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Provision of technical and scientific support to DG ESTAT in relation to EU land footprint estimates and gap-filling techniques for European forest accounts (LAFO)

Administrative arrangement ESTAT-2019-0300

Task 2: Gap-filling and estimates for the European Forest Accounts

Pilli, R., Grassi, G.

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Joint Research Centre

EUR 30581 EN

Contact information
Name: Giacomo Grassi

Email: giacomo.grassi@ec.europa.eu

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Foreword

This document is part of the Administrative Arrangement ESTAT-2019-0300 signed between DG ESTAT and DG JRC in October 2019. This agreement aims to develop and implement a model for the annual estimation of the EU land footprint, and to develop a method to gap-fill existing data reported to EUROSTAT. This specific report focuses on the second task and includes the construction of a complete time series for the stocks and flows of timber volume in EU Member States.

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Authors

Roberto Pilli, Giacomo Grassi

Abstract

This report focuses on the second task of the Administrative Arrangement ESTAT-2019-0300 signed between DG ESTAT and DG JRC. This agreement aims to develop a method to gap-fill the data reported on Table A2a, as provided by the European Forest Accounts (EFA) of EUROSTAT, and gap-fill this table for the period of 2000–2019. This task also includes a preliminary comparison of officially reported data by EU Member States with data already reported to EFA and with the estimates derived from the Carbon Budget Model (CBM) currently used by the JRC, with the purpose to use the model output to gap-fill missing data.

Table A2a reports, on an annual basis, the changes in the volume of the stock of timber between the beginning and the end of each year, taking into account, from one side, the net annual increment attributed to the opening growing stock, and from the other side, the amount of removals and irretrievable losses subtracted within the same year. The main data sources for the gap-filling task include the Forest Resource Assessment 2020 Country Reports (FRA, for growing stock and area), the State of Europe's Forests 2015 (for growing stock, increment and removals), specific statistics published by the Food and Agricultural Organization of the United Nations (FAOSTAT, for removals), National Forest Inventories (mostly for growing stock), and other documents, such as the National Forestry Accounting Plans recently submitted by the EU Member States under the regulation (EU) 2018/841[1]. All these data were further compared with the main assumptions and model output provided by the CBM.

The analysis highlighted that these data sources may considerably differ both in the definitions applied and in the accuracy of the values reported by each database. For growing stock, ancillary information provided by official statistics and scientific literature generally allow to assess and reconcile, through appropriate correction factors, the main differences between various databases. For increment, the lack of detailed information and data generally prevents a detailed assessment of possible inconsistencies. For the removals, despite the relatively large number of databases - including data directly reported by EUROSTAT - and the differences due to the specific definitions applied by each data source, we highlighted some clear discrepancies, which should be carefully assessed.

The approach to gap-fill the missing data on Table A2a was based on a preliminary calibration of the growing stock estimated by the CBM model against data reported by FRA Country Reports. The amount of removals was directly inferred from the data published by EUROSTAT, when available, or otherwise from the data published by FAOSTAT. Missing information on the irretrievable losses were derived from the CBM output. The net annual increment, which was the most uncertain parameter, was indirectly derived from the previous items. The results showed a good match of these estimates both with the data reported by FRA Country Reports and with the data already provided on Table A2a – when available.

This report is complemented by an Excel file, named *EFA_FRA_CBM_Data_analysis* and made publically available on the JRC Data Catalogue of the European Commission[2], including a detailed comparison of the main items reported in Table A2a and specific country's sheets reporting the approach to gap-fill the missing data for each Member State. The detailed application of the gap-filling approach from 2000 to 2019 is reported in additional country-worksheets including further details, comments and specific methodological assumptions applied at country level.

[1] 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. http://data.europa.eu/eli/reg/2018/841/oj

[2] URL: https://data.jrc.ec.europa.eu/dataset/d4be2da6-54a1-4767-a262-dcebf66b f10b

1 Introduction

The Administrative Arrangement ESTAT-2019-0300 includes two tasks. The first one aims to develop and implement a model to estimate the European land footprint. The second task aims to develop a method to gap-fill existing data reported to the European Forest Accounts system of EUROSTAT. The final objective of this second task is to construct a complete time series for the stocks and flows of timber volume in EU Member States[3]. This report focuses on the implementation of the second task of this Administrative Arrangement.

The European Forest Accounts system (EFA) is a set of accounts quantifying the stocks and flows for forest, forestry and logging industry, compatible with the System of Environmental-Economic Accounting – Central Framework and the national accounts. EFA is a voluntary data collection with up to ca. 20 EU Member States reporting for one or more of the seven EFA tables on an annual basis. The reporting on economic variables of the forestry and logging industry is much more complete than reporting for the stock accounts on forest area and timber volume. The outcomes of the second task of this Administrative Arrangement will improve the completeness of this latter table.

1.1 Detailed task description

The aim of this task is to establish and implement procedures to gap-fill data for a subset of variables of EFA Table A2a on stocks and flows of timber for all EU Member States and the EU as a whole, for the period of 2000–2020[4], taking into account the definitions used in EFA as far as possible. This task also includes a preliminary comparison of officially reported data by EU Member States (e.g. to FAO, UNFCCC, Forest Europe, and in National Forest Inventories) with data already reported to EFA and with the estimates derived from the Carbon Budget Model (CBM) currently used by the JRC (Grassi et al., 2018, Camia et al., 2018). This current assessment aims also to use the CBM output to gap-fill missing data on Table A2a. For this purpose, a detailed description of the CBM, focusing on the specific use of the model's output to estimate the main parameters reported in Table A2a, is included as Supplementary Material.

3 This report still includes the UK as an EU Member State.
4 This report covers time period 2000–2019.

2 Key parameters reported in Table A2a

Table A2a reports, on a yearly basis, the changes in the volume of the growing stock between the beginning (opening stock, OS) and the end (closing stock, CS) of each year, taking into account, on the one side, the net annual increment (NAI) attributed to the opening growing stock, and on the other side, the amount of removals (REM) and irretrievable losses (IL) subtracted within the same year. The final yearly balance between these items also includes possible statistical reclassifications (SRC) due to changes in use or status of the corresponding land use and a possible balancing item (BI). All these parameters are combined within the following equation (Eq. 1) (see Table 1 for further details):

$$CS = OS + NAI - REM - IL \pm SRC \pm BI \qquad \text{Eq. (1)}$$

Table 1: Main items reported in Table A2a.

PARAMETERS	Description	Acronym
Opening stocks (December t-1)	Growing stock at the beginning of the reference year	OS
Net increment	Net annual increment	NAI
Removals	Annual removals from logging activities	REM
Irretrievable losses	Felling residues, felling from windthrow that cannot be removed, timber lost due to fires	IL
Statistical re-classifications	Changes in the volume of timber due to changes in use/status of the corresponding land area	SRC
Balancing item	Used to balance out discrepancies between opening and closing stocks after taking account of the flows explicitly defined in this EFA table (increases, decreases and irretrievable losses, and net changes as a result of re-classification) and observed based on the source data.	BI
Closing stocks (December t)	Growing stock at the end of the reference year	CS

Each parameter is available for Forest land (distinguished between Forest Available for Wood Supply (FAWS) and Forest Not Available for Wood Supply (FnAWS)), Other Wooded Land (including an “of which item” Other Wooded Land Available for Wood Supply) and Other Land with Tree Cover Available for Wood Supply. The present analysis only considers the Forest land, further distinguished between FAWS and FnAWS, through a simplified ex-post assessment.

The key variables determining the closing stock reported in Table A2a are NAI, REM and IL, plus, of course, the amount of timber volume attributed to the opening growing stock, as reported at the beginning of each time series. Assessing the consistency of the values reported by countries and, where necessary, proceeding with an appropriate gap filling, requires a preliminary evaluation of these variables. This evaluation includes an analysis of the definition attributed to each parameter by different databases and a detailed comparison of these data series to discern possible differences. To prevent possible inconsistencies due to the forest area considered by each data source, some parameters need to be also scaled per unit of area.

2.1 Growing stock

Table 2 below reports the definitions of growing stock (GS), as considered for Table A2a of the EFA questionnaire, and as used by other data sources including the Forest Resources Assessment (FRA Country Reports), the State of Europe’s Forests (SoEF 2015, hereafter identified as SoEF), the CBM output (see Supplementary Materials for further details) and a “reference definition” as reported by Gschwanter et al. (2019) within a recent study on the harmonization of stem volume estimates from 21 European National Forest Inventories (NFIs).

Table 2: Growing stock, as defined by different data sources, further distinguished between the main components.

Growing stock	Definition	Components	
EFA[1]	Timber available for wood supply, defined as the volume over bark of trees, living or dead, and include all trees regardless of diameter, tops of stems, large branches and dead trees lying on the ground that can still be used for timber or fuel".	Stem	Yes
		Top	Yes
		Stump	Yes
		Large branches.	Yes
		Small branches.	No
		Foliage	No
		Dead trees	Yes, if usable
FAO, as reported in FRA 2020[2]	Volume over bark of all living trees with a minimum diameter of 10 cm at breast height (or above buttress if these are higher). Includes the stem from ground level up to a top diameter of 0 cm, excluding branches.	Stem	with Dbh>10 cm
		Top	Yes
		Stump	Yes
		Large branches.	No
		Small branches.	No
		Foliage	No
		Dead trees	No
SoEF[3]	Generally consistent with FRA 2020		
Gschwanter et al. 2019[4]	Reference volume definition (COST Action E43), plus other country-specific definitions reported in detail within the paper.	Stem	with Dbh >7 cm
		Top	Yes
		Stump	No
		Large branches.	No
		Small branches.	No
		Foliage	No
		Dead trees	No
CBM[5] – Total Aboveground biomass	Volume over bark of all living trees, including top, stump, branches and foliage	Stem	Yes
		Top	Yes
		Stump	Yes
		Large branches.	Yes
		Small branches.	Yes
		Foliage	Yes
		Dead trees	No
CBM[5] – Merchantable Biomass	Volume over bark of all living trees, excluding top, stump, branches and foliage	Stem	with Dbh>≈9 cm
		Top	No
		Stump	No
		Large branches.	No
		Small branches.	No
		Foliage	No
		Dead trees	No
Data sources:	[1] European Forest Accounts (EFA) Questionnaire. Explanatory Notes. Version 21 July 2016. URL: https://circabc.europa.eu/sd/a/4b0d0b1d-aa7d-4b86-9b63-7a8cacaf5415/EFA_Explanatory%20notes_21JUL2016.doc.pdf [2] FAO, Global Forest Resources Assessment 2020. Terms and Definition FRA 2020. URL: https://www.google.com/search?client=firefox-b-d&q=Forest+resource+assessment+definitions [3]RELEVANT TERMS AND DEFINITIONS USED FOR THE IMPROVED PAN-EUROPEAN INDICATORS FOR SUSTAINABLE FOREST MANAGEMENT. 3 June 2015 URL: https://foresteurope.org/wp-content/uploads/2017/02/3AG_UPI_Updated_Terms_Definitions.pdf [4] Gschwantner *et al.* Harmonisation of stem volume estimates in European National Forest Inventories. *Annals of Forest Science* 76**,** 24 (2019). URL: https://doi.org/10.1007/s13595-019-0800-8 [5] See Supplementary Materials for details.		

The EFA definition of GS – to be considered as the default definition within the present study – includes all trees, regardless of diameter, tops of stems, large branches and dead trees lying on the ground, providing that they can still be used for timber or fuel. This definition differs notably from other data sources, for the possible inclusion of dead trees lying on the ground – which are generally excluded from other definitions – and possible inclusion of other tree components. In both cases, the inclusion within the GS is subordinate to the possible use of these biomass components for timber and fuel. If on the one hand, the flexibility of the definition used by EFA allows to fit to the specific circumstances of each country, on the other hand, it could limit the comparison with other data sources. This is mostly evident if countries do not report detailed information on how they adapted their national statistics to the EFA definition. Despite these possible differences, FRA 2020 Country Reports represent the main terms of reference to compare both the data already reported to EFA and other possible data sources. The definition of FRA clearly includes the stem volume, with a minimum diameter of 10 cm, plus top and stump, but it excludes main branches (which are potentially considered by EFA). Considering these differences, based on expert judgment by Member States' representatives[5], it was established that the GS reported by countries within Table A2a should range from -10% to +20% of the GS reported to FRA. As highlighted in Table 3, however, a preliminary screening of the information reported in FRA Country Reports on the reclassifications of national data on GS volume into FRA 2020 definition, shows that in most cases, Member States are not fully consistent with the FAO definition (15 countries), or they do not report any information on this aspect (8 countries). Only 4 countries out of 28 clearly declare to comply with FAO definitions. This means that, in some cases, possible differences between the GS reported from FRA 2020 and from other data sources - including EFA - may be due to the specific assumptions adopted at country level, even within the FRA Country Reports.

5 This issue was discussed and endorsed as a validation rule by the Working groups with Member States on forest statistics and accounts of ESTAT, at their 2019 meetings.

Table 3: Information reported by countries within the FRA 2020 Country Reports on the reclassification of national data on growing stock volume into FRA 2020 definition. Green cells highlight countries which comply with FAO definition; red cells highlight countries which do not report any information; purple cells highlight countries which applied specific definitions, not necessarily in line with FAO definition.

