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Original Article

Biomass factors used to calculate carbon storage of Turkish forests

Türkiye'de ormanlardaki karbon birikiminin hesaplamasında kullanılabilecek bitkisel kütle katsayıları

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ABSTRACT

The countries that are parties to the Kyoto Protocol submit annual inventories of greenhouse gases to the United Nations Framework Convention on Climate Change Secretariat. The reports comprise values of emission and removal of greenhouse gases from different sectors (energy, industrial processes and product use, agriculture, land use, land use change, and forestry, and waste). These reports are prepared by using the methodologies indicated in guides that are prepared by the Intergovernmental Panel on Climate Change. Among the guides, those that are forestry related include: guidelines for the land use, land use change, and forestry (LULUCF) sector reported in 2003 and for the agriculture forestry and other land uses (AFOLU) sector reported in 2006. According to these guidelines, carbon, which is stored in the biomass as stock or annually sequestered amounts, can be calculated by using various factors derived from growing stock or annual increment in forests. Similarly, the amount of carbon removed from the forest by fire, production, or illegal cuttings can also be estimated using such factors. In this study, the biomass expansion factor (BEF_1) is determined as 1.212 for the conifers and 1.310 for the broadleaved species. Also the BEF_2 was updated and determined as 1.326 for the conifers, and 1.262 for the broadleaved species. In this study, the biomass conversion and expansion factors (BCEF's) that are used in the AFOLU guide were also calculated.

Keywords: Agriculture forestry and other land use, biomass conversion and expansion factors, biomass expansion factors, carbon inventory in forests, land use, land use change and forestry

ÖZ

Kyoto Protokolüne taraf olan ülkeler her yıl düzenli olarak sera gazı ulusal envanterlerini hazırlayarak Birleşmiş Milletler İklim Değişikliği Çerçeve Sözleşmesi (BMİDÇS) sekretaryasına sunmaktadırlar. Bu raporlar değişik sektörlerdeki (enerji, endüstriyel süreçler ve ürün kullanımı, tarım, arazi kullanımı, arazi kullanım değişikliği ve ormancılık (LULUCF), atıklar) sera gazları salım ve bağlanma miktarlarını içermektedirler. Raporların hazırlanmasında Hükümetler Arası İklim Değişikliği Paneli (IPCC) tarafından hazırlanan rehberlerde belirtilen yöntemler kullanılmaktadır. Bu rehberlerden ormancılıkla ilgili olanları 2003 yılında yayınlanan arazi kullanımı, arazi kullanım değişikliği ve ormancılık (LULUCF) ile 2006 yılında yayınlanan tarım, ormancılık ve diğer arazi kullanımı (AFOLU) olarak adlandırılan rehberlerdir. Bu rehberlere göre ormanlar tarafından bağlanan karbon miktarının hesaplanmasında ormanlardaki ağaç serveti ya da artım değerlerinden çeşitli katsayılar kullanılarak bitkisel kütlede stok halinde depolanan ya da yıllık olarak biriktirilen karbon miktarları hesaplanabilmektedir. Benzer şekilde yangın, üretim, kaçak kesimler ile ormandan uzaklaştırılan karbon miktarları da yine katsayılar yardımı ile tahmin edilebilmektedir. Çalışmada AFOLU rehberine göre kullanılması gereken bitkisel kütle genişletme faktörlerinden (BEFs) BEF_1 katsayıları ibreliler için 1,212 ve yapraklılar için 1,310 olarak belirlenmiştir. Çalışmada ek olarak kullanılabilir odun hacmini toprakı̈stü bitkisel kütleye dönüştürmede kullanılabilecek BEF_2 katsayıları güncellenerek yapraklılar için 1,326 ve ibreliler için 1,262 olarak bulunmuştur. Ayrıca AFOLU rehberinde verilen yöntemlerde kullanılan bitkisel kütle dönüştürme ve genişletme faktörleri (BCEFs) de hesaplanmıştır.

Anahtar Kelimeler: Arazi kullanımı, arazi kullanım değişikliği ve ormancılık, bitkisel kütle dönüştürme ve genişletme faktörleri, ormancılık ve diğer arazi kullanımı, bitkisel kütle genişletme faktörleri, ormanlarda karbon envanteri, tarım

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INTRODUCTION

The countries that are parties to United Nations Framework Convention on Climate Change (UNFCCC) have to fulfill the requirements of the contract and send various national reports on the implementation of (climate change national communications, national inventory reports of greenhouse gases, and biennial reports) to the UNFCCC Secretariat. Turkey has been included in both the Annex-1 and Annex-2 lists in the UNFCCC and has not signed the contract for many years as the countries in these lists have a greenhouse gas reduction obligation under the Kyoto Protocol. At the 7th Conference of the Parties in Marrakesh in 2001, Turkey was accepted to the Convention in 2004 with the adoption of the special situation of Turkey, its annulment from the Annex-2 list and the granting of a separate status from the countries in the Annex-1 list, and the elimination of the greenhouse gas reduction obligation. The Kyoto Protocol was signed in 2009.

The national reports prepared by the countries in Annex-1 and Annex-2 lists of the UNFCCC differ in terms of their content and time. The national inventory reports of greenhouse gases are prepared annually and include emission and storage amounts of greenhouse gases from energy, industrial processes and product use, agriculture, forestry, wastes, and other sectors. The national inventory reports include the greenhouse gas emission and removal amounts from 1990 to the year two years before the report was submitted. The national communications on climate change are prepared every four years. Unlike the national inventory reports, communications include policies and measures on climate change, expected impacts of climate change, greenhouse gas emission projections, and education, training, and achievements on raising public awareness. In the biennial reports, issues such as greenhouse gas emissions, greenhouse gas reduction targets, projections, and support to developing countries are reported.

