known* (from GHG inventories), and it is due to an age-related effect (e.g. the land converted to forest in the period 2001-2005 is expected to enter the MFL category in 2021-2025, under the default 20 years transition period), the approach taken by JRC is to include this forest expansion (and the associated carbon impact) in the projections for MFL. On the other hand, the future deforestation area is *not known:* in this case, the past rate during the RP may be assumed to continue. Overall, the JRC estimated the future MFL area by:

- Adding to the MFL area at the end of the RP, for every year after the RP, the area of "land converted to forest" expected to enter annually the MFL category (as documented by GHG inventories).
- Subtracting from the MFL area at the end of the RP, for every year after the RP, the average annual area of deforestation observed during the RP (as documented by GHG inventories).

Although in most cases the two processes above will have a relatively small impact on emissions and removals from MFL, this impact needs to be included in the FRL.

This may be done with different methods (with equivalent results):

- Project the extra sink due to land converted to forest after the RP, and the reduced sink due deforestation after the RP, and adding these estimates ex-post to the projections initially done for the MFL area of the RP. This is the method taken by the JRC.
- Alternatively, the projections of emissions and removals in MFL may be directly built upon the total evolution of the MFL area after the RP. Area of land converted to managed forests and deforestation can be considered as stand-alone forest strata (section 2.1), or be subdivided among other strata using the same relative distribution of MFL in the RP.

While the approach above is the one used by JRC to produce the estimates shown in section 3, possible alternatives exist. For example, projections of emissions and removals in MFL may be based upon assuming a constant area of MFL at the end of the RP (e.g. in 2009), or even at the end of year 2005 (which is the base year for all the other sectors) i.e. not accounting for an evolution MFL area for the reasons given above. In these cases, all managed forest expansion/deforestation after 2009 (or 2005) would be considered a change in management relative to FRL, and therefore its impact on future emissions and removals in MFL would be fully reflected by future accounts.

2.4 Projection of the forest carbon pools after the Reference Period

This section describes the essential elements of the method implemented by JRC to project the carbon stock changes of the forest pools (above- and below-ground biomass, dead wood and litter, mineral soil) after the Reference Period (RP) and during the Compliance Period (CP), based on the "continuation of management practice and intensity" documented in the RP, and applied to all EU countries (except Malta and Cyprus). JRC projections were carried out by the Carbon Budget Model (CBM) (Kurz et al. 2009, Pilli et al. 2013, 2016b, 2016c, 2017). The key results aggregated at EU level are shown in section 3. A summary of the main NFI input data used by JRC for the application of the Carbon Budget Model is included in the Annex to this document.

The description here focuses on carbon stock changes of living biomass (above- and below-ground), separately for "gains" and "losses". The carbon stock changes in other carbon pools (dead wood and litter, mineral soil) have been automatically modelled by the CBM, through explicit links between pools (Kurz et al. 2009); non-CO_2 emissions were not estimated. In the absence of a forest growth model, the carbon stock changes in litter, dead wood and mineral soil pools may be estimated by the same method used by the country in its GHG inventory.

The conceptual framework underlying the method described in the following sections is potentially applicable to the vast majority of EU Member States, also through simplified variants (i.e. not necessarily using a formal forest growth model). This method may facilitate the construction of the FRL, however, this is certainly not the only method to fulfil the key principles in section 1.2. Ultimately, the choice of the method to calculate the FRL will depend on the national circumstances, including data availability and modelling capability.

2.4.1 Carbon gains

To project carbon gains of MFL, the biomass stock in each stratum identified above was estimated for each year of the RP, based on country-level data (see Pilli et al. 2016a, and the Annex to this document for a summary of data sources). Then, the *age-related* expected evolution of biomass stock in each stratum was calculated for every year *after* the RP and during the CP, including the impact of the "continuation of current forest management" (described in the following section) on the growth rate (increment) of the remaining biomass.

Currently, the estimate of future biomass increment by CBM is not responsive to climate change or to CO_2 and nitrogen fertilization, whose impact may be relevant in the medium term depending mainly on latitude.

2.4.2 Carbon losses from harvesting

For the continuation of "current forest management practice and intensity", and consistently with what was described above, the total losses resulting from harvesting have been estimated by JRC for each stratum, and for every year *after* the RP and during the CP, through the following steps:

<u>**Calculate the Intensity of Management during the Reference Period**</u>

Step 1: **Calculate the "*biomass available for wood supply*",** for each stratum, during the Reference Period (**$BAWS_{RP}$**, including wood for energy uses). This BAWS is the *potential* biomass subject to the operational criteria documented above (section 3.2) for each forest management practice and in each stratum, e.g. "the final harvest for spruce during the RP may occur between 80 and 140 yrs.", or "when 400m^3/ha are reached" (or other criteria and values defined at country level and duly justified). Note that each stratum can be potentially subject to more operations (e.g. thinning or final felling).