COUNTRY	RECLASSIFICATION INTO FRA 2020 CATEGORIES
BELGIUM	No information reported
BULGARIA	No information reported
CZECHIA	National data on growing stock are reported under bark. Under to over bark coefficients were used for recalculation
DENMARK	No specific information on volume definition reported
GERMANY	Vol. o.b. of all living trees or shortly dead but usable trees with min. Dbh 7 cm, includes stem from ground level up to a top diameter of 7 cm, excluding branches, including stumps – No Reclassification to FRA definition was applied
ESTONIA	National definition complies with FAO definition
IRELAND	Volume estimated according to FAO growing stock definitions.
GREECE	No information reported
SPAIN	Reclassification to FAO definition
FRANCE	Vol. o.b of living trees with Dbh>7.5 cm, including top until 7 cm.
CROATIA	Vol. o.b. of living trees with Dbh>10 cm, from ground level up to a top diam. of 7 cm, excl. branches with diam. < 7cm
ITALY	Vol. o.b. of living trees with Dbh>4.5 cm, estimated above stumps including branches and stem top up to the diam. of 5 cm
CYPRUS	No information reported
LATVIA	FRA 2020 definitions and categories have been used
LITHUANIA	Vol. o.b. of living trees with Dbh>2 cm, including the stem from root collar level, excl. branches
LUXEMBOURG	No information reported
HUNGARY	No information reported
MALTA	Not applicable
NETHERLANDS	Vol. o.b. of living trees with a Dbh>5 cm, including the stem from ground level up to a top diam. of 0 cm, excluding branches.
AUSTRIA	FRA 2020 Growing stock = NFI Growing stock (forests in yield) - Dead wood trees (forests in yield) + Estimated growing stock in protective forests
POLAND	Vol. o.b. of living trees with a Dbh>7 cm, estimated from stump level up to a top diam. of 7 cm, including branches (up to 7 cm diam).
PORTUGAL	No information reported
ROMANIA	No information reported
SLOVENIA	Reclassification to FRA definition assuming min Dbh 10 cm above stump + min. top and branch diam. 7 cm,
SLOVAKIA	National definition reports vol. of living trees with Dbh>7 cm u.b., from stump up to the top with diam. of 7 cm. The growing stock was converted into the over bark vol. using empirical conversion factors.
FINLAND	The growing stock is defined as living stem volume o.b. with min Dbh=0 cm, above stump.
SWEDEN	According to FRA definitions except that figures reported is minimum Dbh=0 cm
UK	Live stemwood and usable branchwood (to 7cm top diam. and at least 3m in length).

Table 4 reports the relative difference between the closing GS reported by 14 countries within Table A2a, and the one reported by the same countries within the FRA 2020 Country Report, for the period 2015–2018 (most of data reported to EFA fall within this time interval). In most cases, the two datasets are aligned, with relative differences within the ±3% range. The GS reported by Slovenia, however, is about 16-19% higher than the values reported to FAO, and some differences can also be noticed for Ireland, France and Romania. Data and definitions reported by SoEF are generally consistent with FRA 2020 and do not need to be further analyzed.

Table 4: Relative difference between the closing growing stock reported by 15 countries within Table A2a, and that reported by the same countries in the FRA 2020 Country Report, within the period 2015–2018.

Countries	2015	2016	2017	2018
Bulgaria	0%	+1%	+3%	-
Germany	-3%	-	-	-
Ireland	+6%	+5%	+3%	-
France[1]	-4%	-4%	-4%	-
Croatia	-1%	-1%	0%	-
Cyprus	0%	0%	-	-
Lithuania	0%	0%	-	-
Luxembourg	-	-1%	-1%	-1%
Netherlands	-	-1%	-1%	-
Poland	0%	0%	0%	-
Romania	-8%	-4%	-3%	-
Slovenia	+19%	+18%	+17%	+16%
Slovakia	0%	0%	0%	-
UK	+2%	+2%	+3%	-
[1] data reported as FAWS, including overseas territories				

Data published by FAO, as well as from other data sources, can be also compared with data directly collected by countries within their NFIs. In this case, the definitions of volume and GS applied at country level may consider, for example, different Dbh-thresholds, the inclusion of different biomass components and the possible inclusion or exclusion of the bark fraction. Taking into account these differences, Gschwantner et al. (2019) harmonised the stem volume estimates provided by 21 European NFIs - including 18 EU Member States - to a common volume definition, defined by the authors as "Cost Action E43". This definition of GS includes the stem over bark, with top. Based on their study, the percentage amount of non-merchantable stem components (top and stump) of the total volume reported by each NFI varies from 12.6% for Finland to 3.1% estimated for the Czech Republic; the share attributed to large branches varies from 18.9% for Ireland to 3.0% estimated for Lithuania (Table 5)[6].

The total volume reported by each NFI[7] as reported by Gschwantner et al (2019) can be also compared with the GS reported by FRA 2020 and by SoEF. When comparing these values, we must also take into account that: (i) NFI data - even if attributed to a single year - are generally collected within a longer time interval, and (ii) the NFI's domain - i.e. the forest definition and the consequent area considered by each NFI - may not perfectly match with the domain considered by other data sources. Despite these differences, the GS reported by different data sources is generally consistent with the values reported by NFIs (see again Table 5). In some cases, however, the GS reported by FRA and SoEF is remarkably lower (e.g., Czech Republic and Romania) or higher (Belgium and Denmark) than the volume estimated by Gschwantner et al. (2019). Considering that most of these countries do not report specific information on their compliance to FAO definition (see again Table 3), this comparison suggests that, in some cases, official statistics probably are not in line with the definition requirements of the FRA Country Reports.

6 According to Gschwantner et al. 2019, large branches contribute between 3 and 21% of the merchantable volume of broadleaves. For most NFIs, the share of large branches was in the range of 10 to 15%. The nonmerchantable stem parts consist of stumps and stem tops and together accounted for 4 to 13% of the whole stem volume. Stumps contributed between 2 and 7% and stem tops accounted for 1 to 9% of the stem volume. The trees below the Dbh-threshold represent up to 6% of stem volume.
7 No information on the total area is provided on this study, therefore we can only compare the total growing stock.

Table 5: Comparison between (i) the percentage share of the non-merchantable biomass components over the total GS reported by each NFI according to Gschwantner et al. 2019 (see Fig. 4 and Tab. 6 in their article); (ii) the GS reported by each NFI and estimated according to the so called Cost Action E43 definition within the same article, including stem and top components (CA GS) for a specific reference year (Ref. year); (iii) the GS reported by FRA Country Reports and SoEF for a comparable year (Comp. year). Last columns (Delta CA/Other data) report the percentage difference between the Cost Action definition and the GS reported by FRA and SoEF. All values of GS are reported in millions of m^3.

Country	Biomass components				NFI			Other data sources			Delta CA/Other data	
	Stump	Top	Large branches	Small branhces	Ref. year	NFI GS	CA GS	Comp. year	FRA 2020	SoEF 2015	Delta FRA	Delta SoEF
Belgium	3.2%	2.1%	14.5%	-	2001	119	127	2000	N.A.	157		24%
Czechia	2.1%	1.0%	12.3%	0.8%	2013	942	1,028	2015	768	791	-25%	-23%
Denmark	2.1%	1.8%	12.8%	N.A.	2014	133	111	2015	131	125	18%	13%
Germany	2.1%	1.4%	15.7%	0.8%	2002	3,368	3,186	2000	3,381	3,381	6%	6%
Estonia	0.7%	2.9%	-	-	2011	476	462	2010	456	470	-1%	2%
Ireland	3.6%	5.9%	18.9%	-	2010	98	99	2010	94	90	-5%	-10%
Spain	3.6%	2.3%	13.3%	5.0%	2002	1,001	1,089	2000	906	906	-17%	-17%
France	2.4%	2.4%	12.5%	6.2%	2011	2,567	2,757	2010	2,649	2,649	-4%	-4%
Latvia	2.9%	4.2%	5.2%	-	2011	660	661	2010	640	614	-3%	-7%
Lithuania	1.7%	3.6%	3.0%	-	2012	543	535	2010	490	490	-8%	-8%
Hungary	2.9%	0.9%	13.1%	2.0%	2012	390	353	2010	359	359	2%	2%
Austria	4.0%	2.2%	13.0%	-	2008	1,107	1,113	2010	1,126	1,129	1%	1%
Portugal	4.7%	3.3%	10.1%	3.1%	2006	158	179	2005		185		3%
Romania	3.8%	0.6%	11.5%	-	2010	2,157	1,961	2010	1,378	1,378	-30%	-30%
Slovenia	4.8%	2.0%	13.1%	-	2012	417	404	2010	406	406	1%	1%
Slovakia	3.5%	3.5%	10.3%	1.0%	2006	570	609	2005		495		-19%
Finland	4.0%	8.6%	-	1.0%	2011	2,343	2,343	2010	2,343	2,320	0%	-1%
Sweden	1.7%	1.9%	4.0%	-	2013	3,494	3,494	2015	3,478	2,989	0%	-14%

To conclude the analysis, the data reported by FRA was compared with the GS derived from the CBM's output (see Supplementary Materials for details). In this case, we can consider either the merchantable volume (i.e., including only the stem biomass component) or the total aboveground biomass (i.e., including all aboveground biomass components)[8]. As highlighted in Figure 1, in 13 out of 26 countries (excluding Malta and Cyprus where no data are available from CBM) the average merchantable volume estimated by CBM is in line (±10%) with the average volume reported by FRA for 2000, 2010 and 2015. For Austria and Portugal, the volume estimated by CBM is considerably higher than the values reported by FRA (+20% and +29%, respectively), while for the remaining countries, the values reported by CBM are generally lower than 90% of the average GS reported by FRA. Apart from a slightly different diameter threshold considered by these data sources (with a minimum Dbh equal to 10 and 9 cm in FRA and CBM, respectively), these differences are due to various factors, including:

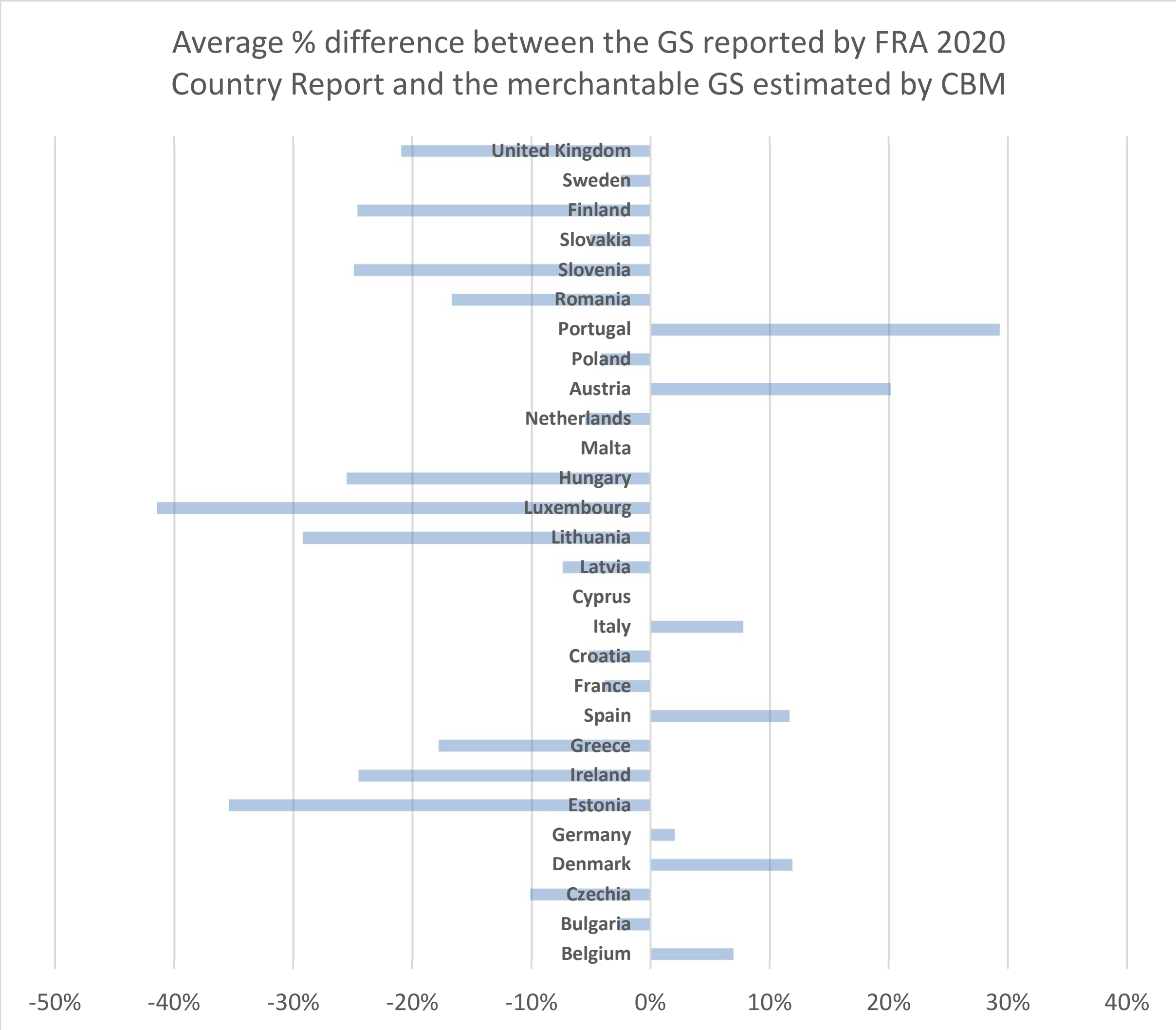
- Tops and stumps are directly included within the FAO definition, but not considered within the merchantable GS derived from CBM.
- Various inconsistencies between the FAO definition and the specific values reported by countries in the FRA Country Reports. As highlighted above, some countries applied a diameter threshold lower than the values considered by either FAO or CBM, implicitly including an additional fraction of biomass that is not considered by CBM (this is for example the case for Finland and the Netherlands, among

8 All CBM results reported in this report are based on the model runs as considered in Grassi et al., 2018. Within these runs, the historical period 2000–2015 was modelled according to the amount of harvest removals reported by FAOSTAT and other ancillary data sources, while since 2016 onwards, the model simulated the theoretical evolution of the forest growing stock assuming the continuation of the current management practices as detected within the period 2000–2009.

others). Some other countries clearly considered a biomass definition not in line with the definition by FRA.

- There are also other differences due to some inaccuracy of the model output. The overall uncertainty of the living biomass stock estimated by CBM is equal to at least to 6.6% (Pilli et al., 2017). In this case, the estimates of the C stock change (i.e., the net increment) are affected by additional uncertainties.

Figure 1: Average percentage difference between the GS reported by FRA Country Reports and the merchantable GS estimated by CBM. The average refers to values reported by FRA and by CBM for 2000, 2010 and 2015, applying to both these data sources a weighting factor equal to 1, 2 and 3 for 2000, 2010 and 2015, respectively.



