VOLUME AND INCREMENT DATA DERIVED BY THE CBM OUTPUT

R. Pilli, V. Blujdea (JRC, 2017)

Estimating volume and increment data from the CBM model outputs, from one side allows to compare (and eventually validate) our results with other information reported by literature (i.e., NFI, FAO, State of European Forests, etc.) or even the actual input data used to parametrize the model. From the other side, since, at EU level, the model is currently applied to 26 different countries (using different input data, collected in different years), summing up the volume and increment at EU level, would provide an overall assessment of the current and future forest resources, useful also for a broader application of CBM, in connection with other models (i.e., to assess the future wood supply, etc.).

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 this 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., YT, yield tables) to t 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 in the bellow case. Notably, we have used this approach so far, since volume was often required.

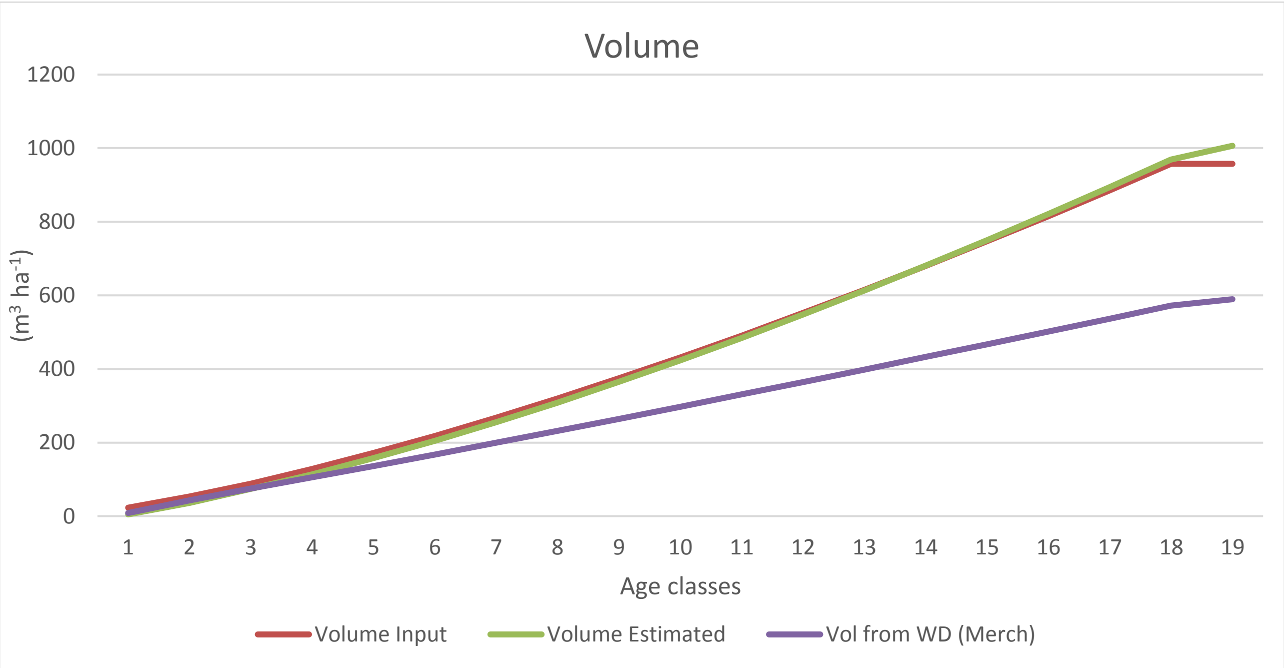

Figure 1: comparison between (i) the original volume reported by the input yield tables, (ii) the volume estimated by applying to the merchantable pool (in t dry biomass ha^{-1}) reported by the CBM the allometric equations used during the model run, (iii) country specific wood density values provided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

So, the question is there any consistent modality to derive volume and increment data from the CBM output?

Solution regarding *merchantable volume*

Key message: CBM output on merchantable standing stock is converted to volume using the inverse of volume-to-biomass equation.

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*[1]) → 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):

$$B_m = a * Vol^b \quad \text{Eq. (1)}$$

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:

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

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[2]:

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

[1] Pay attention to consider only the land use class "*Forest Land remaining Forest Land*".
[2] Assuming that the *Merch_C_ha* reported by CBM (as model's output) includes stembark, we can assume that also the Vol_{ha} estimated through Eq. (3) is over bark.

Solution regarding *merchantable annual increment in volume*

Key message: Annual volume increment is obtained as 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:

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

The Net Annual Increment (NAI), including the trees which have been felled during 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).