Step 2: **Document the harvest amount** (e.g., m^3) during the reference period (**H_{RP}**) for each stratum, split by main type of operation (e.g. thinning or final felling). This may be based on available statistics, modelling, and/or by expert judgment, in which case assumptions should be transparently described and justified.

Step 3: **Calculate the Intensity of Management** (**IM_{RP}**) for each stratum (as average across years of the RP) as:

$$\boldsymbol{IM_{RP}} = \frac{\overline{H_{RP}}}{BAWS_{RP}} \quad \text{Eq. (1)}$$

The IM_{RP} is a proxy that implicitly expresses the impact of all constraints (markets, policies, owners' behaviour, accessibility, etc.) on harvest during RP.

Calculate the harvest after the Reference Period (RP) and during the Compliance Period (CP)

Step 4: **Calculate the expected evolution of the *biomass available for wood supply,*** for each stratum and forest management practice, for every year after the RP, and during CP (**$BAWS_{CP}$**). This should be done by using the same management documented for the historical RP (section 2.2), but applied to the expected age structure of future forests, i.e., the one resulting from age-related evolution of forest biomass and increment. During simulation this requires:

a) Maintaining, for each stratum, the same area[11] documented during the historical RP.
b) Applying to each stratum the same management practices documented during the historical RP.
c) Parameterising each management practice using the same operational criteria and values applied during the historical RP – for example, the same rotation length (i.e., minimum age) for clearcuts, age interval for thinnings, or minimum number of years between two consecutive operations, e.g. for the partial-cut system applied to uneven-aged forests.
d) Maintaining, for each stratum, the same *average* IM_{RP} assessed for biomass (or other relevant parameters) as identified *across the years* of the historical RP[12] (i.e. as an annual mean across the historical RP). Where other parameters are used to determine the Intensity of Management (e.g. area harvested) these parameters need to be estimated and re-applied in an equivalent fashion.

Step 5: **Calculate future harvest,** after the RP and during the CP (**H_{CP}**), by multiplying the intensity of management (IM_{RP}, step 3) by the expected biomass available in the Compliance Period ($BAWS_{CP}$ or other relevant parameter, step 4), for each stratum and year:

$$H_{CP} = IM_{RP} \; x \; BAWS_{CP} \quad \text{Eq. (2)}$$

Applying the IM_{RP} to future forests, subject to the age-related evolution of biomass and increment and to the same management practices described for the RP (section 2.2), enables simulation of the future expected harvest losses associated with the continuation of "current forest management practice and intensity". It is important to note that the Intensity of Management as defined here is DIFFERENT from the ratio between harvest and increment (a widely used indicator used in different contexts). Therefore, **the proposed FRL modelling approach does NOT assume that the ratio between harvest and increment observed during the RP is kept constant in future projections**. As shown in section 3, this ratio is indeed expected to increase under current conditions, because the expected ageing of most EU forests will require a higher harvest (to continue the same management practices and intensity) while increment is expected to decline slightly due to age-related effects (at least in several Member States). On the other hand, model simulations show that, when forest is getting older (i.e. BAWS is increasing), the JRC method described above will lead, sooner or later (some decades, depending e.g. on the rotation length), to a reduction of the BAWS, i.e.

[11] This can be defined as the average area of each stratum during the RP or as the area of each stratum at the end of the RP.
[12] An alternative approach is that, between the end of the RP and the beginning of the CP (i.e., the "gap period"), the amount of harvest is estimated varying the IM according to the real harvest occurring during this gap period.

the harvested forest will return (after regrowth or replanting) younger. Therefore, the possible increase in harvest required in aging forests is a *temporary* phenomenon.

2.4.3 Losses from natural disturbances

The proposed EU LULUCF Regulation includes a special provision allowing countries to exclude (on a voluntary basis) emissions from natural disturbances, based on the concepts of "Background Level" and "Margin" (to be used to determine "normal" emissions from natural disturbances), consistent with the principles and approaches described in the 2013 IPCC KP Supplement (IPCC 2014). Therefore, if this provision is used by a Member State, projections used to set the FRL should also assume the same background level of emissions from natural disturbances calculated using the guidance provided in the EU Regulation (consistent with 2013 IPCC guidance).

While the JRC model runs took into account the impact of all known historical natural disturbances (see Pilli et al. 2016a), no disturbances have been assumed after the RP. However, the ex-post calibration of model results (section 2.4.6) should automatically incorporate in future projections the continuation of past level of GHG emissions produced by natural disturbances.