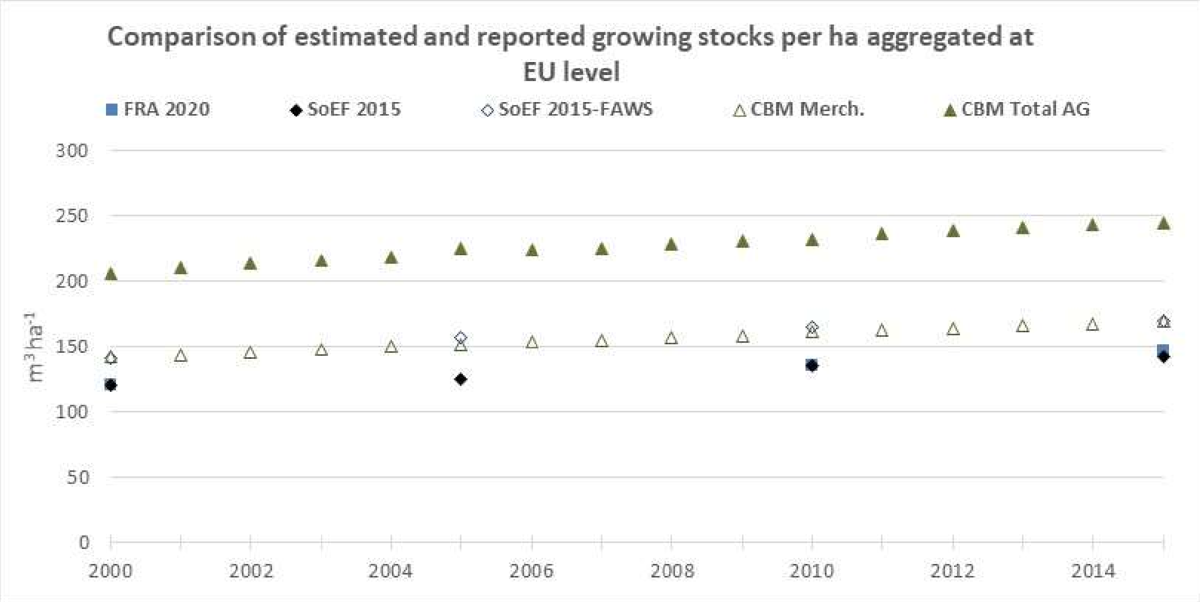
Despite these differences – which in some cases cannot be fully assessed due to lack of detailed information on data reported by countries – it is important to highlight that the overall trend reported by CBM for the merchantable GS per ha is generally consistent with available data reported by other data sources. A detailed comparison between available data sources at country and at EU level - also including additional information reported by Member States within their National Forestry Accounting Plans (NFAPs)[9] - is reported, as supplementary material, within the excel worksheet *EFA_FRA_CBM_Data_Analysis (sheet: Growing_Stock_Comp)*. Based on this analysis, we may conclude that for the GS, the data reported by Member States within EFA Table A2a are mostly in line with other data sources, including FRA Country Reports. For this comparison, the fact that both EFA and FRA use the same definition of forest area constitutes an essential pre-

9 National Forestry Accounting Plans (NFAPs) were recently submitted by EU MEMBER STATES to the European Commission, to compliance with the requirements of the Regulation (EU) 2018/841 (Korosuo et al., 2020).

requisite. In some cases, however, such as for Bulgaria, Romania and Slovenia, the values reported to EFA show some inconsistency with other time series.

When aggregated at EU level (see Figure 2) the estimates derived by the CBM output are fully consistent with the GS reported by SoEF. Because the latter does not refer to the total forest area but to the FAWS, we may argue that, in some cases (e.g.. Greece or Austria), some differences are probably due to the relative fraction of GS attributed to FAWS and FnAWS in different data sources (Alberdi et al., 2020).

Figure 2: Average growing stock per ha (in m^3 ha^{-1}) as estimated by CBM and as reported by different statistics at the EU level (including UK).



2.2 Increment

The estimation of annual volume of increment differs considerably among European Member States. This is due not only to the specific biomass components and thresholds applied by each NFI, but also to the overall NFI framework applied at country level (Gschwantner et al., 2016). For example, NFIs which use permanent plots - eventually combined with temporary plots, such as in Lithuania, Sweden or the UK - generally estimate the volume increment as the difference between two consecutive measurements. On the opposite, NFIs which only use temporary plots - or where a comparable second NFI cycle is not available, such as in Italy or Romania – may derive the increment from borers' measurements carried out at tree level. In some cases, the increment may be also directly derived from yield tables reported by literature (i.e., in Bulgaria or in the first Romanian NFI). For these reasons, data on increment are relatively scarce if compared with the data available for the growing stock, and in some cases, the two are not fully comparable since they may implicitly include different components.

The gross annual increment (GAI) includes the increment of all trees including those which have been felled or died during the reference period. The net annual increment (NAI) is the average annual volume of gross increment *minus* the volume of natural losses due to self-thinning[10] over the same reference period. Both GAI and NAI, of course, consider only trees that exceed a minimum diameter threshold, as defined for the growing stock considered at country level. Harmonizing these data, both at the country and at the EU level, is generally challenging (Gschwanter et al., 2016). Since the FRA Country Reports do not report data on increment, we may compare the NAI reported by SoEF – specifically referring to the FAWS – with the NAI estimated by the CBM, and where available, with the data reported by the countries within their NFAPs. In this last case, it is worth noting that most of these data, reported as GAI, are not directly comparable with the NAI reported by SoEF and

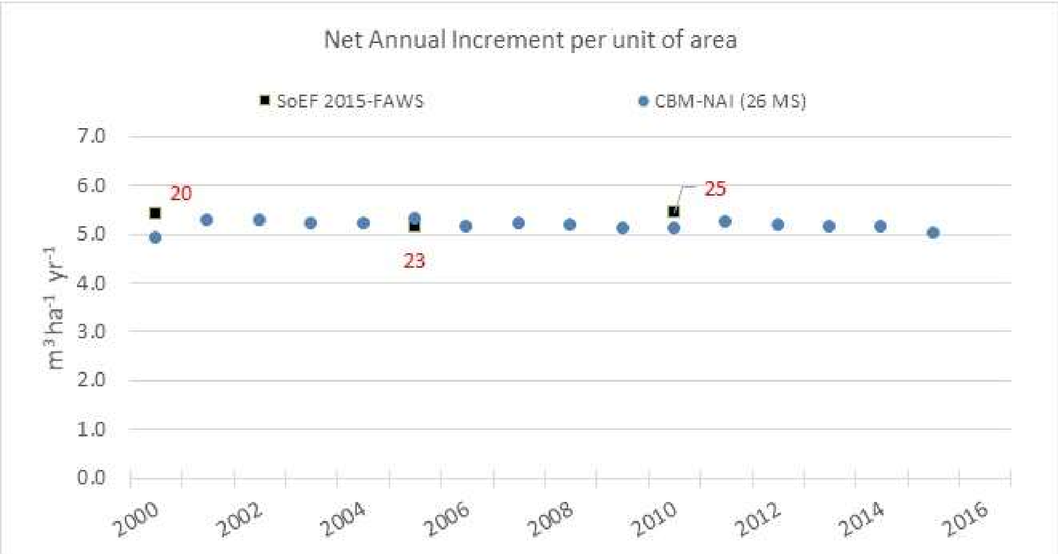
10 RELEVANT TERMS AND DEFINITIONS USED FOR THE IMPROVED PAN-EUROPEAN INDICATORS FOR SUSTAINABLE FOREST MANAGEMENT. 3 June 2015 URL: https://foresteurope.org/wp-content/uploads/2017/02/3AG_UPI_Updated_Terms_Definitions.pdf

CBM, and, in some cases, they were inferred from ancillary information reported within the NFAPs and should be considered with some caution (Korosuo et al., 2020).

A detailed comparison between these data sources is reported as supplementary material within the sheet *NAI_Comparison*. Based on this analysis we found that, at country level, increment data show higher variability than the GS. This is due to different definitions applied at country level, and between data sources (i.e., considering NAI rather than GAI). Even when reported within the EFA Table A2a, in some cases (see for example Bulgaria, Poland, Romania or UK), these values are not fully in line with other data sources.

At the EU level, considering the lack of data reported by other sources, we can only compare the NAI reported by SoEF – referring to FAWS – with the data series extracted from the CBM output (Figure 3). However, even the data reported by SoEF are not fully comparable with CBM due to incomplete data coverage: for 2000 and 2005, when 8 and 5 countries, respectively, are missing in the SoEF reporting. Therefore, the total NAI reported by SoEF at EU level needs to be scaled per unit of area. For 2010, when the two data series are comparable, the average NAI reported by CBM, equal to 5.1 m^3 ha^{-1} yr^{-1}, is consistent with the average value reported by SoEF, equal to 5.4 m^3 ha^{-1} yr^{-1}. As expected, the latter value that only refers to the FAWS is slightly higher than the NAI estimated by CBM that also includes FnAWS, which in some cases correspond to less productive forests.

Figure 3: Comparison between the NAI per unit of area (m^3 ha^{-1} yr^{-1}) reported by SoEF and the merchantable NAI derived from the CBM output for 26 EU Member States (excluding Malta and Cyprus). Please note that the NAI reported by SoEF is referred to FAWS, and only available for 20 (excluding IE, EL, FR, LT, MT, PL, SE), 23 (excluding IE, EL, LV, MT, PL) and 25 (excluding EL, MT, PT) countries, for 2000, 2005 and 2010, respectively (see red numbers). The NAI per ha was estimated as the ratio between the total NAI reported by SoEF and the corresponding area classified as FAWS, considering only those countries for which data was reported in a given year. SoEF 2015 does not report NAI values for the year 2015.

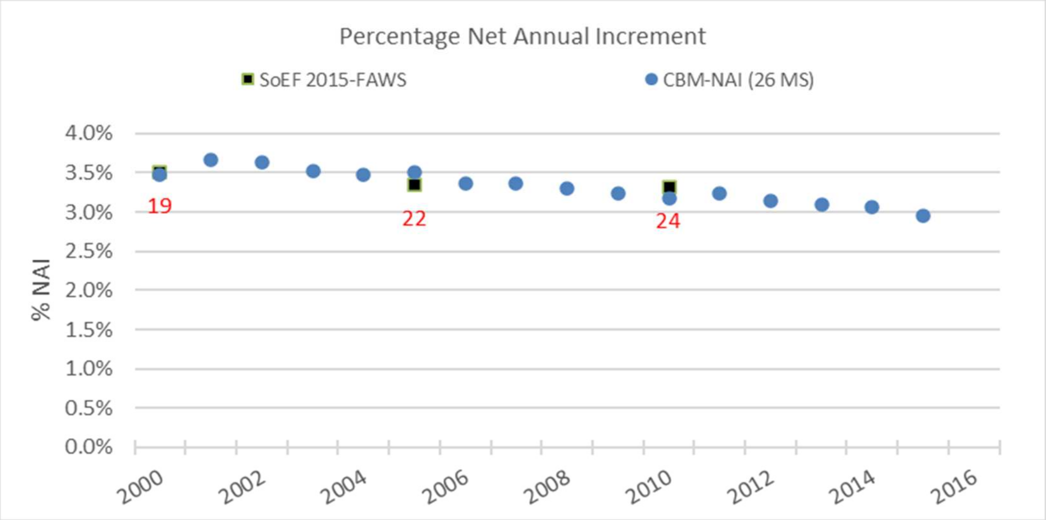


When scaled against the growing stock, the NAI defines the percentage annual increase of the growing stock reported by each data series. Similarly to the previous case, the percentage NAI reported by CBM is consistent with the values derived by SoEF (Figure 4). However, while the average absolute NAI estimated by CBM is quite stable, the percentage annual increment shows a clear declining trend[11], from about 3.7% in 2001[12] to 2.9% in 2015. This is in line with the findings of previous studies reporting a decline in the average forest increment at EU level, mostly attributed to an incipient aging process of European forests (Nabuurs et al., 2013; Pilli et al., 2017).

11 As in the previous case, the trend reported by SoEF is not fully representative, because 9 and 6 Member States are not reporting data for 2000 and 2005, respectively.

12 The percentage NAI estimated by CBM for 2000 is partially affected by the impact of major windstorms affecting European forests in December 1999 (see Pilli et al., 2016 for further details)

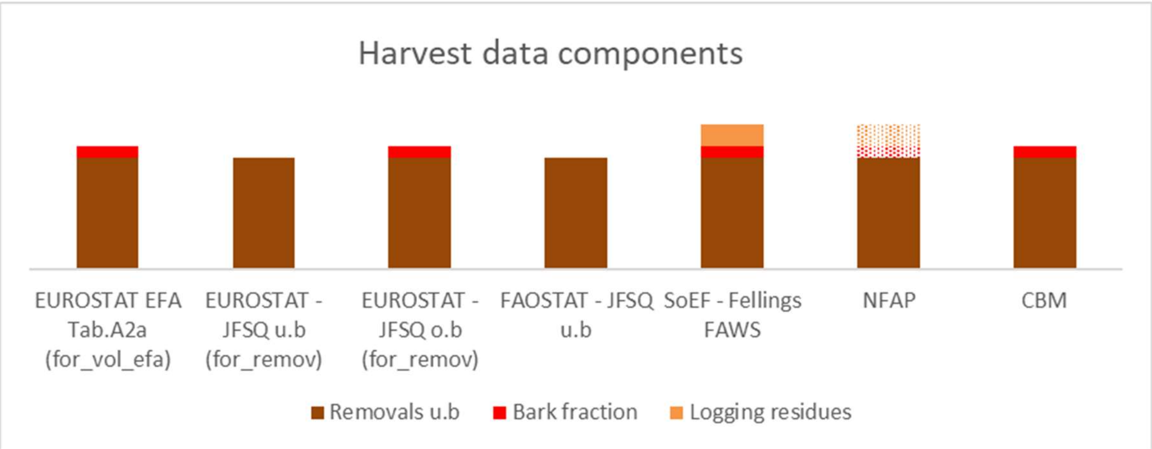
Figure 4: Comparison between the percentage NAI reported by SoEF – referring to the FAWS, and only available for 19, 22 and 24 Member States, for 2000, 2005 and 2010, respectively (see red numbers) – and the percentage NAI derived from the CBM output for 26 EU Member States (excluding Malta and Cyprus). In both cases, the percentage annual increment is calculated as the ratio between the total NAI and the total GS reported by each data source.