Solution regarding *total aboveground annual increment in volume*

Key message: Annual AG volume increment is obtained from carbon stock change of AG multiplied by "CBM default wood density" factor derived as ratio of output merchantable to output volume applied.

The total aboveground increment (including the increment and the volume removed through felling and natural disturbances during one year and the non-merchantable tree components) can be estimated using the [*DeltaBiomass_AG]* reported by the *tblFluxIndicators*. This represent the net aboveground biomass increment before losses from disturbances, in t of C. In order 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.

But, the average annual increment reported by the current YTs and used as input for the model's run includes the volume of the main stem and the decayed wood trees. This means that, in order to compare this input with our model's output, we should add to the NAI estimated by Eq. (5) the average amount of decayed merchantable living biomass (in the period). This last figure can be estimated as [*MerchLitterInput*] (reported by the tbl*FluxIndicators*), converted to volume by the following equation:

$$MerchLitterInput\_Vol_i = \frac{2\ x\ MerchLitterInput_i}{WD_{CBM_i}} \qquad \text{Eq. (8)}$$

Through the area of each FT, we can finally estimate the average *MerchLitterInput_Vol* per ha, applying the same approach reported in Eq. (5).

Numerical example

Input data: model run (with 10 yrs. time steps) based on two FTs (*OB* = Broadleaves, *OC* = Conifers), with an average volume equal to 283 m^3 ha^{-1} (estimated on the Historical YTs, using the area reported for each FT and age class as weighting factor) and an average annual increment equal to 6.58 m^3 ha^{-1} yr^{-1} (estimated on the Current YTs, using the area reported for each FT and age class as weighting factor).

CBM Output:

Table 1 reports, for each time step and FT, the main values applied to Eq. (2), including the *Merch_C_ha* (column C) and the parameters *a* and *b* applied to each FT. We can also estimate additional information on the model's parametrization, including: (i) a Biomass Expansion Factor (*BEF*, equal to the ratio between the merchantable biomass and the total AG biomass); (ii) a Biomass Expansion and Correction Factor (*BCEF*, equal to the ratio between the total AG dry biomass and the total merchantable volume) and the specific wood density applied by model (WD_{CBM} already described on Eq. (6)).

Table 1: main values applied for estimating the Merchantable volume through Eq. (2) and additional parameters based on the CBM run, including: (i) a Biomass Expansion Factor (BEF, equal to the ratio between the merchantable biomass and the total AG biomass); (ii) a Biomass Expansion and Correction Factor (BCEF, equal to the ratio between the total AG dry biomass and the total merchantable volume) and the specific wood density applied by model (WD_{CBM} as described on Eq. (6)).

Column		A	B	C=B/A	Parameters applied to Eq. (2)		D → Eq. (2)	E=A*D	F	G=B/F	H=2*F/E	I → Eq. (6)
TS	FT	Tot Area FT (ha)	Tot Merch C (t C)	Merch C ha (t C ha^{-1})	*a*	*b*	Merch Vol by FT (m^3 ha^{-1})	Tot Merch Vol by FT (m^3)	Tot AG C (t C)	BEF	BCEF	WD_{CBM}
0	OB	533,066	30,952,341	58.06	1.446087	0.790495	256.78	136,881,217	49,911,010	1.61	0.73	0.45
0	OC	599,117	39,075,783	65.22	0.791192	0.888697	312.48	187,213,792	52,496,093	1.33	0.56	0.42
1	OB	532,953	31,260,759	58.66	1.446087	0.790495	260.09	138,616,682	50,396,100	1.61	0.73	0.45
1	OC	598,990	39,573,299	66.07	0.791192	0.888697	317.04	189,903,118	53,117,554	1.33	0.56	0.42
2	OB	532,840	31,559,684	59.23	1.446087	0.790495	263.31	140,303,479	50,866,800	1.61	0.73	0.45
2	OC	598,863	40,062,932	66.90	0.791192	0.888697	321.53	192,554,187	53,729,492	1.33	0.56	0.42
3	OB	532,727	31,862,436	59.81	1.446087	0.790495	266.58	142,016,261	51,344,108	1.61	0.72	0.45
3	OC	598,736	40,545,606	67.72	0.791192	0.888697	325.97	195,171,756	54,332,849	1.33	0.56	0.42
4	OB	532,614	32,163,394	60.39	1.446087	0.790495	269.85	143,723,396	51,819,079	1.61	0.72	0.45
4	OC	598,609	40,953,180	68.41	0.791192	0.888697	329.74	197,386,012	54,838,075	1.33	0.56	0.41
5	OB	532,501	32,479,318	60.99	1.446087	0.790495	273.28	145,519,768	52,318,304	1.61	0.72	0.45
5	OC	598,482	41,383,013	69.15	0.791192	0.888697	333.72	199,724,020	55,372,894	1.33	0.55	0.41