In Turkey, the national inventory report of greenhouse gases is prepared every year since 2006 and sent to the UNFCCC Secretariat. The first national communication on climate change was prepared in 2007. However, because the preparation of the national communication started later than the other countries, national communications for climate change 2, 3, 4, and 5 were written as a single communication and were sent to the secretariat in 2013. The sixth National Communication Report was completed in 2016 and seventh in 2018. Until now, three biennial reports have been prepared.

The guidelines prepared by the IPCC are used in the preparation of national inventories for greenhouse gases. These guidelines include methods for calculating the amount of removal and emissions of greenhouse gases in each sector. According to this method, different land uses such as forestry and agriculture, energy use, industry, agriculture, and forestry and their contribution to the production or consumption of waste, and waste of greenhouse gas are calculated separately in national inventory reports. These national inventories cover emission and removal values from 1990 to the year two years before the inventory was prepared.

In the national reports submitted to the UNFCCC, forests have a special importance both in terms of forming an important pool by storing the atmospheric carbon and as a carbon source in cases like destructive incidents in forested areas. In the national inventory reports of greenhouse gases, the calculation of carbon emission and removal amounts from the forestry sector was carried out according to the methods specified in the Land Use, Land Use Change, and Forestry (LULUCF) section of the IPCC Guide dated 2003 until 2015 (IPCC, 2003). As of 2015, the guidelines for Agriculture, Forestry, and Other Land Use (AFOLU) have been used in the calculations in IPCC's 2006 guide (IPCC, 2006).

The basic approach in both the LULUCF and AFOLU guidelines is to convert the growing stock and annual increment values, which are determined as biomass in the forest inventories, using various factors first to the biomass and then to the content of carbon in this biomass. In the forest inventory, stem wood sections include growing stock and annual increment values of forests in many countries, including Turkey. However, apart from the stem wood, carbon accumulation also happens in branches, leaves, and roots. Although the stem wood is cut out from the ecosystem along with the cutting in forest areas, a significant amount of production waste left on the field is added to the litter and dead wood carbon pools with waste leaves, barks, and roots (Yıldız, 2000; Yıldız and Esen, 2002; Yıldız, 2004). The calculation of the total carbon stock in forest areas or the annual total carbon accumulation should include these parts. In order to achieve this, LULUCF and AFOLU are used to convert and increase the stem wood biomass or annual increment values into the total biomass (Table 1). This conversion and expansion are done with various biomass factors. In LULUCF, these processes are performed by converting the stem wood volume to the stem wood biomass by first multiplying it with the stem weight of the wood and then expanding the biomass to the above-ground biomass by multiplying it with a biomass expansion factor (BEF) as a coefficient. Similar operations in AFOLU are done by using biomass conversion and expansion factors (BCEFs). BCEF is practically equal to the stem wood biomass multiplied by the BEF. Various factors are also used in the calculation of the amount of biomass lost from forests due to reasons such as production, fire, insect-fungus damage, illegal cuttings, and collection of the waste parts from the silvicultural treatments. Then the calculated amount of biomass is multiplied by the carbon content and the amount of carbon accumulated in or removed from the forests is calculated.

Developed by Prof. Dr. Ünal Asan for BEF_1, the coefficient used to extend the stem wood biomass to the above-ground biomass for the calculations relating to forestry in the inventory, Turkey's national GHG conversion factors were calculated as 1.24 and 1.22 for broadleaved and coniferous species, respectively (MEF, 2006). The BEF_2 values, for using merchantable stem wood to calculate the above-ground biomass, were calculated as 1.24 for broadleaved and 1.26 for coniferous species and these biomass factors were used in national inventory reports prepared between 2006 and 2014. However, in these inventories, it was stated that the wood density values used in the calculation of carbon accumulation in living biomass were inaccurate (Tolu-

Table 1. The factors used to calculate the amount of the carbon stock in the living biomass, the annual carbon storage, and the amount of carbon derived from the forest according to the LULUCF and AFOLU guidelines

Factors in LULUCF		Factors in AFOLU	
Symbol	Definition	Symbol	Definition
WD	Wood density (t/m^3)	$BCEF_I$	The biomass conversion and expansion factor for conversion of net annual increment in volume (including bark) to above-ground biomass (t/m^3)
BEF_1	The biomass expansion factor for conversion of annual net increment (including bark) to above-ground biomass increment (dimensionless)	$BCEF_S$	The biomass conversion and expansion factor for expansion of merchantable growing stock volume to above-ground biomass (t/m^3)
BEF_2	Biomass expansion factor for conversion of merchantable volume to above-ground tree biomass (dimensionless)	$BCEF_R$	The biomass conversion and expansion factor for conversion of removals in merchantable volume to total biomass removals (including bark) (t/m^3)
R	Root/shoot ratio (dimensionless)	R	Root/shoot ratio (dimensionless)
f_{BL}	Fraction of biomass left to decay in forest (dimensionless)	CF	Carbon factor (in temperate climate zones, 0.51 for coniferous, 0.48 for broadleaved tree species)

LULUCF: land use, land use change, and forestry; AFOLU: agriculture forestry and other land use