2.3 Harvest

Different data sources provide data on the total amount of harvest at country level. EUROSTAT, apart from the annual removals from logging activities reported in Table A2a[13], makes also available the amount of roundwood removals reported in the Joint Forest Sector Questionnaire (JFSQ)[14]. In this case, the data are expressed both as volume under bark (u.b.) - according to the original data reported by JFSQ - and as volume over bark (o.b.), based on specific conversion factors provided by countries. These data can be further compared with (i) the roundwood production reported by FAOSTAT, expressed as volume u.b. and primarily based on the JFSQ data and (ii) the total amount of fellings reported by SoEF and referring to FAWS. Since in this last case, the fellings also includes the amount of logging residues – i.e., parts of felled trees which are not removed from the forest site - we may expect that the values reported by SoEF are higher than the total removals reported by the former data sources (see Figure 5). At the same time, the removals u.b. reported by FAOSTAT and EUROSTAT, based on the same JFSQ data, should be mutually consistent, and they should be both lower than the total removals o.b. reported by EUROSTAT.

Figure 5: Main components (removals under bark, bark fraction and logging residues) of the harvest reported by different sources (see also the text for further details). The components derived from data reported by each country in their National Forestry Accounting Plan (NFAP) may vary, according to specific country's circumstances. The figure highlights only the components included within different database, therefore the scale is approximate only.



13 Table for_vol_efa reported on EUROSTAT website: https://ec.europa.eu/eurostat/data/database?node_code=hlth
14 Table for_remov reported on EUROSTAT website: https://ec.europa.eu/eurostat/data/database?node_code=hlth

A detailed comparison between these data sources – see the sheet *Harvest_Comparison* in the Supplementary Material - highlights that, in general, they are mutually consistent and in line with the theoretical assumptions described above. In some cases, however, the amount of fellings reported by SoEF is lower than the total removals (see for example Belgium, France or Italy) or the total removals u.b. reported by EUROSTAT and FAOSTAT are not mutually consistent (see for example Denmark, Germany or Estonia).

These data series were also compared with the total amount of harvest considered by the CBM and with other information derived from the countries' NFAPs. In the first case, the harvest used as input by CBM is mostly based on the data reported by FAOSTAT, further corrected to account for the bark fraction and other possible inconsistencies due to country-specific circumstances (see Pilli et al., 2015). In the second case, the harvest was derived – when possible – from the data reported by Member States within their NFAPs, or from an ex-post conversion of the original data - sometimes provided in tons of carbon or other units - to volume (o.b. or u.b., depending on countries), using country-specific correction factors based on other ancillary information. The complexity of this harmonization suggests that these estimates should be considered with some caution because the specific components reported at country level (i.e., the possible inclusion of bark and logging residues) may vary according to the specific assumptions (Korosuo, et al. 2020). The overall analysis of the CBM and NFAP data show that they are generally consistent with the earlier mentioned data sources. However, in some cases, the amount of harvest considered by CBM is not properly considering the bark fraction, such as for France and Spain. In other cases, the latest data extracted from the NFAPs, suggest that the amount of harvest reported by other data sources is probably underestimated, such as in case of Belgium and Luxembourg.

Despite these discrepancies, at EU level, the total removals u.b. reported by EUROSTAT and FAOSTAT - both based on the JFSQ data - are mutually consistent, at least until 2010 (see Figure 6). Since 2011 the data reported by EUROSAT are, on average, 8% lower than the values reported by FAOSTAT. Including the bark fraction within the data reported by FAOSTAT[15] the total removals o.b. (reported as *FAOSTAT_corrected* in Figure 6) are considerably higher (+21%) than total removals o.b. reported by EUROSTAT. This is probably due not only to the fact that this last data series is partially uncomplete, but also to some further discrepancy, which suggests that JFSQ removals o.b. reported by EUROSTAT may be partially underestimated[16]. The total removals reported by CBM are generally in line with the data derived by FAOSTAT, when including bark, at least until 2010. Since 2011, the CBM data series is about 5% lower. Within the period 2000–2010, for which all Member States report some information on harvest, the data provided by NFAPs - further harmonised to the other data sources, in order to exclude logging residues and to account for bark[17] – show the same trend as reported by other data sources, but the absolute amount of harvest is about 5% higher than the FAOSTAT data series corrected for bark. Even if any comparison with data derived from NFAPs should be considered with some caution (Korosuo et al., 2020), this finding suggests that the total removals reported by FAOSTAT and other statistics are generally underestimated both at country and at EU level. Similar conclusions have been derived by previous studies (Camia et al., 2018). The suspected underestimation also concerns the total fellings reported by SoEF, equal to about 522 mil m^3 in 2010, when all countries, except Luxembourg and Malta, report data. Even if referred to FAWS only, this figure should be comparable with other data sources. However, in this case total fellings, which also include logging residues, are lower than the total removals derived by FAOSTAT, equal to about 525 mil m^3 o.b.

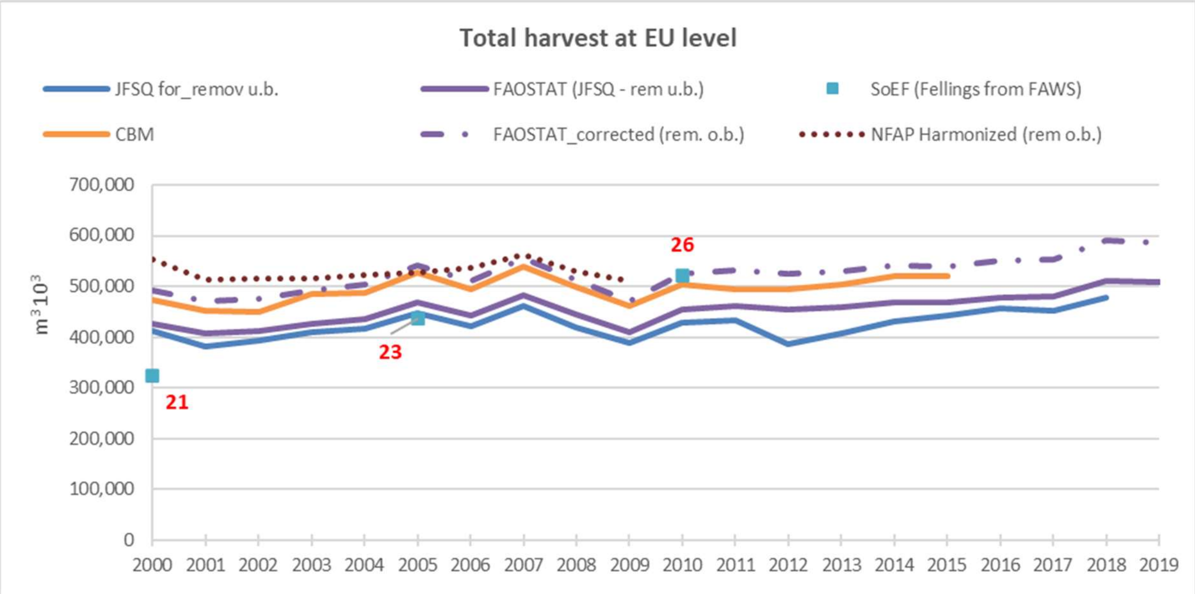
15 Using as correction factor the ratio between removals o.b. and u.b. reported by EUROSTAT.

16 At the time of completing the present report, JFSQ data o.b. of EUROSTAT (for_remov) are under revision.

17 NFAP data were preliminarily harmonised to removals o.b. when aggregated at EU level by:

1. Applying a bark correction factor to harvest data reported u.b., based on the average ratio between removals o.b. and u.b. as reported on the EFA for_remov database.
2. Eventually excluding logging residues from total fellings through a specific correction factor based on (i) data reported by NFAP, if available or (ii) other data sources or (iii) assuming that at least 15% of total fellings is left as logging residues (generic assumption, based on the CBM model output).

Figure 6: Comparison between total removals calculated at the EU level according to the data reported by (i) EUROSTAT (JFSQ for_remov u.b.); (ii) FAOSTAT (JFSQ – rem u.b), further corrected to account for the bark fraction (FAOSTAT_corrected); (iii) CBM, reported as removals o.b. and (iv) derived from the data reported by Member States in their NFAPs, further harmonized to exclude logging residues and include bark's fraction. The figure also highlights the total amount of fellings reported by SoEF, including logging residues and referred to the FAWS – this data series is only available for 21 (excluding EI, FR, LT, LU, MT; PL, SE), 23 (excluding EI, FR, LU, MT; PL) and 26 (excluding LU, MT) countries, for 2000, 2005 and 2010, respectively. SoEF 2015 does not report the amount of fellings for the year 2015.



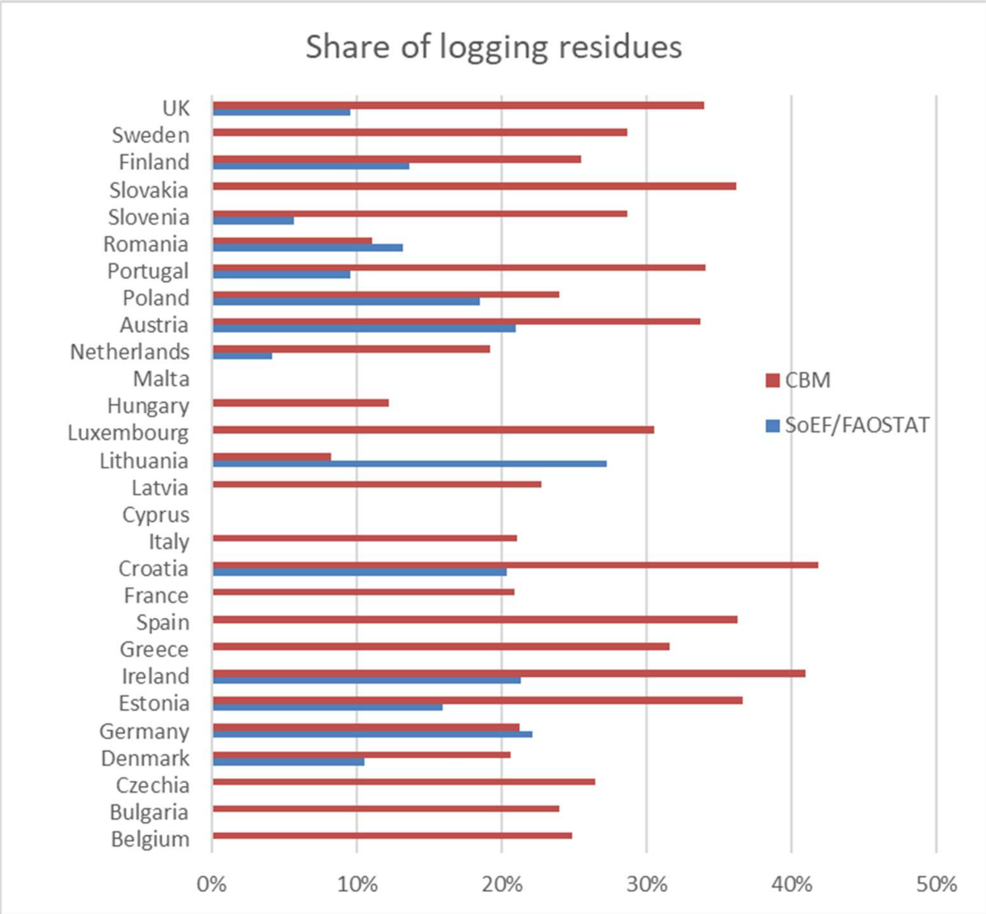
2.4 Irretrievable losses

According to the definition adopted by EFA, irretrievable losses include felling residues, felling from windthrow that cannot be removed, and timber lost due to fires. No database is currently reporting specific information on this category, and even countries already reporting data within Table A2a, in some cases omitted these information (e.g., Bulgaria, the Netherlands or Slovenia).

The amount and the relative share of felling residues can be inferred by comparing the total fellings reported by SoEF with the total removals reported by FAOSTAT, further corrected to account for the bark fraction. Based on this approach, the average share of logging residues at EU level corresponds to about 15% of the total amount of removals[18]. This share considerably varies between different Member States and can only be provided if the amount of fellings reported by SoEF is higher than total removals reported by FAOSTAT, i.e. for 14 out of 28 Member States (Figure 7). Where available, these values can be compared with the amount of logging residues estimated from the CBM output. In this case, the figures provided by CBM also include other possible losses due to major windthrows, fires and other natural disturbance events occurred at country level. These losses are not directly accounted in SoEF, but they can be considered as part of the irretrievable losses considered by EFA. Therefore, the CBM output generally provides a higher share of harvest losses, equal on average to 27% of the total removals at EU level, partially due to additional losses linked to natural disturbances. It is important to highlight, however, that both these estimates are rather uncertain. Indeed, from one side, the values derived by SoEF are in some cases clearly underestimated or not consistent with other data sources. From the other side, the CBM output may be overestimated, because it may also include non-merchantable wood components, related to natural disturbances, and not usable for timber or fuelwood production. Further details are reported in the sheet *Irretrievable_losses* within the Supplementary Material.

[18] Estimated as the average share of forest residues calculated for countries where the amount of fellings reported by SoEF is smaller than total removals reported by FAOSTAT (see the sheet Irretrievable_losses within the Supplementary Material for further details)

Figure 7: Percentage share of logging residues estimated as the ratio between the total fellings reported by SoEF and the total removals reported by FAOSTAT (corrected to account for bark's fraction). This approach cannot be applied if fellings ≤ removals. The figure also reports the share of logging residues and other losses due to natural disturbances estimated by CBM for 26 EU Member States (excluding Malta and Cyprus).