Column		A	B	C=B/A	Parameters applied to Eq. (2)		D → Eq. (2)	E=A*D	F	G=B/F	H=2*F/E	I → Eq. (6)
TS	FT	Tot Area FT (ha)	Tot Merch C (t C)	Merch C ha (t C ha^{-1})	*a*	*b*	Merch Vol by FT (m^3 ha^{-1})	Tot Merch Vol by FT (m^3)	Tot AG C (t C)	BEF	BCEF	WD_{CBM}
6	OB	532,388	32,795,379	61.60	1.446087	0.790495	276.72	147,321,731	52,816,700	1.61	0.72	0.45
6	OC	598,355	41,776,203	69.82	0.791192	0.888697	337.37	201,865,946	55,859,224	1.33	0.55	0.41
7	OB	532,275	33,044,123	62.08	1.446087	0.790495	279.45	148,745,058	53,206,458	1.61	0.72	0.44
7	OC	598,228	42,141,355	70.44	0.791192	0.888697	340.77	203,857,879	56,308,890	1.33	0.55	0.41
8	OB	532,162	33,329,196	62.63	1.446087	0.790495	282.58	150,378,694	53,655,353	1.61	0.71	0.44
8	OC	598,101	42,520,411	71.09	0.791192	0.888697	344.30	205,927,841	56,777,742	1.33	0.55	0.41
9	OB	532,016	33,579,523	63.12	1.446087	0.790495	285.37	151,819,947	54,048,739	1.61	0.71	0.44
9	OC	597,937	42,901,183	71.75	0.791192	0.888697	347.88	208,011,205	57,249,792	1.33	0.55	0.41
10	OB	531,696	33,795,879	63.56	1.446087	0.790495	287.91	153,082,863	54,387,780	1.61	0.71	0.44
10	OC	597,577	43,308,596	72.47	0.791192	0.888697	351.84	210,251,163	57,757,663	1.33	0.55	0.41

The values reported by Table 1 can be further aggregated at country level, by using the area of each FT as weighting factor (as in Eq. (3)), to estimate the average volume per ha (see Table 2), and from here the Merchantable increment according to Eq. (4). By adding the merchantable volume removed during the same period we can estimate the NAI.

Table 2: the average volume per ha aggregated at country level is used as input for Eq. (4), to estimate the Merchantable Increment and the NAI, by adding the amount of merchantable volume removed during the same period (*HWP_{Merch}*) as reported in Eq. (5). In this case we applied country-specific values of wood density, reported by literature, to convert the merchantable carbon reported by CBM to volume (0.58 for OB and 0.39 for OC).

Column	A	B	C: B - A	Based on default WD	Eq. (5)
TS	Merch Vol (m^3 ha^{-1})	Merch Vol (m^3 ha^{-1})	**Merch Incr** (m^3 ha^{-1} yr^{-1})	**HWP_{Merch}** (m^3 ha^{-1} yr^{-1})	**NAI** (m^3 ha^{-1} yr^{-1})
0	286.26				
1	290.23	286.26	3.97	1.78	5.75
2	294.12	290.23	3.89	2.03	5.92
3	298.01	294.12	3.89	2.07	5.96

Column	A	B	C: B - A	Based on default WD	Eq. (5)
TS	Merch Vol (m^3 ha^{-1})	Merch Vol (m^3 ha^{-1})	**Merch Incr** (m^3 ha^{-1} yr^{-1})	**HWP_{Merch}** (m^3 ha^{-1} yr^{-1})	**NAI** (m^3 ha^{-1} yr^{-1})
4	301.54	298.01	3.53	2.31	5.84
5	305.26	301.54	3.72	2.24	5.96
6	308.81	305.26	3.55	2.39	5.94
7	311.90	308.81	3.09	2.29	5.38
8	315.24	311.90	3.34	2.54	5.89
9	318.45	315.24	3.21	2.60	5.81
10	321.74	318.45	3.29	2.51	5.81

The *DeltaBiomass_AG* reported by the *tblFluxIndicators* as tons of C, can be converted to aboveground volume increment by using the WD_{CBM} factors estimated on Table 1 (see Table 3).

Table 3: the tblFluxIndicators reports the DeltaBiomass_AG and the Tot_MerchLitterInput (in t C yr^{-1}) for each TS and FT. Both these values can be converted to volume through the WD_{CBM} factors estimated on Table 1 for each FT.