2.4.4 Other losses

Consistent with what was described above, other carbon losses (e.g. mortality, pruning) need to be estimated *after* the RP and during the CP, for each stratum and year. Different methods may be followed. The CBM runs done by the JRC automatically include many of these losses (see Kurz et al. 2009 and Pilli et al. 2013). Alternatively, the estimated rate of "other losses" for each stratum observed in the RP could be combined with the area evolution (due to forest expansion/deforestation) of each stratum expected after the RP and during the CP (section 2.3).

2.4.5 Summing gains and losses

Once all the components detailed above have been estimated, the overall projections for the forest carbon pools of Managed Forest Land have been computed as the sum of all gains and losses for all strata and years in the CP.

Any relevant non-CO_2 emissions (e.g. CH_4 and N_2O emissions from drained peatlands), as reported by GHG inventory, should also be added to the projections. While current JRC model runs do not explicitly include non-CO_2 emissions, the ex-post calibration of model results based on GHG inventories (see section 2.4.6) implicitly incorporates the continuation of past level of non-CO_2 emissions.

The uncertainty in the original input data and the methodological assumptions of the model may result in uncertainty of the projections. Different factors, such as natural disturbances (fires and storms), the criteria for rotation lengths (or amount of biomass, minimum Dbh, etc.), the share of harvest between different silvicultural operations (i.e., clearcut and thinnings) and between different species, may considerably affect the projected age class distribution and, as a consequence, the future amount of harvest (Pilli et al. 2017). In particular, this method is highly sensitive to (i) the initial age class distribution (i.e., at the beginning of the model run) and (ii) the rules for the evolution of age classes during the model run (as affected by harvest or other disturbances).

2.4.6 Ex-post calibration of model results with GHG inventories

According to the proposed EU LULUCF Regulation, the model used to project the FRL should be able to reproduce historical data from the national GHG inventory.

To this aim, the GHG emissions and removals estimated by CBM after 2000 were "calibrated *ex-post*" (adjusted) to match the historical data for emissions and removals in "forest-land remaining forest land" reported by the 2017 GHG inventories for the period 2000-2015. This procedure, identical to the one applied by many Member States when setting the FMRL in the 2nd Commitment period of the Kyoto Protocol[13], aims to ensure consistency between country data and model results in terms of:

(i) Absolute level of emissions and removals from forest biomass, i.e., the calibration reconciles differences in estimates which may be due to a large variety of factors, including different input data, different parameters (e.g. biomass expansion factor), different estimation methods (e.g., some countries use a 'stock-change approach', while the model essentially uses a 'gain-loss approach');

(ii) Coverage of non-biomass pools and GHG sources.

This *ex-post* calibration procedure represents an application of the 'overlap' method included in the IPCC 2006 Guidelines (IPCC 2016) and in the IPCC 2013 KP Supplement (IPCC 2014) to ensure time-series consistency when different estimation methods are used over time.

The magnitude of the calibration carried out on the results of the JRC modelling (i.e., the difference between the original CBM results and the sum of Member States' GHG inventories for the period 2000-2015) is relevant for some Member States, but very small at the EU level. The average 2000-2015 sink is -378 $MtCO_2$/year based on GHG inventories and -389 $MtCO_2$/year based on the CBM runs (therefore, the original CBM results were corrected with +11 $MtCO_2$/year for the whole time series).

The future trend projected by JRC (section 3) is not affected by this calibration.

2.5 Projecting the Harvested Wood Products (HWP) pool

This section shortly describes the method applied by the JRC to model the Harvested Wood Products (HWP) pool consistently with "continuation of current forest management practice and intensity" (including the key principles in section 1.2).

Assuming the continuation of the IPCC methodologies for the "production"-based approach (IPCC 2014), the following data and assumptions have been used:

(a) Future *amount* of wood commodities entering the HWP pool: projected consistently with the estimated harvest level during the Compliance Period (see Step 5 above in section 2.4.2), by assuming the use of the same *fraction* of harvest for the HWP commodity production as in the Reference Period[14];

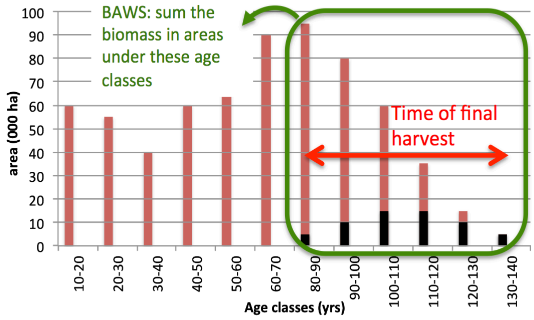
(b) Future *use* of wood: the same % of HWP commodities (sawnwood, wood-based panels, paper and paperboard) as documented for the historical Reference Period is used to determine the projections for the Compliance Period.