3 Gap-filling

3.1 Gap-filling approach

A preliminary overview of the information made available within the EFA database[19] under the Table A2a (for_vol_efa) highlights that only 14 out of 28 EU Member States (including the UK), reported at least one value within the period 2000 – 2019 and mostly after 2014 (see Table 6).

Table 6: List of EU Member States reporting at least some information (green cells) on Table A2A, within the period 2006-2018 (no information is reported before 2006).

GEO/TIME	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Belgium														
Bulgaria														
Czechia														
Denmark														
Germany														
Estonia														
Ireland														
Greece														
Spain														
France														
Croatia														
Italy														
Cyprus														
Latvia														
Lithuania														
Luxembourg														
Hungary														
Malta														
Netherlands														
Austria														
Poland														
Portugal														
Romania														
Slovenia														
Slovakia														
Finland														
Sweden														
UK														

Excluding balancing items and other statistical reclassifications, the closing GS at the end of each year t is primarily determined as:

$$GS_t = GS_{t-1} + NAI - REM - IL \qquad \text{Eq (2)}$$

19 https://ec.europa.eu/eurostat/web/forestry/data/database?p_p_id=NavTreeportletprod_WAR_NavTreeportletprod_INSTANCE_NcyvNbN2qoBC&p_p_lifecycle=0&p_p_state=normal&p_p_mode=view&p_p_col_id=column-2&p_p_col_count=2

Each parameter reported on Eq. (2) can be determined, for the total forest area and for the period 2000-2019, through the following steps:

1. The **growing stock** can be estimated from the merchantable GS per ha reported by CBM[20] for the period 2000–2015 (GS_{CBM}, based on historical harvest data), further corrected to account for possible differences/inconsistencies with the values reported under Table A2a (when available[21]) or by FRA Country Reports (GS_{FRA}) for 2000, 2010 and 2015 (when missing, these values were replaced with data reported by SoEF), through a country specific Correction Factor (CF_{GS}), equal to:

$$CF_{GS} = \frac{(GS_{FRA}^{2000}+2*GS_{FRA}^{2010}+3*GS_{FRA}^{2015})}{(GS_{CBM}^{2000}+2*GS_{CBM}^{2010}+3*GS_{CBM}^{2015})} \quad \text{Eq. (3)}$$

   The resulting, *rectified* growing stock per ha (GS_R), is determined as:

$$GS_R = GS_{CBM} * CF_{GS} \quad \text{Eq. (4)}$$

   For the period 2000–2015, the total closing GS is equal to GS_R multiplied by the corresponding forest area, as reported by FRA for 2000, 2010 and 2015 or based on a linear interpolation of these values when missing. For the period 2016–2019, the closing GS is determined by the algebraic sum of the variables reported on Eq. (2), estimated according to the following steps.

2. The **total amount of removals** can be inferred for the entire period 2000–2019 by different data sources, including:

   (i) Total removals o.b. reported by EUROSTAT (*for_remov o.b.*), based on the JFSQ data already including bark according to additional information directly provided by countries. If these data are not available, the following sources can be considered.

   (ii) Total removals u.b. reported by EUROSTAT (*for_remov u.b.*) based on the JFSQ data. These values must be further corrected to account for the bark fraction using an average correction factor determined as the ratio between *for_remov o.b.* and *for_remov u.b,* when both are available for the same years. If neither option (i) or (ii) are feasible, the following source can be considered.

   (iii) Total removals u.b. reported by FAOSTAT, further corrected to account for the bark fraction, according to the approach described above.

3. The total amount of **irretrievable losses** can be estimated by multiplying the total amount of removals determined above by the annual fraction of forest residues *(RF_Y)* estimated by CBM for the period 2000–2015, then assumed as constant until 2019 and equal to the last value reported for 2015.

4. Once all the abovementioned parameters are determined, the **net annual increment** per ha can be estimated:

   - for the period 2000–2015: by adding the annual removals and the corresponding amount of irretrievable losses estimated on steps (2) and (3) to the difference between the closing and the opening GS determined for each year, as determined on step (1):

$$NAI = GS_t - GS_{t-1} + REM + IL \quad \text{Eq. (5)}$$

   - For the period 2016–2019, the NAI is assumed as constant and equal to the last value attributed to 2015.

The final total NAI to be reported in Eq. (2) is equal to the NAI per ha multiplied by the total area attributed to each year, as defined on step (1).

The gap-filling approach described above can be applied both to Member States which do not report any information in Table A2a and to the countries which already report some data. In this last case, if a country filled the table since a certain year *z*, an additional balancing item may be added on year z-1, to align the closing GS provided with the present approach to the opening GS directly reported by Member State on year *z*.

20 A preliminary analysis of the GS reported by the Member States highlighted that, despite the different definition considered by EFA (see Table 2), the figures already reported on Table A2a are mostly in line with the values reported by FRA. These values are, in turn, generally consistent with the definition of merchantable GS estimated by CBM, therefore, the present approach was based on these last values.

21 These values are mostly reported since 2014 and they were used, when possible, mostly to replace GS_{FRA}^{2015}.in Eq. (3). Further details are reported within the sheet Growing_Stock_Comp as supplementary material

The relative extent of this item, expressed by the ratio between the BI and the GS, depends not only by the accuracy of present estimates but also by the consistency between the GS directly reported by the country and the one reported by FRA[22].

Where no additional information is available, the total GS is proportionally distributed between FAWS and FnAWS according to the proportion of GS reported by SoEF. Removals and IL are entirely attributed to FAWS, while NAI is estimated as the algebraic difference between the other items. No estimate is provided for the other land use categories of the EFA questionnaire.

The gap-filling approach was applied at country level, first defining the main parameters reported in Eq. (2), then applying each item, year by year, to table A2a, including additional balancing items – when needed – and scaling the data between FAWS and FnAWS. The first part, reported in the file *EFA_FRA_CBM_Data_analysis*, includes 27 countries' sheets (excluding Malta and including the UK), reporting for each Member State:

(a) Total forest area (in ha 10^3) reported by FRA Country Report for 2000, 2010, 2015 and for the period 2016-2019, if available (sometimes these last values are constant or based on a simple linear interpolation of previous data series). A linear interpolation between these values and an extrapolation to 1999 is also reported.

(b) The GS (in m^3 10^3) reported by FRA Country Report for 2000, 2010, 2015 and for the period 2016-2019, if available. The confidence interval -10% - +20% referred to the same values is also reported, to assess the reliability of the final estimates. In some cases, when FRA does not report any value, the SoEF data were used instead.

(c) Closing GS (in m^3 10^3) reported by country to EFA within Table A2a, if available.

(d) Merchantable GS per ha (GSCBM, in m^3 ha^{-1}) estimated by CBM for the period 1999-2015. For Cyprus, due to the lack of data provided by CBM, the sheet reports the GS reported by FRA for 2000, 2010 and 2015, further interpolated for missing data (in this case the CF_{GS} is equal to 1).

(e) Average Correction Factor (CF_{GS}) applied to GS_{CBM}, to account both for different definitions of the biomass' components considered by CBM and by Country Reports, and for possible inaccuracies of the model output.

(f) Rectified GS per ha (GS_R, in m^3 ha^{-1}) estimated by multiplying the GS reported by CBM by the CF_{GS}, as estimated above.

(g) Ratio between the GS of FAWS and the GS of the total forest area, as reported by SoEF for 2000, 2005, 2010 and 2015 (if available). A linear interpolation between these values is also reported.

(h) NAI per ha (in m^3 ha^{-1} yr^{-1}) estimated according to Eq. (5). Values after 2016 are assumed as constant and equal to NAI reported for 2015.

(i) Total NAI (in m^3 10^3) estimated by multiplying the NAI per ha by the total forest area reported by FRA.

(j) Total annual removals (in m^3 10^3) estimated as:

(i) Total removals o.b. reported by the *for*_vol table (only for countries already reporting some data within Table A2a) if available, otherwise:
(ii) Total removals o.b. reported by the for*_remov* table if available, otherwise:
(iii)Total removals u.b. reported by the for*_remov* table, further corrected to account for the bark fraction if available, otherwise:
(iv) Total removals u.b. reported by FAOSTAT, further corrected to account for the bark fraction.

(k) Relative share of IL, expressed as percentage of annual removals, derived by the CBM output. For Cyprus irretrievable losses were not considered.

(l) Total amount of IL (m^3 10^3), estimated by multiplying the total annual removals by the relative share reported above.

(m) Total GS (in m^3 10^3) estimated from 2000 to 2019 according to Eq. (2).

The detailed application of each parameter at country level is reported in 27 country-specific worksheets including, for each year between 2000 and 2019, opening and closing GS, NAI, REM, IL and other items (if

22 According to the approach described on step 1, GS_{CBM} was aligned to GS_{FRA}, through a specific CF.

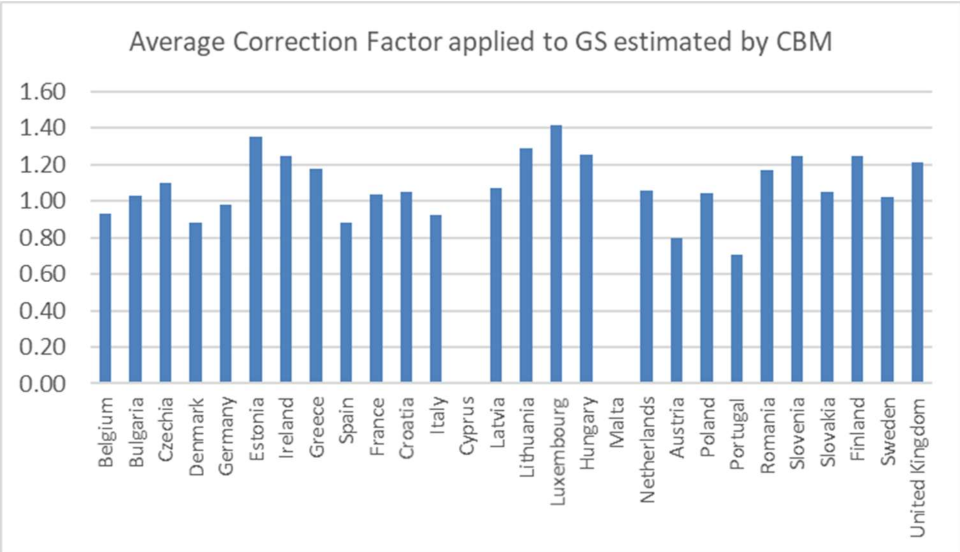
relevant) reported in Table A2a, as estimated according to the present methodological approach or directly reported by the Member States. No estimate can currently be provided for 2020.

Further details, comments and specific methodological assumptions are reported as supplementary material in the country-specific sheets.

4 Results

The approach proposed within the present study is based on the combination of existing data sources, reporting the total annual removals at country level, with the annual GS per ha derived from the CBM model, further calibrated against the corresponding GS reported by FRA Country Reports. This calibration is performed through an average CF which also represents the relative difference between the expected values reported by countries (in FRA) and estimated by model. This factor was equal on average, for all Member States to 1.08 (i.e., on average the GS estimated by CBM is about 8% lower than the values reported by countries), with a standard deviation equal to ±0.17. Higher CFs were applied to Luxembourg and Estonia, where the GS estimated by CBM is underestimated by about 41% and 35%, respectively. On the opposite side, for Portugal the GS estimated by CBM is overestimated by about 30% in comparison to FRA.

Figure 8: Average Correction Factor applied to align the original GS per ha estimated by CBM to the corresponding GS reported by FRA Country Reports.



As highlighted in Figure 9, the total GS estimated in this report is generally in line both with the values directly reported by Member States - when available - and with the values reported by FRA Country Reports, with the corresponding confidence interval (-10% - +20%). In few cases, such as for Ireland, Portugal and Romania, where the GS reported by FRA is highly variable within the period 2000–2015, the estimates derived by CBM are not fully in line with the GS reported by countries. Further details and comments are reported on the specific countries' worksheets.