Table 2. References used in this study

Species	Tree count	Diameter (cm)	Reference	Species	Tree count	Diameter (cm)	Reference
Pinus sylvestris	10	19.5–31.0	Uğurlu et al., 1976	*Quercus* sp.	32	10.0–31.0	Durkaya, 1998
Pinus sylvestris	33	17.0–66.0	Atmaca, 2008	*Quercus* sp.	310	7.0–38.5	Makineci et al., 2011
Pinus sylvestris	46	10–50	Aydın, 2010	*Fagus orientalis*	32	11.0–46.0	Saraçoğlu, 2000
Pinus sylvestris	50	10–46	Ülker, 2010	*Fagus orientalis*	11	8.6–16.0	Makineci et al., 2011
Pinus sylvestris	55	7.1–63.2	Çömez, 2011	*Castanea sativa*	34	15.0–37.0	İkinci, 2000
Pinus sylvestris	13	6.1–10.9	Tolunay, 2012	*Alnus glutinosa*	86	7.0–30.0	Saraçoğlu, 1998
Pinus brutia	14	9.0–39.8	Sun et al., 1980	*Robinia pseudoacacia*	12	7–15	Tüfekçioğlu and Güner, 2008
Pinus brutia	33	8.0–52.0	Ünsal, 2007	*Carpinus* sp.	12	6.9–20.4	Makineci et al., 2011
Pinus nigra	44	12.0–60.0	Çakıl, 2008	*Sorbus* sp.	12	7.1–23.4	Makineci et al., 2011
Picea orientalis	30	20.0–52.0	Özkaya, 2004				
Abies sp.	34	7–56	Karabürk, 2011				
Cedrus libani	36	10-46	Ülküdür, 2010				

nay and Çömez, 2008; Tolunay, 2011). In addition, the increasing number of biomass studies in recent years for forest sector (Uğurlu et al., 1976; Sun et al., 1980; Durkaya, 1998; Saraçoğlu, 1998; İkinci, 2000; Saraçoğlu, 2000; Özkaya, 2004; Ünsal, 2007; Atmaca, 2008; Çakıl, 2008; Tüfekçioğlu and Güner, 2008; Aydın, 2010; Ülker, 2010; Ülküdür, 2010; Çömez, 2011; Karabürk, 2011; Makineci et al., 2011; Tolunay, 2012) revealed the necessity to renew the BEF_1 and BEF_2 coefficients used in the calculations. The biomass factors given in this study were used in The National Inventory reports of greenhouse gases after 2015.

MATERIAL AND METHODS

For the calculation of the factors used in the LULUCF and AFOLU guidelines, first of all, the studies on biomass and wood density in Turkey were compiled. In most of these studies, the tree biomass equations have been developed using diameter at breast height or diameter and tree height as independent variables. In some studies, tree biomass tables have been created by using developed tree biomass equations. Apart from the studies conducted by Çömez (2011) and Tolunay (2012), no studies were reported directly on generating BEF's. For this reason, biomass factors were calculated by using the values obtained from the measurements or equations derived from studies related to tree biomass. However, calculations can be inaccurate when the leaves, branches, and above-ground biomasses of the trees obtained from the equations or tables are outside the diameter range covered by the study. For this reason, the diameter ranges used in the studies in the generation of biomass factors were taken into consideration (Table 2).

According to the LULUCF guideline, the BEF_1 was calculated as follows:

$$BEF_1 = \frac{B}{SB} \qquad (1)$$

Here, B is the above-ground biomass (t) and *SB* is the stem biomass (including bark) (t).

In addition to the BEF_1, even if it is not included in the guidelines, the coefficients that can be used to estimate the leaf and branch biomass have been produced by using leaf and branch weights instead of the above-ground biomass.

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The BEF_2 coefficient was calculated as follows:

$$BEF_2 = \frac{B}{MSB} \qquad (2)$$

In the equation, MSB is the merchantable stem biomass (including bark) (t). However, no studies were reported in Turkey to convert merchantable stem biomass to above-ground biomass. Difficulties in calculating this coefficient are due to the use of branches and trunk end pieces thicker than 3–4 cm in our country as firewood. For this reason, the approach developed by Asan and given in MEF (2006) was used in the calculation of BEF_2 coefficient. In this approach, pine, larch, Scotch pine, Taurus cedar (*Cedrus libani*), fir (*Abies* sp.), oriental spruce (*Picea orientalis*), oak (*Quercus* sp.), and oriental beech (*Fagus orientalis*) species are used from the tables of product varieties made by Sun et al. (1978). The following assumptions were made in the calculations.

- There is no information about branch biomass in the tables of types of wood products. Therefore, from previous studies, branch biomass was calculated according to diameter steps for tree species and it was accepted that 50% of this branch biomass was merchantable branch wood.
- It is assumed that half of the firewood rates given for diameter steps in the product range tables remain in the forest.
- Calculations are made for coniferous species (calabrian pine (*Pinus brutia*), Scotch pine (*Pinus sylvestris*), Taurus cedar, fir, oriental spruce) and broadlevaed species (oak and oriental beech). Because there is no table of types of wood products for Anatolian chestnut (*Castanea sativa*), the types of wood products for this species are considered to be the same as those of oriental beech.

As there is no study reported in our country, no investigation can be done to develop the fraction of biomass left to decay in forest (f_{BL}). This value was accepted as 0.15 in LULUCF (IPCC, 2003) and 0.19 in the national inventory reports of greenhouse gases of Turkey (MEF, 2006).

The biomass conversion and expansion factors (BCEF's) are practically equal to the multiplication of stem biomass (including bark) and BEF's. Therefore, the $BCEF_I$ and $BCEF_S$ coefficients were obtained by multiplying the wood densities by the BEF_1 and BEF_2 factors described previously. The $BCEF_R$ was calculated by dividing the $BCEF_S$ coefficient by 0.92 for coniferous and by 0.9 for broadleaved species as explained in the AFOLU guidelines (IPCC, 2006).