[13] http://unfccc.int/files/meetings/ad_hoc_working_groups/kp/application/pdf/awgkp_eu_2011_rev.pdf

[14] This implicitly means continuing with the same % share of energy vs non-energy use of wood as documented for the historical RP.

Box 1. Summary of JRC method for the "continuation of forest management"

(see text for details)



2.1. **Stratify the MFL area** in the RP into strata described by a common set of management practices

2.2: **Document the forest management practices** for the historical RP (e.g. final harvest for spruce occurs between 80 and 140 yrs)

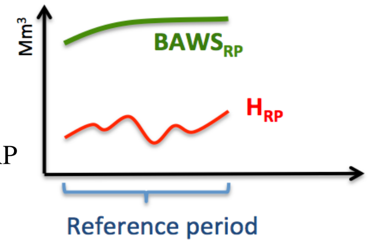
2.3 Project the evolution of MFL area after the RP

2.4 Project the forest carbon pools after the RP

2.4.1 Carbon **gains**: project biomass growth after the RP

2.4.2 Carbon **losses**:

Harvest: For each strata and management practice:

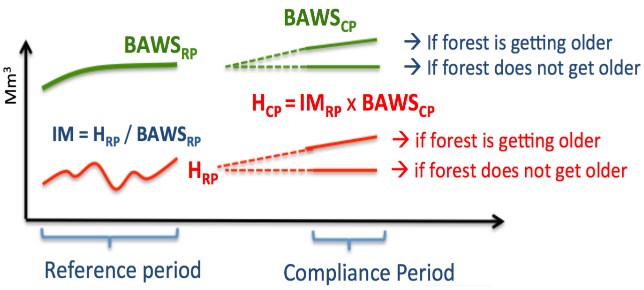


Step 1 calculate the "*biomass available for wood supply*" in the RP (**$BAWS_{RP}$**, e.g. biomass within 80 and 140 years).

Step 2: document the **harvest amount** during the RP (**H_{RP}**).

Step 3: estimate the **Intensity of Management** (**IM_{RP}**) during RP as: **$IM_{RP} = H_{RP}$** / **$BAWS_{RP}$**. IM_{RP} is a proxy that expresses the impact of all constraints on the harvest during RP.

Step 4: estimate the future biomass available for wood supply ($BAWS_{CP}$) by applying the same practices and intensity of the RP to the expected age-related evolution of forest characteristics (e.g., biomass and increment)



Step 5: **set future harvest** (**H_{CP}**) as: $IM_{RP} \times BAWS_{CP}$

2.4.3 and 2.4.4: **Natural disturbances and other losses**

2.4.5: **Sum gains and losses**

2.4.6 **Ex-post calibration of model result with GHG inventories**

2.5 Project the HWP pool

3 Key results at EU level

Using the approaches and methods described in the previous sections, the JRC has projected emissions and removals under "continuation of current forest management practice and intensity" in Managed Forest Land (MFL) for each individual Member State (except Malta and Cyprus, due to lack of adequate data).

This section presents the main results for the expected harvest, net increment and emissions/removals levels (for both the forest pools and the HWP pool), aggregated at EU level, including the impact of different Reference Periods (RP). A comparison with IIASA's estimates included in the EU Reference Scenario 2016[15], and with HWP estimates from Rüter (2011), are also included. Results are shown only at EU level because – among other things – Member States may use more detailed/accurate information on forest characteristics and management of their forests than the ones used here.

3.1 Harvest and increment

Figure 1 shows a comparison of country harvest data and independent projections from JRC and IIASA. Under the KP, most Member States included *assumptions* on the *future impact* of policies adopted by the end of 2009, and this led to a significant increase in harvest being factored in the FMRL (e.g. dashed blue line in Fig. 1). By contrast, the harvest in 2021-2030 projected by JRC for the "continuation of forest management" does not include policy assumption, but just reflect the age-related forest dynamics. **The future harvest estimated by JRC is always higher than the average historical harvest in 2000-2015 (by 7% to 12%,** depending on the RP), and is comparable to IIASA's Reference Scenario 2016.