Figure 9: For each Member State the figure reports the total growing stock (Final GS) estimated in this report, further compared with the GS reported by FRA Country Reports (FRA 2020, with the corresponding confidence interval -10%- +20%) and with the closing GS reported on Table A2a (EFA, * when available). In few cases FRA data, when missing, were replaced with the total GS reported by SoEF (see the country's sheets for details)

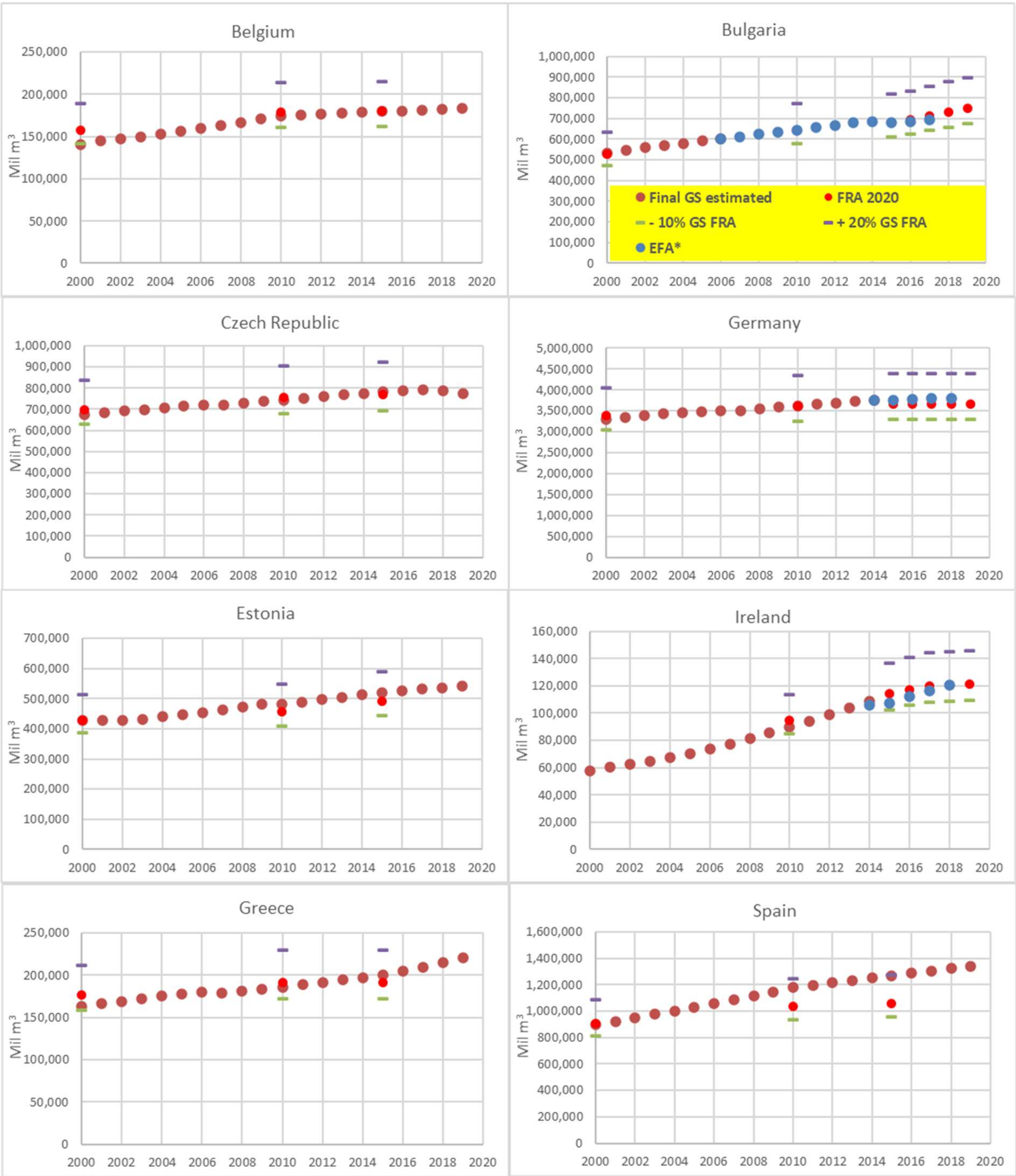
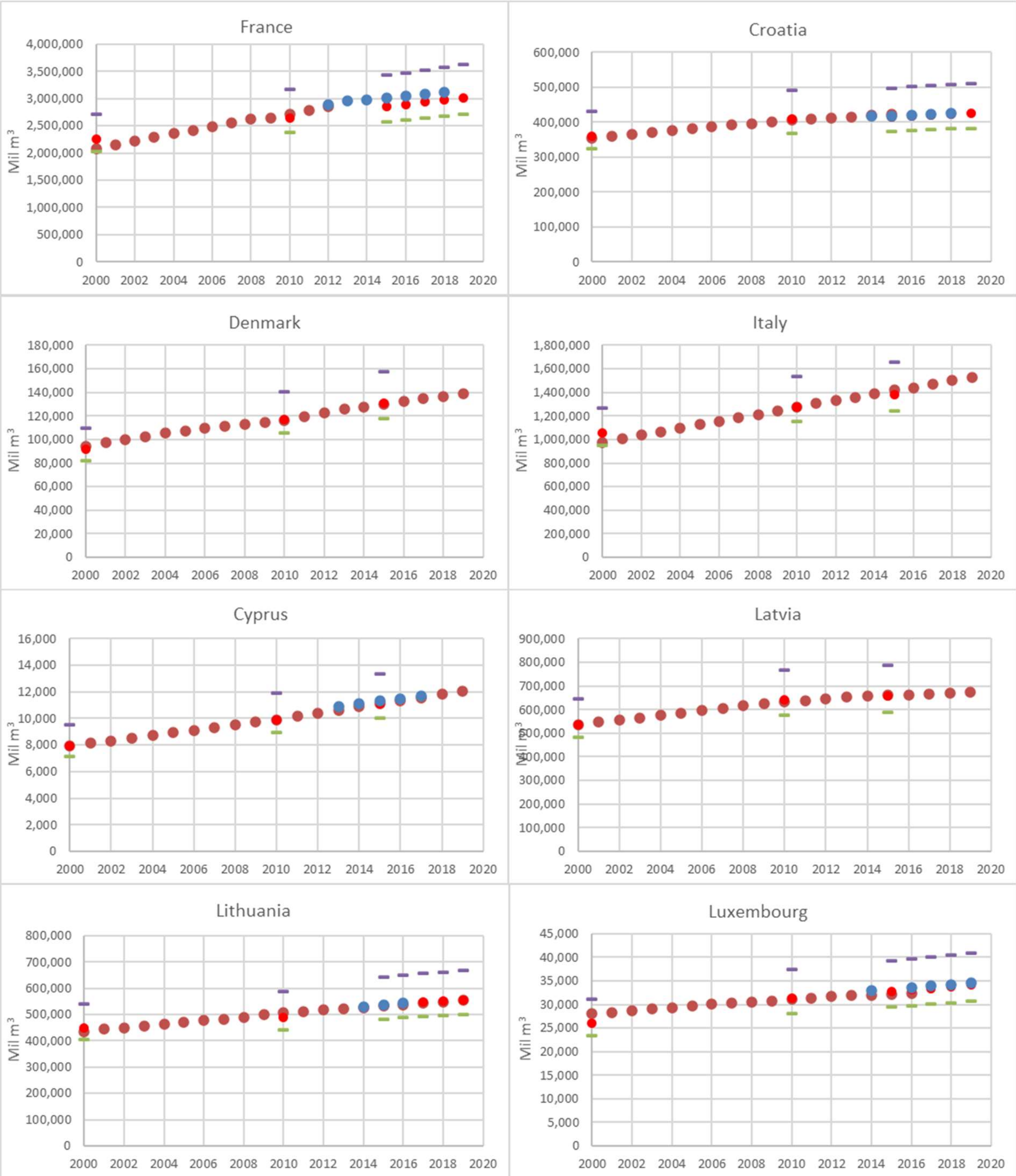


Figure 9 - continued



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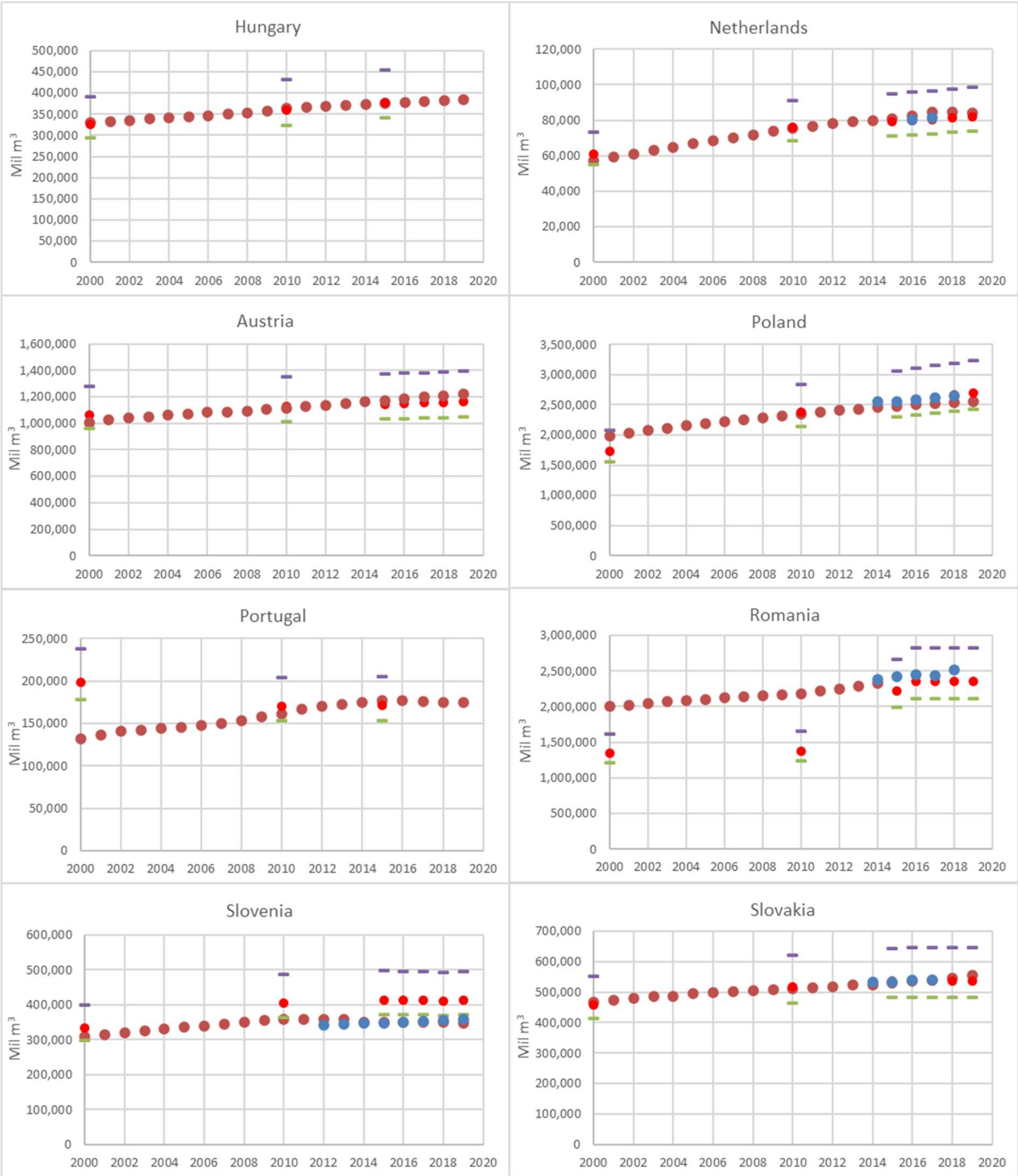
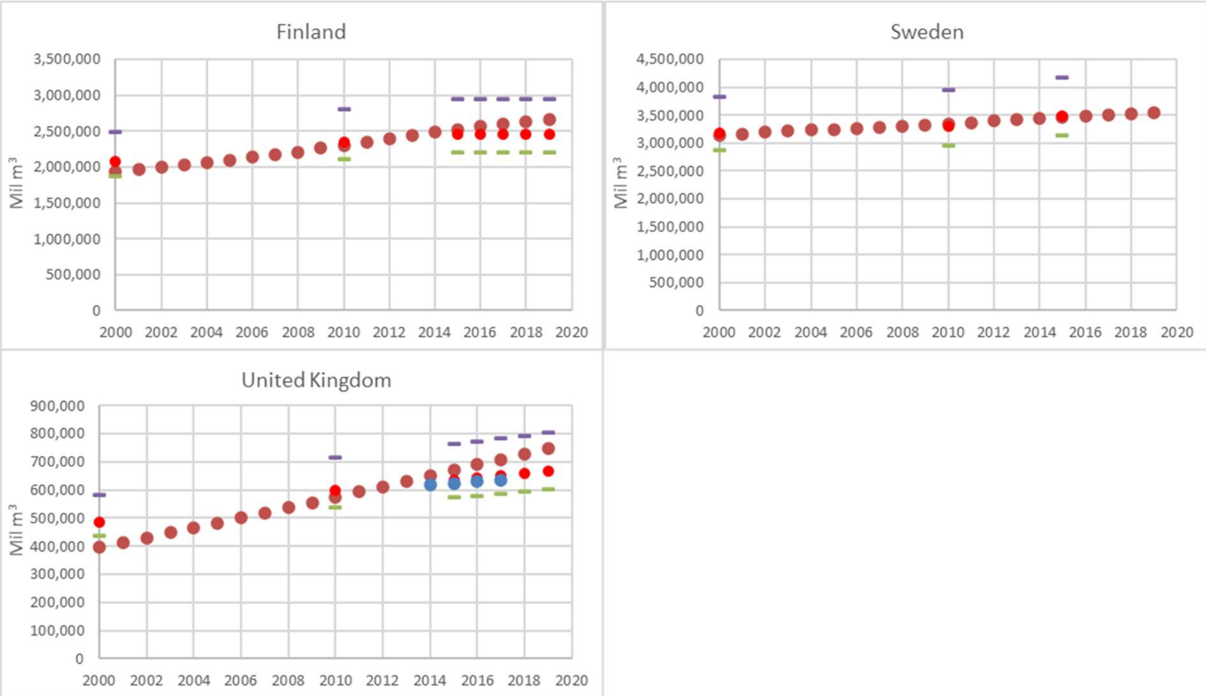
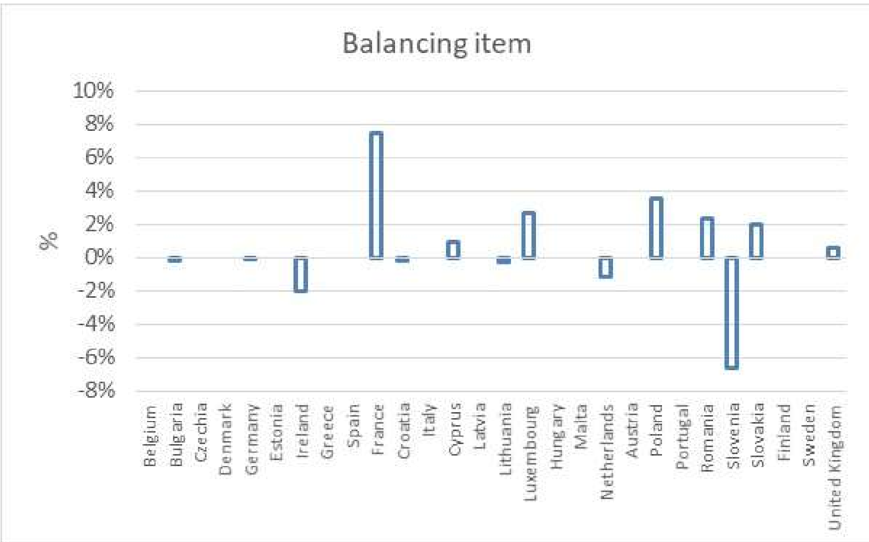


Figure 9 - continued



The balancing item applied to align the present estimates to the values directly reported by Member States may indirectly measure the consistency between the two data series. The percentage balancing item applied to each country (calculated as the ratio between BI and corresponding closing GS) generally falls within the range +4% - -2% (see Figure 10). In few cases (France and Slovenia), where the GS reported on Table A2a diverges from the data series reported by FRA, this share is larger than ±6%.