Column	A	*B*	C	D	Eq. (7): 2*B/D	E	F
TS	FT	*DeltaBiomass_AG* (t C yr^{-1})	Area (ha)	WD_{CBM} (see Tab. 1	*$Delta\_AG\_Vol_i$* (m^3 ha^{-1} yr^{-1})	MerchLitterInput*i* (t C yr^{-1})	MerchLitterInput_Vol*i* (m^3 ha^{-1} yr^{-1})
1	OB	888,227	532,953	0.45	3,938,585	90,428	400,975
1	OC	1,003,020	598,990	0.42	4,813,260	118,334	567,859
2	OB	886,476	532,840	0.45	3,940,967	92,574	411,554
2	OC	1,002,418	598,863	0.42	4,817,915	117,953	566,914
3	OB	884,676	532,727	0.45	3,943,151	93,734	417,788
3	OC	1,001,807	598,736	0.42	4,822,332	119,375	574,627
4	OB	883,180	532,614	0.45	3,946,523	92,810	414,726
4	OC	1,001,256	598,609	0.41	4,825,850	121,299	584,635
5	OB	882,275	532,501	0.45	3,952,929	93,799	420,255
5	OC	999,827	598,482	0.41	4,825,399	123,487	595,978
6	OB	881,188	532,388	0.45	3,958,428	94,634	425,111

6	OC	997,811	598,355	0.41	4,821,504	124,662	602,377
7	OB	879,258	532,275	0.44	3,957,899	97,695	439,767
7	OC	996,217	598,228	0.41	4,819,176	124,127	600,461
8	OB	877,497	532,162	0.44	3,959,196	97,449	439,680
8	OC	995,224	598,101	0.41	4,819,902	125,563	608,108
9	OB	876,096	532,016	0.44	3,961,009	96,941	438,291
9	OC	994,168	597,937	0.41	4,820,337	128,513	623,109
10	OB	874,337	531,696	0.44	3,960,423	97,558	441,902
10	OC	994,078	597,577	0.41	4,825,974	128,228	622,512

Both the *Delta_AG_Vol*$_i$ and the *MerchLitterInput_Vol*$_i$ can be add at country level and divided by the total forest area, to estimate the average *Delta_AG_Vol* and *MerchLitterInput_Vol* per ha as reported in Table 4.

Table 4: the Delta_AG_Vol$_i$ and the MerchLitterInput_Vol$_i$ can be add at country level and divided by the total forest area, to estimate the average Delta_AG_Vol and MerchLitterInput_**Vol** ***per ha***

Column	A	B	C = A/B	D	E =D/B
TS	Tot_DeltaVol_AG (m^3 yr^{-1})	Tot Area (ha)	DeltaVol_AG_ha (m^3 ha^{-1} yr^{-1})	Tot_MerchLitterInput_Vol (m^3 yr^{-1})	MerchLitt_Input_ha (m^3 ha^{-1} yr^{-1})
1	8,751,844	1,131,943	7.73	968,834	0.86
2	8,758,882	1,131,703	7.74	978,468	0.86
3	8,765,483	1,131,463	7.75	992,415	0.88
4	8,772,373	1,131,223	7.75	999,361	0.88
5	8,778,328	1,130,983	7.76	1,016,234	0.90
6	8,779,933	1,130,743	7.76	1,027,488	0.91
7	8,777,075	1,130,503	7.76	1,040,228	0.92
8	8,779,098	1,130,263	7.77	1,047,788	0.93
9	8,781,346	1,129,953	7.77	1,061,401	0.94
10	8,786,397	1,129,273	7.78	1,064,415	0.94

By adding the *MerchLitterInput_Vol_ha* to the NAI, we can estimate the increment including the volume of the decayed wood trees, as reported on the input YTs, as reported on *Table 5*.

Table 5: *adding the MerchLitterInput_Vol_ha estimated in Table 4 to the NAI* estimated inTable 2, we can estimate the total increment per ha including the volume of the decayed wood trees.

Column	A	B	C= A + B
TS	MerchLitt_Input_ha (m^3 ha^{-1} yr^{-1})	NAI (m^3 ha^{-1} yr^{-1})	NAI with Litterfall (m^3 ha^{-1} yr^{-1})
1	0.86	5.75	6.61
2	0.86	5.92	6.78
3	0.88	5.96	6.84
4	0.88	5.84	6.72
5	0.90	5.96	6.86
6	0.91	5.94	6.85
7	0.92	5.38	6.30
8	0.93	5.89	6.82
9	0.94	5.81	6.75
10	0.94	5.81	6.75

The average merchantable volume estimated at the TS 0, equal to 286.3 m^3 ha^{-1} and the NAI including the litterfall equal to 6.6 m^3 ha^{-1} yr^{-1} are consistent with the input data, reporting an average volume equal to 283 m^3 ha^{-1} and an average increment equal to 6.6 m^3 ha^{-1} yr^{-1}.