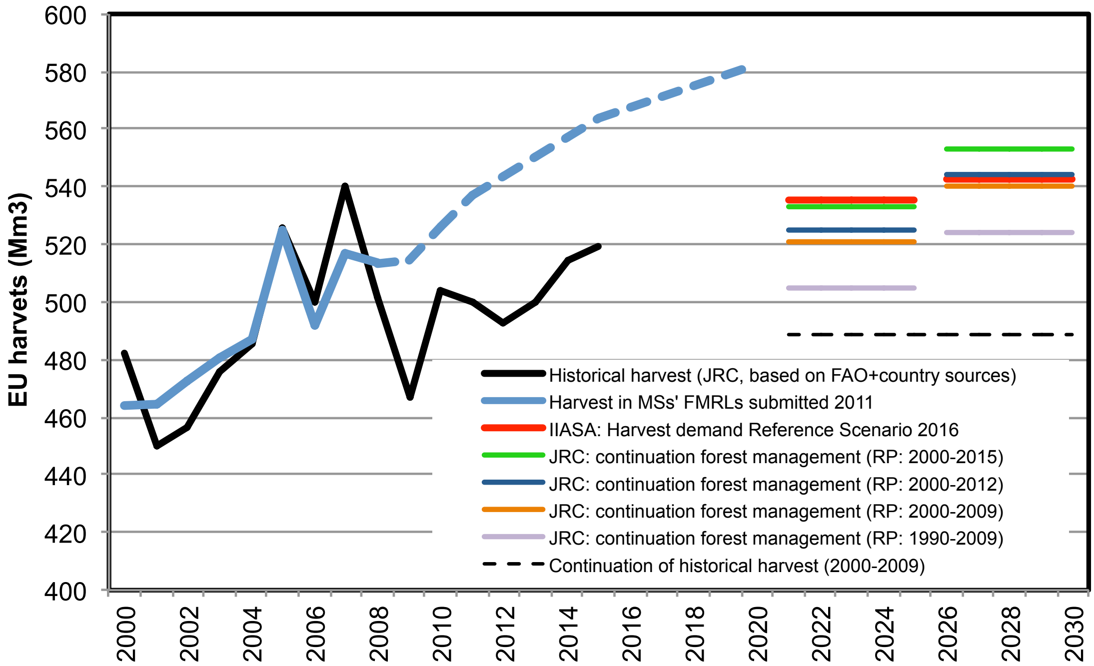


Figure 1 Comparison of harvest data by Member States (aggregated at EU level) and independent projections from JRC and IIASA. (i) latest historical harvest 2000-2015 from countries (black line) and from the FMRL country submissions in 2011 (blue line, projected if dashed); (i) IIASA harvest demand in Reference Scenario 2016 (red line, including the future assumed impact of market and of policies approved up to 2014) and (iii) JRC harvest for managed forest land expected under

[15] Including the future assumed impact of markets and of policies and measures adopted at EU- and MS-level by December 2014. https://ec.europa.eu/energy/en/news/reference-scenario-energy

"continuation of current forest management", using different Reference Periods (RP). The thin black dashed line is the average of historical country harvest (2000-2015) continued in the 2021-2030 period. Both JRC and IIASA results were ex-post calibrated with country harvest (2000-2012).

Figure 1 also shows that the proposed FRL approach implicitly incentivizes increasing current EU harvest volumes. The expected increase in harvest, related to the natural forest dynamics and not to policy plans, will generate additional GHG savings in other GHG sectors (due to the related wood substitution effects) without creating LULUCF 'debits'. With harvest volumes beyond the age-related increase in harvest included in the FRL, trade-offs between LULUCF and other GHG sectors *may occur*[16]. If this happens, the large potential mitigation from substitution effects may partly of fully compensate possible LULUCF debits, also in the short term[17].

The net forest increment (rate of annual growth) is predicted to decline by 2-3% in 2021-2030 vs. 2000-2015, both in JRC (Fig. 2) and in IIASA projections. This trend of slightly declining increment, due to forest ageing, is consistent with the recent trend of net forest increment reported by forest inventories and in the scientific literature (e.g. Nabuurs et al., 2013): after a long-lasting increase in net forest increment from 1960s to early 2000s, from around 2005 the forest increment at EU level showed the first signs of a possible decline.

The FRL proposal would maintain in the future the same ration of harvest to biomass available for wood supply as observed in the historical RP (section 2.4.2). Since BAWS is going up, the absolute harvest volume is also going up. As a result, **at the EU-level, the ration of harvest to increment that would result from the FRL proposal (i.e. the % of increment that could be harvested without debits) is expected to increase by more than 10%**[18]. At the same time, more harvest in FRL generates GHG saving in other sectors.