Figure 10: Relative size of the balancing item (calculated as the ratio between BI and corresponding closing GS) applied to align the GS estimated within the present study to the values directly provided by countries on Table A2a, when available.



The overall approach is based on a balance between different items, derived from existing data sources, such as REM, or estimated through a modelling approach, such as IL and GS, which is the final output expected by this study. NAI, which was the most uncertain parameter, was indirectly estimated from other items and it is therefore affected by possible inconsistencies in other data sources. Interannual variations on NAI may be due to various reasons, including discrepancies on the total amount of removals reported by other data sources (e.g. in case of Estonia for 2000), changes on the overall trend reported by FAO for the forested area or the GS (such as in case of Spain and Romania), the indirect effect of exceptional disturbance events such as fires or windstorms (which also affect the absolute amount of REM and IL), or the fact that, within the period 2000-2019, total removals were inferred combining various data series, sometimes not reciprocally coherent. For these reasons, the absolute value attributed to NAI should be considered with some caution.

In the same way, also the relative share attributed to FAWS and FnAWS within the different items is affected both by the share of biomass attributed to FAWS by SoEF, and by possible inconsistencies between these last data and the values directly reported by countries within Table A2a.

5 Conclusions

Having identified growing stock, increment and removals as the main items reported in EFA Table A2a, this study analysed in detail the main data sources which report some information on these parameters. These sources include the FRA 2020 Country Reports (for GS and area), the State of Europe's Forests 2015 (for GS, increment and removals), FAOSTAT (for removals), NFI data (mostly for GS), and other information directly reported by literature, such as the National Forestry Accounting Plans recently submitted by EU Member States under Regulation (EU) 2018/841. All these data were further compared with the main assumptions and model output provided by the Carbon Budget Model (CBM), to assess the accuracy of these last estimates. The results highlighted that, in some cases, these sources may differ both for the definitions applied and for the accuracy of the values reported by each data base. For GS, however, ancillary information provided by literature generally allowed to assess and reconcile, through appropriate correction factors, the main differences between various databases and with the CBM output itself. For the increment, the lack of detailed information and data generally prevents a detailed assessment of possible inconsistencies. For the removals, despite the relatively large number of databases - including also the data directly reported by EUROSTAT - and the differences due to the specific definitions applied by each data source, we highlighted some clear discrepancies, which should be further assessed.

Considering these premises, the approach to gap-fill the missing data in Table A2a, was based on a preliminary calibration of the GS estimated by the CBM output against the data reported by FRA Country Reports. The amount of removals was directly inferred by the databases reported by EUROSTAT, when available, or otherwise from the data reported by FAOSTAT, further corrected to account for the bark fraction. Missing information on irretrievable losses, including logging residues and other losses due to natural disturbance events, were derived from the CBM output. The net annual increment, which is the most uncertain parameter, was indirectly derived from the other parameters, and for this reason it is sometimes affected by possible inconsistencies concerning other parameters, such as the total amount of removals.

The results show a good consistency of these estimates both with the data reported by FRA Country Reports and, when available, with the data already provided on Table A2a. It is important to highlight, however, that this approach does not aim to substitute the data directly provided by Member States but only to provide a temporary gap-filling of these data or, eventually, to gap-fill data for previous years, where detailed information could be missing (for example because no NFI is available). In some cases, this analysis may also help to identify possible inconsistencies between different data sources, taking advantage both of other ancillary information reported by literature, such as the NFAPs submitted by Member States, and of an overall model assessment performed at EU level, such as the one used within the present report, based on the CBM model. Despite some unavoidable uncertainties of the results, this approach can provide a harmonised evaluation of different variables, taking into account of possible discrepancies due to country-specific definitions (i.e. on NFI data) and, at the same time, providing a temporal alignment of the NFI data provided by different countries.

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List of abbreviations and definitions

BI	Balancing item
CBM	Carbon Budget Model
CF	Correction factor
CS	Closing stock
Dbh	Diameter at breast high
EFA	European Forest Account system
FAWS	Forest available for wood supply
FnAWS	Forest not available for wood supply
GAI	Gross annual increment
GS	Growing stock
IL	Irretrievable losses
NAI	Net annual increment
NFAP	National Forestry Accounting Plan
NFI	National Forest Inventory
o.b.	over bark
OS	Opening stock
REM	Removals
SoEF	State of Europe's Forests
SRC	Statistical re-classifications
u.b.	under bark

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Supplementary Materials and Annexes

Supplementary Material 1. Worksheet EFA_FRA_Data_analysis

This excel worksheet includes:

- a first part focusing on the comparison between different data sources, further distinguished between forest area (sheet *Area_Comp*), growing stock (sheet *Growing_Stock_Comp*), harvest (sheet *Harvest_Comparison*), increment (sheet *NAI_Comparison*) and irretrievable losses (sheet (*Irretrievable_losses*)
- a second section includes 27 sheets reporting, for each Member States (excluding Malta) the main parameters needed to apply the gap-filling approach as described above

Both these sections are preceded by further details reported on specific sheets.

The worksheet is publically available on the JRC Data Catalogue at the following URL: https://data.jrc.ec.europa.eu/dataset/d4be2da6-54a1-4767-a262-dcebf66bf10b

Supplementary Material 2. Country worksheets

These 27 worksheets report, for each Member States (excluding Malta) the detailed application of the gap-filling approach from 2000 to 2019. Further details are reported on each specific sheet.

Annex 1. The Carbon Budget Model (CBM-CFS3)

Since 2009, the JRC tested and applied to the EU countries the Carbon Budget Model (CBM) developed by the Canadian Forest Service (Kurz et al. 2009). The CBM is an inventory-based, yield-data driven model that simulates the stand- and landscape-level C dynamics of above- and belowground biomass, dead wood, litter and soil.

The model has been adapted and used by the JRC to simulate forest C dynamics in 26 EU Member States (Pilli et al., 2016). This includes modelling specific characteristics of European forests, such as, for example, (i) uneven-aged forest management (Pilli et al., 2013); (ii) a large variety of other management systems (e.g. coppice, coppice with standards, shelterwood, etc.), and (iii) the use of national standing volume and annual increment data.

The model provides annual predictions - both at national and at EU level - on C stocks and fluxes, such as the annual C transfers between pools, from pools to the atmosphere and to the forest product sector, as well as ecological indicators such as NPP and NEP. Apart from these direct model outputs, the CBM was also used as a tool to assist the European Commission to verify the countries' GHGIs and to estimate the forest carbon dynamics under different economic or theoretical assumptions, e.g., for testing the current rules applied within the Regulation EU 2018/841 (Grassi et al. 2018). Moreover, the model can be linked to other tools, such as the Global Forest Trade Model (GFTM, Jonsson et al., 2018), within a broader modelling framework, including the estimate of the harvested wood products mitigation and substitution potential.

Overall model description

The CBM spatial framework conceptually follows the IPCC Reporting Method 1 in which the spatial units (SPUs) are defined by their geographic boundaries. Each forest stand is attributed to a SPU, characterized by age, area, and up to 10 classifiers, including administrative and ecological information, the link to the appropriate yield curves, and other parameters defining the forest composition, management strategy and other management information.

During the model run, a library of yield tables (YTs) defines the gross merchantable volume production by age class, for each species. These yields represent the volume in the absence of natural disturbances and management practices (these factors, reducing the gross merchantable volume, will be applied during the model run). Species-specific, stand-level equations (Boudewyn et al., 2007) convert the merchantable volume production into different aboveground biomass components. The belowground biomass, its increment and annual turnover are calculated using the equations provided by Li et al. (2003). Annual dead wood and foliage input is estimated as a percentage (i.e., turnover rate) applied to the standing biomass stock.

To estimate the decomposition rate of each DOM pool (Dead Organic Matter, including litter and dead wood) the CBM adjusts the base decomposition rates, defined at 10 °C, according to the mean annual temperature defined for each spatial unit. The model uses an initialization process to estimate the size of all DOM pools at the start of the simulation. The initialization starts with all DOM pools containing zero C stocks and then the model simulates multiple iterations of growth and stand-replacing disturbances, gradually increasing the size of the DOM pools. During this preliminary stage, the CBM can apply the same set of YTs selected for the main simulation or a different historical YTs library, specifically defined for the initialization. The rotations continue until the slowly-decaying C pools (i.e., the soil) at the end of two successive rotations meet a difference tolerance of 0.1%.

During the following run, the model applies a set of natural and anthropogenic disturbances such as fire, insects or storms and partial or clear-cut harvesting. For each of these disturbances, users define: (i) the amount, type and intensity, by year and SPU; (ii) eligibility criteria, such as forest type, age, or other classifier values to define the eligible stands for each disturbance (Kull et al., 2016). The impact of each disturbance, on each C pool is defined by the user, using a 'disturbance matrix' that quantifies the proportion of C transferred between different forest pools (i.e., internal to the model framework), transferred to the forest product sector (i.e., removed from the forest, as harvest wood products) or released to the atmosphere (e.g., with fires). The land use change (i.e., afforestation and deforestation) can be also represented with specific disturbance types with their own disturbance matrices and transitions to and from the forest land.

The model provides annual predictions on C stocks and fluxes, such as the annual C transfers between pools, from pools to the atmosphere and to the forest product sector, as well as ecological indicators such as NPP and NEP.

The main limitation of the current version of the CBM model is the difficulty in simulating the impacts of environmental changes (e.g. climate) on forest growth because the model does not explicitly simulate the impacts of environmental variations on yields.

Specific implementation of the CBM to the European countries

The CBM was specifically adapted to EU forest characteristics taking into account the following aspects:

1. Yield data-driven models, like CBM, cannot be directly applied to uneven-aged forest stands, where no yield tables are available. To overcome this limitation, the default model design was adapted to the tree selection system using the volume and increment data provided by NFIs for the uneven aged forests. At this purpose, all the uneven-aged forest area was allocated to a reference age class, with the average volume equal to the volume reported by the NFI for these stands. Starting from this age class, a decreasing percentage increment was applied to the subsequent (older) age classes. We assumed that, after a certain number of years, equal to species-specific cutting cycles defined at country level, each uneven-aged stand was disturbed and moved back to the initial reference age class (Pilli et al., 2013). This approach was tested through a number of simulations, varying different parameters. Overall, we simulated (i) a faster (but decreasing) re-growth phase during the first period following the partial cut and (ii) a decreasing growth phase during the following years. Since uneven-aged forests cover about 30% of the forest area in Europe, addressing this issue is relevant for the application of the CBM to European countries.
2. Where additional information provided by NFIs or by literature were available, country-specific equations were selected to convert the merchantable volume into aboveground biomass. If no data was available, we used the same equations selected for other countries and similar forest types, defined according to the main species.
3. In order to run the model for a period antecedent to the reference NFI year, i.e., to reconstruct the age structure before the reference NFI year, each age class of the even-aged forests was decreased by 10 years. When, applying this rule to the youngest age class (i.e., age < 10 years), we obtained a negative number (γ), we assumed that γ was the forest area affected by a clear cut (or other stand –replacing disturbance events, such as storms) at a certain age, established by a set of species-specific silvicultural rules. This allows the validation of model results, through comparisons with historical data from other sources.
4. The CBM model assumes that the values reported in the YTs represent the gross merchantable wood volume (Kurz et al., 2009). For the application of the CBM to the European countries, two sets of YTs were generally applied (Pilli et al., 2013). The first one, named historical library, was based on the standing volume, which reflects the net standing volume, including the impacts of past silvicultural activities. This library was applied by the simulation-initialization procedure, providing the starting aboveground volume and biomass of each stand, resulting by the past management practices and disturbance events. The second set of tables, named current library, was based on the current annual increment (CAI), which represents the gross volume yield of each stand. This library was applied during the model run to estimate the current gross volume and increment potential of each stand. During the model run, this volume will be directly reduced by management and natural disturbance events. This is a relevant issue for the application of the CBM and potentially of other yield-data driven models to European countries.
5. In addition to preparing model input data reflecting various management and disturbance scenarios for CBM projects, an essential step was to update the original Archive Index Database (AIDB[23]) with information specific to the EU context, and create an EU-AIDB (Pilli et al., 2018). The EU-AIDB incorporates 1 034 spatial units resulting from the intersection of 204 European administrative regions (defined at the NUTS 1 and NUTS 2 levels for most of the EU countries), and 35 ecological boundaries representing climatic units, as defined by Pilli (2012). It also contains updated parameters for 192 of the main tree species reported by the National Forest Inventories of each EU country. The release of this database ensures a transparent documentation of the parameterisation behind the JRC's runs with CBM. Furthermore, it provides ecological parameters specific to the EU context, potentially useful for greenhouse gas (GHG) inventory or research communities interested in applying the CBM-CFS3.

[23] The Archive Index Database (AIDB) is a Microsoft Access database that tracks the relationship between the model inputs and the results, tracks the status of the simulations, and stores all of the default information and parameters applied by model when creating a new project.