Species-specific BEF and BCEF factors were found with the approaches described above. However, in both LULUCF and AFOLU guidelines, it is stated that the calculations can be made not only on the basis of species but also on the total of coniferous and broadleaved species groups. However, the total tree growing stock and annual increment values of oak and oriental beech in broadleaved and calabrian pine and black pine (*Pinus nigra*) in coniferous species in our country are more than other ones. For this reason, for each of the coniferous and broadleaved species classes, growing stock values, total stem wood, and total above-ground biomass amounts were calculated for each species using coefficients on the basis of species. Then, at country level, total above-ground biomass values calculated separately for coniferous and broadleaved species were divided by total stem biomass and generalized factors were developed for coniferous and broadleaved species. Growing stock values in forests change every year. Because the calculations have been made since 1990 and with the developed coefficients, retroactive calculations will be made and the growing stock in 2004 was used in the calculation.

Although there are some studies on the carbon concentration of trees in Turkey (Tolunay, 2009; Çömez, 2011; Makineci et al., 2011; Durkaya, 2013), such studies remained at the local level and the carbon content specific to the tree species was not calculated as the given carbon ratios were used in national inventories made by other countries in LULUCF or AFOLU.

Table 3. Basic wood densities of the main tree species in Turkey (t/m³ in dry weight)

Coniferous	Wood density t/m³	Broadleaved	Stem wood Bulk density t/m³
Pinus brutia	0.478[a]	*Fagus orientalis*	0.530[a]
Pinus nigra	0.470[a]	*Quercus* sp.	0.570[a]
Pinus sylvestris	0.426[a]	*Carpinus* sp.	0.630[d]
Pinus pinea	0.470[b]	*Alnus* sp.	0.407[a]
Pinus halepensis	0.480[c]	*Populus* sp.	0.350[d]
Pinus pinaster	0.440[d]	*Castanea sativa*	0.480[d]
Pinus radiata	0.380[e]	*Fraxinus* sp.	0.562[g]
Abies sp.	0.350[a]	*Robinia pseudoacacia*	0.680
Picea orientalis	0.358[a]	*Liquidambar orientalis*	0.468
Cedrus libani	0.430[a]	Other Broadleaved	0.550
Juniperus sp.	0.460[a]		
Other Coniferous	0.431[f]		

[a] As et al. (2001); [b] Erten and Sözen (1997a); [c] Erten and Sözen (1997b); [d] IPCC (2003); [e] Topaloğlu (2005); [f] Coniferous mean; [g] Gürsu (1971); [h] Broadleaved mean

There are very few studies on the determination of root/shoot ratios in Turkey (Kantarcı, 1983; Tüfekçioğlu and Güner, 2008; Doğan, 2010; Çömez 2011; Sargıncı, 2014). Because the studies were carried out in limited number of species in limited number of trees, root/shoot ratio coefficients that could be used throughout the country were not calculated.

RESULTS AND DISCUSSION

The wood density values of various tree species distributed in Turkey have been compiled and shown in Table 3 (As et al., 2001, Erten and Sözen, 1997a, Erten and Sözen, 1997b, Gürsu, 1971, IPCC, 2003; Topaloğlu, 2005). Again, the BEF factors calculated on the basis of tree species by re-evaluation of the biomass studies are given in Table 4 and BCEF factors are given in Table 5. However, in the national inventory reports of greenhouse gases, carbon accumulations in forests can be calculated only for coniferous and broadleaved species groups without taking into account the tree species. Therefore, generalized factors are also produced for the groups of coniferous and broadleaved species. The wood density and BEF factors used in LULUCF are shown in Table 6 and BCEF factors used in AFOLU are shown in Table 7. As mentioned earlier, the number of studies on root biomass in Turkey is quite low. Therefore, by increasing the number of studies on root biomass, the coefficients given in the IPCC guidelines can be used until the root/shoot ratio coefficients can be used safely in the calculations. The coefficients in these guidelines are also given in Table 8.

Wood density values to be used to convert the stem volume (including bark) to stem biomass for Turkish forests were cal-

Table 4. The BEF_1, BEF_2, BEF_{leaf}, and BEF_{branch} factors that are generated from the biomass studies