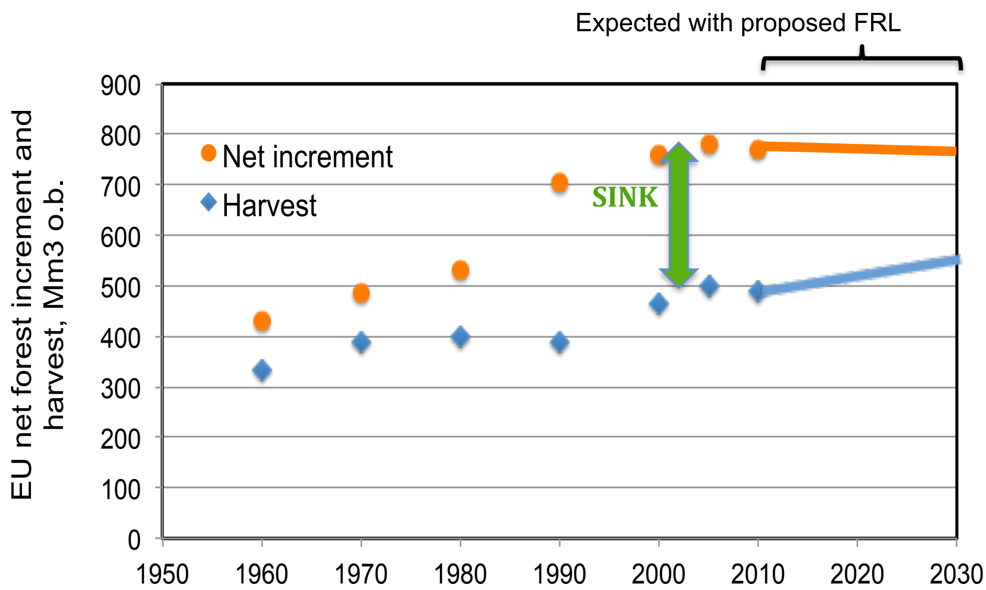


Figure 2 Comparison of historical forest net annual increment and harvest at EU level (data from Nabuurs et al. 2013), with the sink representing the difference between net increment and harvest, and their expected evolution up to 2030, according to JRC estimates with the proposed FRL approach.

[16] This trade-off is not automatic. FRL is about net emissions, not about harvest per se. If an increase in harvest beyond what included in the FRL is compensated by an increase in forest growth (e.g. due to better forest management), the sink may remain greater than FRL and therefore no LULUCF debits would occur.

[17] http://www.efi.int/files/attachments/publications/efi_fstp_2_2015.pdf

[18] Using increment and harvest data from Eurostat, this would translate into an increase of harvest/increment ratio from about 0.7 to about 0.8.

3.2 Sink in managed forest and land

Figure 3 shows a comparison of country forest sink data (aggregated at EU level) and independent projections from JRC and IIASA. Based on the latest GHG inventories (2017 GHGIs) the difference between the reported forest sink (black line) and the forest management reference levels (blue line in 2013-2020) is about 130 $MtCO_2$/yr at EU28 level[19] (average of 2013-2015), equivalent to 3% of current total EU GHG emissions. This reflects the anticipated increase in harvest embedded in the FMRLs under KP CP2 (Fig. 1).

The sink of Managed Forest Land (MFL) projected for 2021-2030 by JRC under the "continuation of forest management" is generally comparable to IIASA' projections, with some variation depending on the RP, but is significantly smaller than the historical sink reported by Member States for the period 1990-2015. This declining sink in JRC projections is *not* driven by policy/market assumptions, but only by a well-determinable (and fully reviewable) age-related evolution of forest structure and dynamics, i.e., the declining increment and the increased harvest needed to continue the "current forest management" in older, more biomass-dense forests at EU level.