The CBM output

The model provides annual predictions on C stocks and fluxes, such as the annual C transfers between pools, from pools to the atmosphere and to the forest product sector, as well as ecological indicators such as the net primary production (NPP), net ecosystem production (NEP) and net biome production (NBP). All these variables can be further disaggregated, within the model output, to a detailed level, such as reported, for example, on Figure 11 – taken from Pilli et al., 2017. Here the forest carbon (C) flow modelled for 26 EU Member States by CBM for the historical period 2000 – 2012, is further distinguished between forest management area (FM) and afforestation (AR). The figure highlights the main forest pools and fluxes further distinguished between: living biomass (LB), which includes roots, leaves, merchantable tree portion and other wood components (OWCs, branches and tops), dead wood and litter pools (DOM) and soil. C moves from the atmosphere to LB through photosynthesis (*A*) and from there to DOM (black arrows, only highlighted for the FM area) because of litterfall and natural mortality (*B*) and natural disturbance events (fires and storms, arrows *C* and *D*). Red arrows highlight the main C fluxes due to direct human activities: harvest, moves a fraction of the merchantable portion to IRW (industrial roundwood, *E*) and to FW (fuelwood, *F*), part of the OWCs moves to FW (*G*) and a fraction of the standing dead trees may be collected as FW (*H*). A fraction of the living biomass is left as residues that move from LB to DOM (*I*). Salvage logging (*J*) following natural disturbances moves C from the LB to IRW or FW. Deforestation releases LB and DOM C to the atmosphere (*K*) of which the LB fraction (about 50% of the total C removed by deforestation), could in the future be used as FW or IRW. Further releases are related to natural disturbances, i.e., fires (*L*), and the decay rate of DOM (*M*) and soil (*N*) pools. The C used for energy (FW) is directly released to the atmosphere (i.e. immediate oxidation, *O*) while the C stocked as IRW has a carbon retention time before being emitted to the atmosphere (*P*). The figure also reports (inside the main boxes) the average total C stock (red numbers between parenthesis, in Tg C) estimated for EU 26, for the main FM pools (i.e., living biomass and its sub-pools); the total amount of fellings, further distinguished between roundwood removals and harvest residues; the roundwood removals used as fuelwood and industrial roundwood. The fluxes (in Tg C yr^{-1}), reported near the main arrows, are further distinguished between: (1) inputs, i.e., the NPP (highlighted by green arrows) distinguished between FM and AR area; (2) outputs (red arrows), including (i) direct C emissions from the forest to the atmosphere; (ii) harvest removals from living biomass and dead wood to the Harvested Wood Product pool and due to the salvage logging after natural disturbances and provided by AR; (3) internal fluxes (black arrows), from the living biomass to the DOM pool, due to natural processes, to natural disturbances, and to harvest activities (i.e., residues). The total C sink referred to the FM activities (including the effect of deforestation) is equal to the sum of inputs and outputs to/from the FM area. From the total roundwood removals, further releases of C to the atmosphere are due to the direct oxidation of the wood used as FW.

Annex 2. Deriving NFI variables from CBM output[24]

All CBM results reported within the present study are based on the model's runs as considered in Grassi et al., 2018. Within this study the historical period 2000 – 2015 was modelled combing the amount of harvest removals reported by FAOSTAT with other ancillary data sources, in order to properly reproduce the actual evolution of the forest stands until 2015. Since 2016 onwards, the model simulated the theoretical evolution of the forest growing stock assuming the continuation of the current management practices as detected within the previous period. Taking into account this information, all CBM data will only be reported for the historical period 2000 - 2015.

Estimating volume and increment data from the CBM model output, from one side allows to compare (and eventually validate) model results with other information reported by literature (i.e., NFI, FAO, etc.). From the other side, it allows - such as within the present study - to eventually use this output to gap-fill missing data on various data sources. Deriving these parameters requires an ex-post elaboration of the model output, usually reported in tons of C. The CBM assumes that the input data (mainly provided by NFI or Forest Management Plans) reported by the Yield Tables are referred to the merchantable stem volume, under bark, excluding top (from a diameter of 7 cm), stump (from 15 cm height) and branches, and including all trees with a min Dbh equal to 9 cm. This requires a preliminary comparison with the definitions applied, at country level, by each NFI and, in many cases, a correction on the original volume and increment data reported by the NFI. Once these

24 Further details are reported in Pilli & Blujdea, 2017, available at https://ec.europa.eu/jrc/en/scientific-tool/eu-archive-index-database-customised-carbon-budget-model-cbm-cfs3

corrections have been done, we can compare the model's output both with our input data (to ensure a full consistency between input and output) and with other data sources.

The CBM convert the merchantable volume per ha reported by the growth curves (i.e. yield tables) to tons of dry biomass through species-specific allometric equations (used as Biomass Expansion and Conversion Factors, without any additional value of wood density), selected by the original dataset provided by Boudewyn et al. (2009). This means that the model's output, in tons of C, can be converted back to volume using the invers of the same equation. The alternative of simple use of wood density values provided by literature (generally country average values) provides a bias, i.e. underestimation as highlighted in Figure 12.

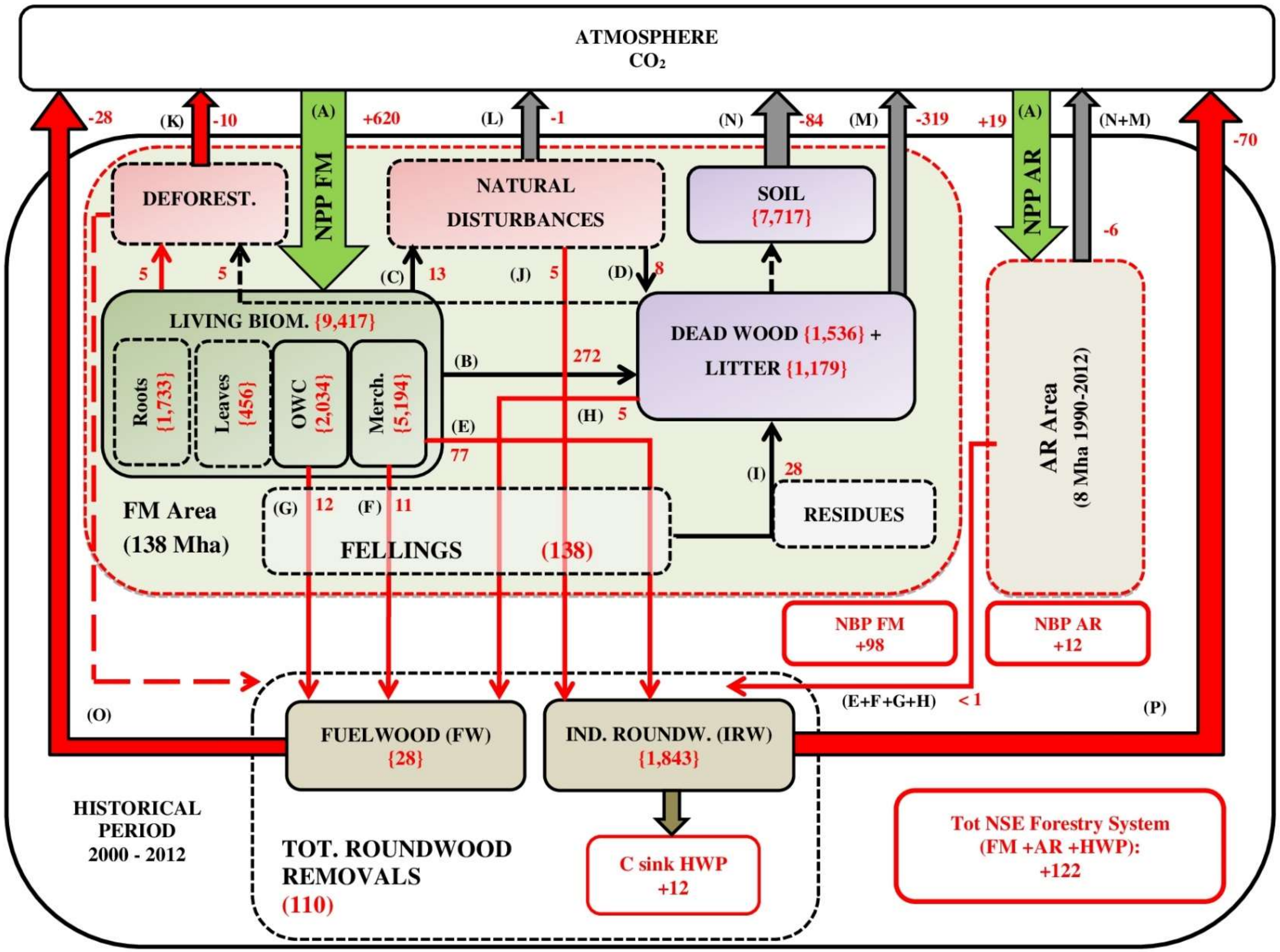
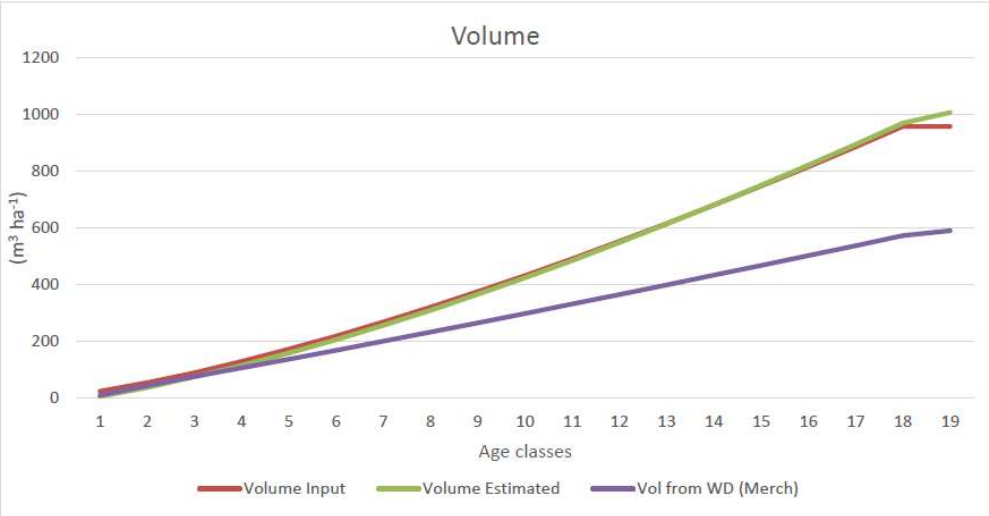


Figure 11: Example of the CBM output, as reported in Pilli et al. 2017 (Fig. 1S, Supplementary Material) – see the text for further details.

Figure 12: comparison between (i) the original volume reported by the input yield tables, (ii) the volume estimated by applying to the merchantable pool (in t dry biomass ha^{-1}) reported by the CBM the allometric equations used during the model run, (iii) country specific wood density values provided by literature, applied to the merchantable pool (in t dry biomass ha^{-1}).



In this case, the merchantable volume per ha can be derived by the Merchantable C pool reported by CBM, i.e., *[HW_Merch]* and *[SW_Merch]* as reported by the *tblPoolIndicators*, through the following steps:

1. Summing up, for each time step and main species (i.e., Forest type, FT_i, as defined by the *tblSpeciesType*) the total Merchantable C amount: $T\_Merch\_C_i$
2. For each time step, the $T\_Merch\_C_i$ can be divided by the total forest area corresponding to each *FT* (i.e., $Area_{FTi}$ as reported by the *qryTotalArea*) → estimate the $Merch\_C\_ha_i$.
3. Select, for each FT_i, the corresponding parameters *a* and *b* applied by CBM, as reported by the *tblBioTotalStemwood*. These parameters correspond to the following equation (Boudewyn et al., 2009):

6. $B_m = a * Vol^b$ Eq. (1)
7. where,

B_m is the total stemwood biomass including stumps and tops, of merchantable-sized trees, in t ha^{-1}.

Vol, is the gross merchantable volume per ha, excluding stumps, tops and non-merchantable trees, in m^3 ha^{-1}.

a, b are the parameters applied by model, for each species as defined in the *tblSpeciesType*.

4. From Eq. (1), we derive its inverse:

$$Vol_i = \left(\frac{2x\ Merc\ \_C\_ha_i}{a}\right)^{\frac{1}{b}} \quad \text{Eq. (2)}$$

By applying Eq. (2) to the $Merch\_C\_ha_i$ as estimated on step *2,* we can estimate the volume per ha for each *FT* ($Vol\_ha\_FT_i$). Number "2" in Eq.2 stands for conversion from C to biomass.

5. For each time step, the total average volume per ha (Vol_{ha}) is equal to[25]:

$$Vol_{ha} = \frac{\sum Vo\ ha_{FTi} * Area_{FTi}}{\sum Area_{FTi}} \quad \text{Eq. (3)}$$

The annual volume increment is obtained as the sum of a) carbon stock change of merchantable and b) harvest, in the period. Their values are converted back to volume using a "CBM default wood density" factor derived as ratio of output merchantable to output volume applied. The merchantable increment (excluding the amount of volume removed as felling) per ha can be estimated using a stock change approach between two consecutive time steps (i.e., 1 and 2), as:

25 Assuming that the Merch_C_ha reported by CBM (as model's output) includes stembark, we can assume that also the Volha estimated through Eq. (3) is over bark.

$$Merch\_Incr = Vol_{ha_2} - Vol_{ha_1} \qquad \text{Eq. (4)}$$

The Net Annual Increment (NAI), including the trees which have been felled within one year, can be estimated as:

$$NAI = Merch_{Incr} + HWP_{Merch} \qquad \text{Eq. (5)}$$

Where, HWP_{Merch} is the amount of merchantable volume removed during the same period, estimated by applying country-specific wood density factors for each species to the merchantable harvest reported by CBM (expressed as t C, multiplied by 2).

The total aboveground increment (AG, including the increment and the volume removed through felling and natural disturbances within one year and the non-merchantable tree components) can be estimated using the [*DeltaBiomass_AG]* reported by the *tblFluxIndicators*. This represents the net aboveground biomass increment before losses from disturbances, in tons of C. To convert this amount to volume (i.e., m^3) we can estimate, for each FT, a CBM specific wood density value based on the CBM runs (WD_{CBMi}), equal to:

$$WD_{CBM_i} = \frac{2x\ Merch\_C\_ha_i}{Vol_i} \qquad \text{Eq. (6)}$$

For each FT, the total $Delta\_AG\_Vol_i$ (i.e., the *DeltaBiomass_AG* reported in m^3) is equal to:

$$Delta\_AG\_Vol_i = \frac{2x\ DeltaBiomass\_AG_i}{WD_{CBM_i}} \qquad \text{Eq. (7)}$$

Through the area of each FT, we can finally estimate the average *Delta_AG_Vol* per ha.

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