Species	BEF_1	BEF_2	BEF_{leaf}	BEF_{branch}	Reference
Pinus sylvestris	1.242±0.092	1.254±0.088	0.063±0.025	0.179±0.073	Uğurlu et al., 1976
Pinus sylvestris[a]	1.198±0.032	1.239±0.113	0.071±0.023	0.127±0.021	Atmaca, 2008
Pinus sylvestris	1.324±0.224	1.318±0.164	0.126±0.112	0.198±0.137	Aydın, 2010
Pinus sylvestris	1.159±0.176	1.192±0.101	0.091±0.149	0.068±0.051	Ülker, 2010
Pinus sylvestris	1.279±0.106	1.266±0.082	0.062±0.029	0.207±0.087	Çömez, 2011
Pinus sylvestris	1.263±0.050	1.459±0.036	0.085±0.019	0.178±0.040	Tolunay, 2012
Weighted mean	1.247±0.154	1.265±0.128	0.085±0.091	0.162±0.098	
Pinus brutia	1.225±0.062	1.251±0.098	0.038±0.017	0.187±0.049	Sun et al., 1980
Pinus brutia[a]	1.349±0.022	1.384±0.112	0.112±0.044	0.237±0.023	Ünsal, 2007
Weighted mean	1.319±0.064	1.329±0.109	0.094±0.051	0.225±0.038	
Pinus nigra[a]	1.071±0.026	1.180±0.087	0.011±0.005	0.060±0.023	Çakıl, 2008
Picea orientalis[a]	1.132±0.009	1.203±0.026	0.052±0.003	0.080±0.005	Özkaya, 2004
Abies[a]	1.345±0.069	1.350±0.102	0.121±0.033	0.224±0.040	Karabürk, 2011
Cedrus libani[a]	1.300±0.055	1.337±0.052	0.080±0.042	0.220±0.049	Ülküdür, 2010
Quercus sp.	1.324±0.157	1.378±0.051	0.094±0.047	0.230±0.130	Durkaya, 1998
Quercus sp.	1.322±0.195	1.366±0.870	0.079±0.076	0.243±0.154	Makineci et al., 2011
Weighted mean	1.322±0.192	1.367±0.085	0.080±0.073	0.242±0.152	
Fagus orientalis[a]	1.228±0.080	1.257±0.071	0.021±0.007	0.177±0.058	Saraçoğlu, 2000
Fagus orientalis	1.556±0.166	1.576±0.060	0.234±0.115	0.321±0.084	Makineci et al., 2011
Weighted mean	1.305±0.174	1.303±0.119	0.071±0.106	0.234±0.089	
Castanea sativa[a]	1.320±0.068	1.334±0.087	0.020±0.005	0.300±0.066	İkinci, 2000
Alnus glutinosa[a]	1.103±0.051		0.030±0.018	0.073±0.037	Saraçoğlu, 1998
Robinia pseudoacaci[a]	1.315±0.085		0.091±0.025	0.224±0.071	Tüfekçioğlu and Güner, 2008
Carpinus sp.	1.482±0.193		0.145±0.082	0.337±0.160	Makineci et al., 2011
Sorbus sp.	1.338±0.185		0.089±0.041	0.249±0.182	Makineci et al., 2011

[a] Biomass table and equations developed by the authors were calculated for the diameter ranges measured in the field
BEF_1: the biomass expansion factor for conversion of annual net increment (including bark) to above-ground biomass increment; BEF_2: biomass expansion factor for conversion of merchantable volume to above-ground tree biomass; BEF_{leaf}: the biomass expansion factor for conversion of annual net increment (including bark) to leaf biomass increment; BEF_{branch}: the biomass expansion factor for conversion of annual net increment (including bark) to branch biomass increment

Table 5. The $BCEF_I$, $BCEF_S$, $BCEF_R$, $BCEF_{leaf}$ and $BCEF_{branch}$ factors that are generated from the biomass studies

Species	$BCEF_I$ (t/m³)	$BCEF_S$ (t/m³)	$BCEF_R$ (t/m³)	$BCEF_{leaf}$ (t/m³)	$BCEF_{branch}$ (t/m³)
Pinus sylvestris	0.531±0.066	0.539±0.055	0.586±0.059	0.036±0.039	0.065±0.042
Pinus brutia	0.630±0.031	0.635±0.052	0.691±0.057	0.045±0.024	0.108±0.018
Pinus nigra	0.503±0.012	0.555±0.041	0.603±0.044	0.005±0.002	0.028±0.011
Picea orientalis	0.405±0.003	0.431±0.009	0.468±0.010	0.019±0.001	0.029±0.002
Abies sp.	0.471±0.024	0.473±0.036	0.514±0.039	0.042±0.012	0.078±0.014
Cedrus libani	0.559±0.024	0.575±0.022	0.625±0.024	0.034±0.018	0.095±0.021
Quercus sp.	0.754±0.102	0.779±0.045	0.866±0.046	0.046±0.039	0.138±0.081
Fagus orientalis	0.692±0.099	0.691±0.060	0.767±0.061	0.038±0.060	0.112±0.051
Castanea sativa	0.528±0.033	0.534±0.042	0.593±0.042	0.008±0.002	0.120±0.032
Alnus glutinosa	0.449±0.021			0.012±0.007	0.030±0.015
Robinia pseudoacacia	0.894±0.058			0.062±0.017	0.152±0.048
Carpinus sp.	0.934±0.122			0.091±0.052	0.212±0.101
Sorbus sp.	0.736±0.102			0.049±0.023	0.137±0.100

$BCEF_I$: the biomass conversion and expansion factor for conversion of net annual increment in volume (including bark) to above-ground biomass; $BCEF_S$: the biomass conversion and expansion factor for expansion of merchantable growing stock volume to above-ground biomass; $BCEF_R$: the biomass conversion and expansion factor for conversion of removals in merchantable volume to total biomass removals; $BCEF_{leaf}$: the biomass conversion and expansion factor for conversion of net annual increment in volume (including bark) to leaf biomass; $BCEFb_{ranch}$: the biomass conversion and expansion factor for conversion of net annual increment in volume (including bark) to branch biomass

Table 6. The generalized factors of wood density, BEF_1, BEF_2, BEF_{leaf} and BEF_{branch}

Vegetation Type	Stem wood Bulk Density (t/m³)	BEF_1	BEF_2	BEF_{leaf}	BEF_{branch}
Coniferous	0.446	1.212	1.262	0.062	0.150
Broadleaved	0.541	1.310	1.326	0.073	0.237

BEF_1: the biomass expansion factor for conversion of annual net increment (including bark) to above-ground biomass increment; BEF_2: biomass expansion factor for conversion of merchantable volume to above-ground tree biomass; BEF_{leaf}: the biomass expansion factor for conversion of annual net increment (including bark) to leaf biomass increment; BEF_{branch}: the biomass expansion factor for conversion of annual net increment (including bark) to branch biomass increment

Table 7. The generalized coefficients of $BCEF_I$, $BCEF_S$, $BCEF_R$, $BCEF_{leaf}$ and $BCEF_{branch}$