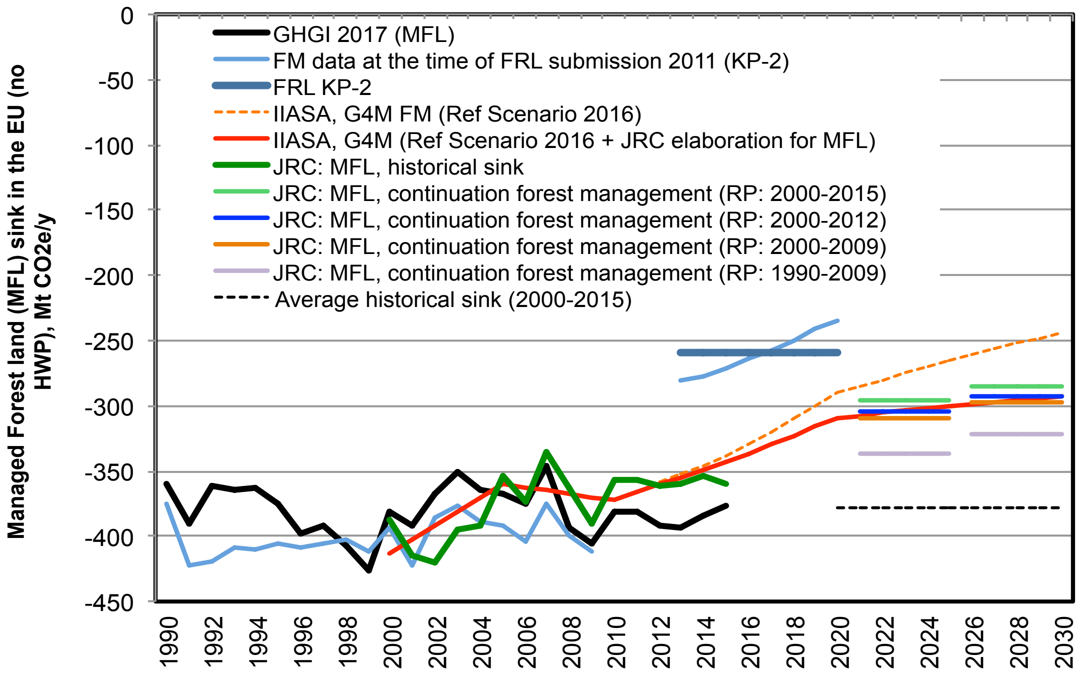


Figure 3. Comparison forest sink estimates (without HWP) submitted by Member States under UNFCCC (aggregated at EU level) and independent estimates from JRC and IIASA. (i) Official countries' data (aggregated at EU level) on the historical forest sink (black line, MFL: managed forest land 1990-2015 from 2017 GHGIs) and on Forest Management projections for 2013-2020 made in 2011 (blue line; the thick blue line is the FMRL for 2013-2020) (ii) IIASA's forest sink according to the harvest demand in the Reference Scenario 2016 for Forest Management (FM: forest existing in 1990, dashed orange line, *not comparable with JRC projections*) and for MFL (red line, JRC elaboration of IIASA data[20] to allow comparability with JRC projections) and (iii) JRC sink for MFL expected under "continuation of forest management", using different Reference Periods (RP, i.e. the historical period that defines the "current forest management"). The black dashed line

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[19] This 130 $MtCO_2$/yr at EU28 level represents the volume of uncapped potential forest credits. When Harvested Wood Products (HWP) and the available information on "technical corrections" is considered, this number does not significantly change.

[20] The JRC elaboration of IIASA data included: (i) a small (about 5 Mt CO_2/y) recalibration of original FM sink data (orange dashed line) to make them match with GHGIs 2017 for the period 2000-2012; (ii) adding the sink of forest expansion after 1990 that would be included in MFL (e.g. the sink of forest expansion 1990-2005 is included in MFL 2025) to the original IIASA values of FM, to obtain IIASA values (red line) comparable to the JRC's sink for MFL.

is the average of the recent historical sink (2000-2015) continued in the 2021-2030 period (i.e. basis for a "net-net" accounting). The simulations for MFL in this graph assume a transition period of 20 yrs for afforested land to managed forest land. Both JRC and IIASA data were "calibrated" with 2017 GHGIs (for the period 2000-2012). The HWP pool is not included (see Fig. 4).

Finally, the HWP sink estimated by JRC is also comparable with both country historical data and with future projection by IIASA (Figure 4). The expected increase of harvest by about 10% under the continuation of current management scenario (see Fig. 1) leads to a slightly increasing HWP sink up to 2030.