Vegetation Type	$BCEF_I$ (t/m³)	$BCEF_S$ (t/m³)	$BCEF_R$ (t/m³)	$BCEF_{leaf}$ (t/m³)	$BCEF_{branch}$ (t/m³)
Coniferous	0.541	0.563	0.612	0.028	0.067
Broadleaved	0.709	0.717	0.797	0.039	0.128

$BCEF_I$: the biomass conversion and expansion factor for conversion of net annual increment in volume (including bark) to above-ground biomass; $BCEF_S$: the biomass conversion and expansion factor for expansion of merchantable growing stock volume to above-ground biomass; $BCEF_R$: the biomass conversion and expansion factor for conversion of removals in merchantable volume to total biomass removals; $BCEF_{leaf}$: the biomass conversion and expansion factor for conversion of net annual increment in volume (including bark) to leaf biomass; $BCEF_{branch}$: the biomass conversion and expansion factor for conversion of net annual increment in volume (including bark) to branch biomass

Table 8. The root to shoot ratio given for the temperate zone forests in the LULUCF and AFOLU guidelines

	LULUCF (IPCC, 2003)		AFOLU (IPCC, 2006)	
Vegetatio Type	Above-ground Biomass (t/ha)	Root/Shoot Ratio	Above-ground Biomass (t/ha)	Root/Shoot Ratio
Coniferous	< 50	0.46	< 50	0.40
	50–150	0.32	50–150	0.29
	> 150	0.23	> 150	0.20
Oak sp.	> 70	0.35	> 70	0.30
Broadleaved	< 75	0.43	< 75	0.46
	75–150	0.26	75–150	0.23
	> 150	0.24	> 150	0.24

LULUCF: land use, land use change, and forestry; AFOLU: agriculture forestry and other land use; IPCC: intergovernmental panel on climate change

culated as 0.446 t/m³ for coniferous species and 0.541 t/m³ for broadleaved species (Table 6). In previous calculations, made up to 2015, the wood density values were used as 0.496 t/m³ and 0.638 t/m³ for coniferous and broadleaved species, respectively (NIR Turkey, 2014). The wood densities calculated in this study were lower. This is due to the use of oven dry wood densities (oven dry weight/oven dry volume), not the wood density values (oven dry weight/fresh volume), in the calculations up to 2015. Oven dry wood densities are higher than the basic wood densities, leading to overestimation of carbon accumulations or stocks. In coniferous species, fir has the lowest basic wood density of 0.350 t/m^3 and Aleppo pine (*Pinus halepensis*) has the highest basic wood density of 0.480 t/m^3. In broadleaved species, basic wood densities vary between 0.350 t/m^3 and 0.680 t/m^3 (Table 3). The basic wood densities compiled for the main tree species of Turkey are similar to those used in other countries' greenhouse gas national inventories (Table 9).

In Turkey, the biomass expansion factor for conversion of stem biomass to above-ground biomass (BEF_1), which was used in national greenhouse gas inventories until 2015, was obtained from the studies carried out by cutting 24 coniferous and 184 broadleaved trees, and it was calculated as 1.22 for coniferous species and 1.24 for broadleaved species (NIR Turkey, 2014). However, over time, the number of plant biomass studies has increased considerably (Tables 2, 4). Therefore, the need to renew these factors has emerged. In this study, according to 18 different studies, BEF and BCEF factors were produced by using data of 398 coniferous and 541 broadleaved trees which were

Table 9. Biomass factors that are used in the national inventory reports of greenhouse gases in forestry sector of some countries on coniferous (C) and broadleaved (B) species

	Stemwood Bulk Density (t/m^3)		BEF_1		BEF_2		Carbon Factor (CF)		
Country	C	B	C	B	C	B	C	B	Reference
Austria	0.38	0.54					0.47	0.48	NIR Austria, 2015
Bulgaria	0.43	0.603			1.08	1.03	0.50	0.50	NIR Bulgaria, 2015
Croatia	0.39	0.56	1.15	1.20	1.30	1.40	0.50	0.50	NIR Croatia, 2015
Switzerland							0.50	0.50	NIR Switzerland, 2015
Germany			1.33–1.65	1.34-1.69			0.50	0.50	NIR Germany, 2015
Hungary	0.37-0.49	0.34-0.64					0.51	0.48	NIR Hungary, 2015
Italy	0.38-0.53	0.29-0.69	1.29-1.53	1.23-1.53			0.47	0.47	NIR Italy, 2015
Japan	0.287-0.464	0.294-0.668	1.15-1.67	1.18-1.41			0.51	0.48	NIR Japan, 2015
Lithuania	0.41	0.47	1.221	1.178			0.51	0.48	NIR Lithuania, 2015
Latvia	0.36-0.38	0.40-0.47	1.27-1.58	1.19-1.45			0.528-0.531	0.508-0.521	NIR Latvia, 2015
Belgium	0.40-0.55	0.35-0.60			1.23-1.40	1.29-1.42	0.50	0.50	NIR Belgium, 2015
Poland	0.4464	0.4464			1.30	1.40	0.47	0.47	NIR Poland,2015
Romania	0.40	0.644					0.47	0.47	NIR Romania, 2015
LULUCF	0.31-0.49	0.35-0.63	1.15	1.20	1.30	1.40	0.50	0.50	IPCC, 2003
Turkey	0.35-0.48	0.35-0.68	1.071-1.3455	1.103-1.482	1.18-1.35	1.303-1.367	0.51	0.48	This study
	0.446	0.541	1.212	1.310	1.262	1.326			
	$BCEF_I$ (t/m^3)		$BCEF_S$ (t/m^3)		$BCEF_R$ (t/m^3)		CF		
Country	C	–	–––	B	C	B	C	B	Reference
Czech Rep.	0.53–0.60	0.74–0.85			0.52–0.57	0.70–0.82	0.49	0.48	NIR Czech Rep., 2015
Finland	0.572–0.812	0.805–0.813			0.62–0.64	0.73–0.85	0.50	0.50	NIR Finland, 2015
Greece			0.44–0.74	0.62–1.28			0.50	0.50	NIR Greece, 2015
Spain			0.44–0.80	0.62–1.28			0.50	0.50	NIR Spain, 2015
Holland			0.764	0.764			0.51	0.48	NIR Holland, 2015
Portugal	0.528–1.166	0.630–1.230					0.51	0.48	NIR Portugal, 2015
Slovakia	0.45–0.81	0.45–0.95					0.50	0.49	NIR Slovakia Rep., 2015
AFOLU	0.53–1.50	0.48–1.50	0.70–3.00	0.80–3.00	0.77–3.33	0.89–3.33	0.51	0.48	IPCC, 2006
Turkey	0.405–0.63	0.449–0.934	0.431–0.635	0.534–0.779	0.468–0.691	0.593–0.866	0.51	0.48	This study
	0.541	0.709	0.563	0.717	0.612	0.797			