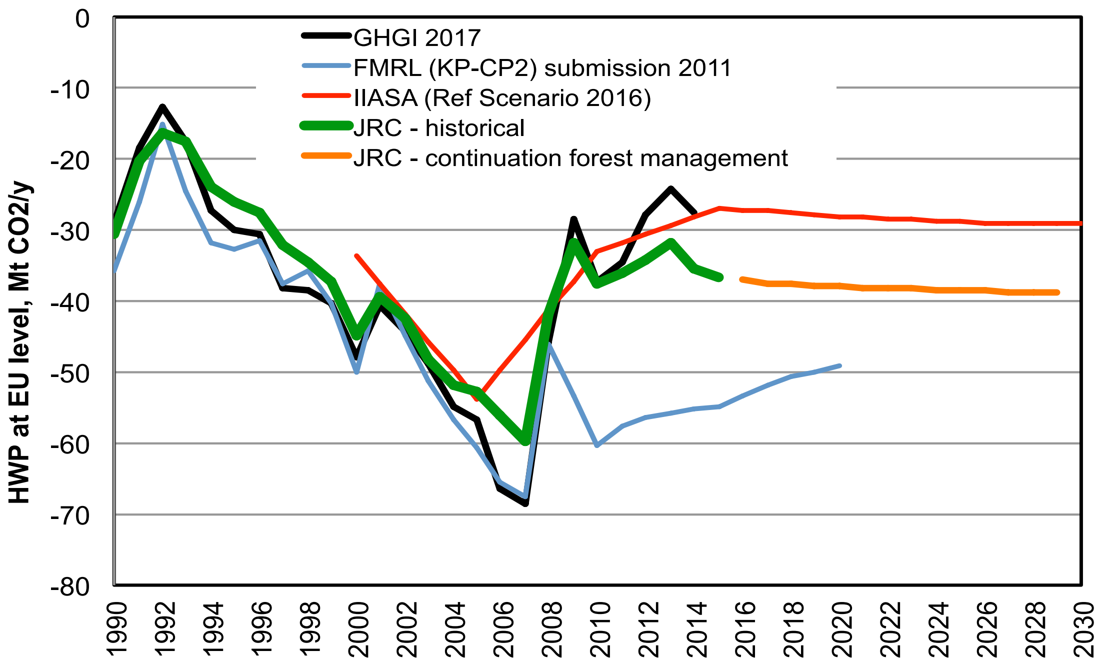

Figure 4. Comparison of historical Member States data (aggregated at EU level) on Harvested Wood Product (HWP) "sink" and estimates from independent sources. (i) Official country data (black line, 2000-2015 from 2017 GHGIs) and the FMRL submissions in 2011 (blue line) (ii) historical HWP estimates from Rüter (2011); (iii) IIASA historical and future HWP estimates included in the Reference Scenario 2016; and (iv) historical and future HWP estimates from JRC sink, as expected under "continuation of current forest management", using the RP 2000-2009 as example. IIASA and JRC estimates have not been "calibrated" with GHGIs.

Annex

Summary of the main NFI input data currently used by JRC for the application of the Carbon Budget Model. For further details (including references included in this table) see Pilli et al., 2016a.

COUNTRY	NFI year	NFI Data source
Austria	2008	NFI data: Österreichische Waldinventur 2007-2009
Belgium	1999	NFI data: 2000 Walloon Inventory (Lecomte et al., 2003) integrated with additional data for Flanders
Bulgaria	2000	Data directly provided by country to JRC
Croatia	2006	Data directly provided by country to JRC
Czech Republic	2000	EFI database*
Denmark	2004	NFI data: NFI (2002-2006), integrated with additional data sources (Submission of information on forest management reference levels by Denmark (Kvist Johannsen et al., 2011)
Estonia	2000	Data directly provided by country to JRC
Finland	1999	NFI data: NFI 9 (Tompoo et al., 2008)
France	2008	NFI data: Inventaire Forestier 2006-2010
Germany	2002	NFI data: Zweiten Bundeswaldinventur
Greece	1992	Data directly provided by country to JRC
Hungary	2008	Data reported in the Submission of information for forest management reference levels by Hungary (2011), integrated with additional data provided by country (see Pilli et al., 2016)
Ireland	2005	Data directly provided by country to JRC
Italy	2005	NFI data: Second Italian NFI (Gasparini and Tabacchi, 2011)
Latvia	2009	NFI 2009 and additional data directly provided by country
Lithuania	2006	EFI database* and additional information provided by literature
Luxembourg	1999	NFI data: 1998-2000 Forest Inventory of Luxemburg
Netherlands	1997	EFI database*
Poland	1993	NFI data: Second NFI (2010-2014)
Portugal	2005	NFI data, mainly reported in the Submission of information for forest management reference levels by Portugal (2011)
Romania	1985	Data directly provided by country to JRC
Slovakia	2000	EFI database* and additional information provided by literature
Slovenia	2000	EFI database*
Spain	2002	NFI data provided by different data sources
Sweden	2006	NFI data: NFI 2004-2008, integrated with further information provided by the Official Statistics of Sweden (Forestry statistics, 2010) and specific data at country level.
United Kingdom	1997	EFI database*
* European Forest Information Scenario Database http://www.efi.int/portal/virtual_library/databases/efiscen/inventory_database/		

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List of abbreviations and definitions

BAWS	Biomass available for wood supply
CBM	Carbon Budget Model
CP	Compliance Period
CP2	2nd Commitment Period of the Kyoto Protocol
Dbh	Diameter at breast height
FMRL	Forest Management Reference Level
FRL	Forest Reference Level
GHG	Greenhouse gas
GHGI	Greenhouse gas inventory
H	Harvest amount
HWP	Harvested Wood Products
IM	Intensity of Management
KP	Kyoto Protocol
LULUCF	Land Use Change and Forestry
MFL	Managed Forest Land
RP	Reference Period

List of tables

List of boxes

List of figures

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