BEF_1: the biomass expansion factor for conversion of annual net increment (including bark) to above-ground biomass increment; BEF_2: biomass expansion factor for conversion of merchantable volume to above-ground tree biomass; $BCEF_I$: the biomass conversion and expansion factor for conversion of net annual increment in volume (including bark) to above-ground biomass; $BCEF_S$: the biomass conversion and expansion factor for expansion of merchantable growing stock volume to above-ground biomass; $BCEF_R$: the biomass conversion and expansion factor for conversion of removals in merchantable volume to total biomass removals evaluated for biomass studies. In Turkey, biomass studies have been carried out in 13 different tree species. The most tree species which have been investigated are Scotch pine (*Pinus sylvestris*). Oak is the most sampled species by cutting 342 trees in 2 different studies. In the species of hornbeam (*Carpinus* sp.), wild service tree (*Sorbus* sp.), and pseudoacacia (*Robinia pseudoacacia*), there are only above-ground biomass values belonging to 12 trees (Table 2). With the reassessment of biomass studies, the BEF_1 factors were determined with the lowest as 1.071 in European black pine (*Pinus nigra*) species and the highest as 1.345 in fir genus (Table 4). The mean BEF_1 value for the coniferous species was calculated as 1.212 (Table 6). Broadleaved BEF_1 values are slightly higher and vary between 1.103 and 1.482 (Table 4). The generalized BEF_1 factor that can be used for broadleaved species was found to be 1.310 (Table 6). These values were compared with the national inventories of greenhouse gases submitted to the UNFCCC Secretariat by other countries (NIR Austria, 2015; NIR Belgium, 2015; NIR Bulgaria, 2015), NIR Croatia; NIR Czech Rep., 2015; NIR Finland, 2015; NIR Germany, NIR Greece, 2015; 2015; NIR Holland, 2015; NIR Hungary, 2015; NIR Italy, 2015; NIR Japan, 2015; NIR Latvia, 2015; NIR Lithuania, 2015; NIR Poland; 2015; NIR Portugal, 2015; NIR Romania, 2015; NIR Slovakia Rep., 2015; NIR Spain, 2015; NIR Switzerland, 2015) in 2015 and were found to be very close (Table 9). The species-specific BEF factors given in Table 4 can be used to calculate carbon by species. However, in Turkey, most of the species in relationship between the biomass of the stem over bark and the above-ground biomass (branch + leaf) has not been examined to show clearly on enough trees. As a matter of fact, it is known that these factors may vary according to some factors (species, age, silvicultural treatments, crown closure, and site conditions) (Lehtonen et al., 2004; Jalkanen et al., 2005; Teobaldelli et al., 2009; Çömez, 2011). In addition, BEF factors may vary according to climate zones (IPCC, 2003). The fact that biomass factors are highly variable and change from stand to stand increases the uncertainties in biomass samplings. It is very difficult to develop biomass factors for each stand. For this reason, it would be more appropriate to determine the ecological regions first and then develop the biomass factors separately for each tree species with sufficient sampling according to the variables affecting the ratios among the tree crown such as age, closure, and site index (Tolunay, 2012).

In the study, the BEF_2, which is used in the calculation of the amount of carbon removed from the forest with cuttings, has been calculated with various assumptions. Because, in Turkey, the number of biomass studies is quite inadequate for converting the merchantable biomass to above-ground biomass. In this study, the BEF_2 was found 1.262 for coniferous and 1.326 for broadleaved species by using the product types table made by Sun et al. (1978) (Table 6). BEF_2 was accepted as 1.24 for coniferous and 1.26 for broadleaved species in the calculations up to 2015 (NIR Turkey, 2014), which is lower than the values found in this study. This leads an underestimation of the amount of carbon removed from the forests. The recalculated BEF_2 factors are lower than the coefficients given in the IPCC (2003) guideline, but are quite similar to the BEF_2 factors calculated on the basis of species in Belgium (Table 9). However, there is still a need to increase the number of studies to calculate the BEF_2 coefficient.

Practically, the BCEF's in the AFOLU guideline are calculated by multiplying the basic wood density and the BEF factors. Within these biomass factors, $BCEF_I$ converts growing stock directly to above-ground biomass. The $BCEF_I$ for Turkey was determined as 0.541 t/m^3 for coniferous and 0.709 t/m^3 for broadleaved species (Table 7). $BCEF_S$ was found 0.563 t/m^3 and 0.717 for coniferous and broadleaved, respectively (Table 7). $BCEF_R$ was calculated as 0,613 t/m^3 in coniferous and 0,797 t/m^3 in broadleaved species. These calculated factors are in parallel with the BCEF factors used in other countries (Table 9).

In this study, the $BCEF_{leaf}$ and $BCEF_{branch}$ factors that can be used to calculate the biomass of leaves and branches were generated from growing stock for the first time in Turkey. These factors can also be used for many different purposes, such as determining the amount of carbon and nutrients that reach the litter by litterfall in forests. For instance, Koca et al. (2013) has calculated the amounts of biogenic volatile organic compounds derived from Turkish forests by using the $BCEF_{leaf}$ in this study.

As mentioned before, the number of studies on the root biomass of trees is quite low in Turkey. It will be more accurate to use the coefficients given in the guidelines until the number of root biomass studies increases (Table 8).

In this study, biomass carbon concentration that can be used throughout the country were not calculated enough due to the small number of studies. Among these studies, Tolunay (2009) and Çömez (2011) found that the weighted mean carbon contents of the Scots pine type above-ground biomass were 51.93% and 52.46%, respectively. In some other studies, the above-ground biomass carbon content was not predominantly calculated, and the carbon concentrations of each of the tree components were measured separately. In these studies, the average carbon concentrations of tree components in Taurus cedar (*Cedrus libani*) 49.5–52.8% (Durkaya et al., 2013a), *Abies nordmanniana* subsp. *bornmulleriana* 47.8–51.1% (Durkaya and et al., 2013b), 50.2–51.6% in calabrian pine, 50.3–52.6% in Scots pine, and 51.4–52.3% in European black pine (Durkaya et al., 2015). Among the broadleaved species, carbon contents of various components of the oaks found to be 47.4–49.8% (Makineci et al., 2015), 49.29–54.19% in oriental beech and 49.01% -55.76% in chestnut (Sargıncı, 2014). In the AFOLU guideline, it is stated that carbon content can be used as 0.51 for coniferous and 0.48 for broadleaved forests in temperate zone forests (IPCC, 2006). In the studies, all conducted in Turkey, there are generally conclusions that the carbon ratios of coniferous species are slightly higher than 50% and slightly lower in broadleaved species. For this reason, until the studies on the carbon ratios of the tree components increase, the carbon content values given in the AFOLU guidelines can be used.

Since 2006, Turkey has been preparing a national inventory report of greenhouse gases and submitting it to the UNFCCC

Secretariat every year. In the reporting period, including 2014, the calculation of carbon emissions and removals in the forestry sector was made by using the methods given in LULUCF and using the factors produced from a small number of biomass studies. Using the biomass factors presented in this study by Karabıyık (2014), carbon stocks and annual net carbon accumulations between 2002–2012 were calculated. As a result, while the average annual net carbon accumulation was 13.64 million t C/year according to the national greenhouse gas inventory report in the 10-year period examined, it was determined by Karabıyık (2014) that there was 8.04 million t C/year carbon accumulation. The difference is up to 5.6 million t C/year and is quite high. As a matter of fact, according to FAO data, annual net carbon accumulation in live trees is 7.9 million tons C/year between 2000 and 2010 (FAO, 2011). Therefore, Karabıyık (2014) explained that the biomass factors produced by this study can be used safely in the calculation of carbon accumulation in the forests of Turkey. Thereafter, since the reporting made to the UNFCCC Secretariat in 2015, the biomass factors produced in this study and the methods given in the AFOLU guide have been used in the calculations (NIR Turkey, 2015). In this report, the average annual carbon accumulation for the period 2002–2012 was determined as 9.02 million t C/year (NIR Turkey, 2015) and the difference from the value calculated by Karabıyık (2014) decreased to 1 million t C/year. This difference is due to the fact that the amount of wood collected from the forests and illegal cuttings are taken as official recordings.

CONCLUSION

According to the provisions of UNFCCC and Kyoto Protocol, countries listed in Annex 1 are obliged to prepare greenhouse gas inventories. These inventories and other reports (biennials and national communications) also undergo various evaluation processes. The communications prepared by Turkey and the national inventory reports of greenhouse gases are also subject to these evaluations. However, because Turkey does not commit to reduce greenhouse gases due to its special position, evaluations have mostly remained at the level of recommendations. In addition, the Kyoto Protocol expired in 2012 but was extended until the end of 2020. The long-standing negotiations for the preparation of a new agreement for the post-Kyoto period resulted in a new agreement at the end of 2015 at the 21st Climate Change Parties Conference (COP21) in Paris. All climate change negotiations are expected to be measurable, reportable and verifiable in terms of greenhouse gas emission and removal amounts, commitments and other activities of the Contracting Parties on climate change. In this study, new biomass factors which can be used to calculate carbon accumulation in forests were calculated. These factors were compared with the factors used in other countries and were found to be quite similar. In a study conducted by Karabıyık (2014), these carbon coefficients were recalculated in the forests of Turkey and it was stated that FAO could be used in the calculations since it is very close to the values given for annual carbon accumulation in Turkey's forests (FAO, 2011). As of 2015, these coefficients have been used in the national inventories of greenhouse gases and received positive responses in the assessment processes carried out by the UNFCCC. However, these developed biomass factors are still produced from a few biomass studies and need to be developed by considering factors such as forest type (degraded or productive; high forests or coppice), tree species, age, canopy closure, site index, silvicultural treatments throughout the country. In addition, it is necessary to carry out studies to determine the amount of carbon that is not given in this study in the future, but which is removed from the forest by fire, insect, and fungal damage.

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